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DE LAS ALTERNATIVAS
AL CANAL DE PANAMA

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de las Alternativas
al Canal de Panamá
CENTRO DE INFORMACION

Comisión de Estudio
de las Alternativas
al Canal de Panamá
CENTRO DE INFORMACION

FINAL REPORT
ENVIRONMENTAL ANALYSIS COMPONENT
STUDY OF ALTERNATIVES TO THE PANAMA CANAL

PREPARED FOR
THE COMMISSION FOR THE STUDY OF
ALTERNATIVES TO THE PANAMA CANAL

JULY 16, 1993

DAMES & MOORE

PANAMA CITY, PANAMA

DAMES & MOORE

3191 CORAL WAY, SUITE 628, MIAMI, FLORIDA 33145-3213
(305) 447-2355 FAX (305) 441-2306

July 16, 1993

Commission for the Study of
Alternatives to the Panama Canal
Avenida Samuel Lewis
Edificio Banco Union, 2nd. Floor
Panama, Republic of Panama

Attention: Mr. Masaru Ito
Executive Director

Reference: **Submittal of Final Report**
Environmental Analysis Component
Study of Alternatives to the Panama Canal

Gentlemen:

The Dames & Moore Team is pleased to submit the Final Report for the Environmental Analysis Component of the Study of Alternatives to the Panama Canal. This study was completed in accordance with our Agreement with the Commission for the Study of Alternatives (CAS) to the Panama Canal dated March 19, 1993.

The Final Report presents results from an evaluation of potential environmental effects associated with two canal alternatives under consideration by CAS. The purpose of this analysis was to review the available biological information, evaluate the environmental impacts anticipated from each of the two alternatives, identify data gaps, and recommend mitigation measures and additional environmental studies, if deemed necessary.

The Environmental Analysis evaluated the effects of different activities associated with the construction, operation, and maintenance of the canal alternatives. This analysis was based on information provided in the final reports of the Preliminary Engineering and Cost Estimates and the Operating Characteristics and Capacity Evaluation components and on results presented in the first three of four quarterly reports from the Biological Data Background and Biological Inventory study. On the basis of this information, together with available aerial photographs, additional bibliographic material, and the personal experience of the project team members, a generalized habitat classification was prepared for the purposes of the study.

From our analysis, we concluded that regardless of the alternative selected for construction. a new canal will result in both temporary and permanent impacts on the environment. Both terrestrial and aquatic habitats will be temporarily or permanently disturbed by equipment staging areas, materials and stock pile locations; work space requirements; and other required infrastructure. Permanent losses will occur along the sites and in the immediate vicinity of excavations, construction, and spoil placement areas.

In general terms, it can be stated that, without appropriate mitigation measures, the most significant impact from the High-Rise Lock Canal alternative would be to the remaining forested areas west of Gaillard Cut as well of east of the Gatun Locks and across from Barro Colorado Island. With the current design, the spoil deposition areas would destroy important biological resources and would increase the effect of the biological barrier for animal dispersal. In addition, the construction of the dams on the Indio, Ciri, or Trinidad Rivers would have significant effects on the local environment. It is recommended that spoil placement sites be relocated to areas that already suffered deforestation, and that additional sources of water be identified in future studies.

The Sea-Level Canal alternative would have significant impacts on both aquatic and terrestrial habitats. However, the effects of a salt-water passage connecting the Atlantic and Pacific Oceans could be far reaching. The most significant potential aquatic impacts include introduction of predators, competitors, parasites, and diseases for which the resident biota have no adaptations. In addition, dredging in the Pacific Ocean approach channel may impact the commercial fishing industries. For this alternative, the effectiveness of a freshwater barrier, with or without other design improvements, should be thoroughly studied to prevent the migration of marine biota.

A Sea Level Canal would also have severe direct impacts on terrestrial flora and fauna on the remaining forested areas located near the Caribbean shore. Due to prior terrestrial environmental disturbances south of Lake Gatun, the impacts to this area would have less repercussions. However, this area has large wetlands that would be drained by the construction of a proposed diversion channel. It is recommended that the spoil deposition areas located north of the Gatun Lake be relocated to areas with less valuable biological resources, and that the design of the diversion channel system be modified in order to protect the wetlands.

Recommendations for mitigation measures and strategies developed to avoid or reduce significant impacts of the project alternatives on the biological environment are presented in the attached report. The level of detail provided for such measures is of a general nature, since much of the baseline information collected from surveys, studies, and reports were of a regional rather than site-specific nature.

Due to the limitations associated with the available information and schedule constraints, a second phase study, consisting of a combined Biological Inventory and Environmental Analysis, is recommended prior to or during final design of either of the two canal alternatives. The Phase II Environmental Analysis should include habitat mapping to obtain a relatively high degree of certainty with regards to the specific locations of sensitive resources within areas of impact.

The Dames & Moore Team appreciates the opportunity of working with CAS on this challenging project. Should you have any questions, please contact us at your convenience.

Very truly yours,

DAMES & MOORE, INC.

C. Mendez

Carlos A. Mendez, P.E.
Project Manager

Carlos F. Garcia, P.G.
Technical Director

ACKNOWLEDGEMENTS

The attached report is the product of an intense three month effort performed by a joint team of scientists and professionals from Panama and the United States which collaborated to address the environmental concerns related with the feasibility studies for the Alternatives to the Panama Canal. This Environmental Analysis study was lead by Dames & Moore, and was completed in association with the Centro de Estudios Latinoamericanos (CELA) and other independent consultants. The Dames & Moore Team included the following participants which are gratefully acknowledged:

Dames & Moore Staff

Ralph Alzate
Bruce Barnett, Ph. D.
Bill Behar
Gary Falxa, Ph. D.
Carlos Garcia
Umesh Kale
Kenneth McDonald
Claudius Maranhao
Ramon Martinez, Ph. D.
Scott McEuen, Ph. D.
Carlos Mendez
Jonathan Motherwell
James Morris
Greg Reub, Ph. D.
Roberto Sanchez
Steve Tata
Pedro Zuloaga

Panamanian Members

Abdiel Adames, Ph. D.
Evidelio Adames
Eldis Barnes
Arturo Cerezo
Ricardo Chan Lei
Belgis Chial
Marco Diaz
Eduardo Duran
Marco Gandasegui, Ph. D.
Plinio Gondola
Jaime Gonzales
Cecilia Guerra
Victor Martinez
Elba Medrano
Ricaurte Pacheco
Belisario Polo
Anibal Taymes

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July 16, 1993

Dames & Moore

ENVIRONMENTAL ANALYSES COMPONENT
STUDY OF ALTERNATIVES TO THE PANAMA CANAL

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FINAL REPORT
ENVIRONMENTAL ANALYSIS COMPONENT
STUDY OF ALTERNATIVES TO THE PANAMA CANAL

PREPARED FOR THE COMMISSION FOR THE STUDY OF ALTERNATIVES TO THE PANAMA CANAL

EXECUTIVE SUMMARY

INTRODUCTION

The Environmental Analysis Component of the Study of Alternatives to the Panama Canal is an evaluation of the potential environmental effects associated with two canal upgrading alternatives under consideration by a study commission (CAS) composed by the governments of Panama, the United States and Japan. The purpose of this analysis was to review the available biological information, evaluate the environmental impacts anticipated from each of the two alternatives, identify data gaps, and recommend mitigation measures and additional environmental studies, if deemed necessary.

The Environmental Analysis evaluated the effects of different activities associated with the construction, operation, and maintenance of canal alternatives. This analysis was based on information provided in the Preliminary Engineering and Cost Estimate (ECE) Final Report, dated April 1993, prepared by Yachiyo Engineering Co. Ltd. and on results presented in the first three of four quarterly reports from the Biological Data Background and Biological Inventory (BD/BI) component prepared by the University of Panama Consortium - ANCON Consortium. Neither the fourth quarterly report nor the final report of the latter study were available during the performance of the environmental analysis. Both the ECE and the BD/BI components were undertaken by others.

Although the June 1993 Annex to the ECE Report became available for review after completion of the Environmental Analysis Final Draft Report, appropriate sections were updated, when possible, to reflect some of the most significant design modifications associated with the alternate single lane options considered in the ECE Annex for both the High-Rise Lock Canal and the Sea Level Canal.

PROJECT BACKGROUND

The existing Panama Canal consists of three sets of two-lane locks, located at Gatun on the Caribbean side, and Pedro Miguel and Miraflores on the Pacific side. Ships entering from the Caribbean Sea are raised through the three-step Gatun Locks to an Elevation (El.) of +26 meters (m), (Precise Level Datum, PLD, as adopted by PCC which corresponds to El. -0.30m Mean Sea Level datum, MSL). Ship navigation continues under their own power through Gatun Lake, and enter Gaillard Cut after passing the town of Gamboa. Ships exit Gaillard Cut at Pedro Miguel locks, where they are lowered to +16 m through a single-step

lock. They continue through Miraflores Lake to the Miraflores Locks, and are lowered through the two-step lock to the level of the Pacific Ocean.

From the time construction on the existing canal was completed in 1914, there have been additional widening activities, feasibility studies and evaluations for new canal routes. As a result of Article XII of the September 7, 1977 Torrijos-Carter Treaty, the Commission for the Study of the Alternatives to the Panama Canal (CAS) was created with the objective of evaluating the possible changes and improvements that could be incorporated into the present canal, a system that is capable of handling ships of up to 65,000 Dead Weight Tons (DWT).

After the evaluation of several canal upgrading schemes, two final alternatives remain under consideration: a High-Rise Lock Canal and a Sea-Level Canal. The alternatives selected for evaluation would complement the existing system, and not replace it. In addition to the actual construction operations related to building a canal, either alternative will require additional infrastructure support. This includes roadways, bridges, quarries, crushing plants, batching plants, temporary docks and/or jetties, equipment laydown areas, and worker camps.

HIGH-RISE LOCK CANAL

The High-Rise Lock Canal alternative contemplates the construction of additional lock structures on the Pacific Ocean and Caribbean Sea entrances. There are two options for this alternative. One would construct locks capable of handling ships of up to 150,000 DWT, and the second one would have locks for ships up to 200,000 DWT. These new locks would consist of two parallel lanes of two levels each, similar in set-up as the existing Miraflores Locks. The Caribbean Sea entrance would be constructed east of the existing Gatun Locks. The Pacific Ocean locks would be constructed west of the existing Miraflores Locks. The construction of the Pacific Ocean locks would require the excavation of a new channel that would bypass the Pedro Miguel Locks.

According to the ECE Report a 200,000 DWT High Rise Lock canal would require the movement of approximately 600 million cubic meters (MCM) of soil and rock. This volume represents 242 MCM of dry excavation and 358 MCM of dredging. The total volume of excavation will be reduced to 512 MCM for the 150,000 DWT alternative, or 217 MCM of dry excavation and 295 MCM of dredging. A breakdown of the excavation volumes by zones is presented in Table ES-1.

The majority of the material moved using dry excavation will be deposited in placing areas to the west of the existing canal. Most of the dredged material will be disposed in placing areas within Gatun Lake, and to the west of the Canal approaches in the Caribbean Sea and the Pacific Ocean.

Based on traffic projections indicated in the ECE Report, it is anticipated that the volume of water available in the Gatun Lake/Madden Lake watershed will be insufficient for the operations of both the existing and the new locks. Consequently, an additional source of water will be required. To meet this demand, one option has been identified as a dam on the Indio River, west of Gatun Lake with additional, regulator dams on either the Ciri or Trinidad rivers. If the 150,000 DWT option is constructed, the dams on the Indio and Ciri rivers will be required by the year 2060. For the 200,000 DWT option, the Indio River dam will be required by the year 2020 and the Trinidad River dam by the year 2060.

A second option to overcome the lack of natural sources of water for the High Rise Lock canal is to use a pumping scheme that would require the construction of recycling basins at both entrances. Freshwater from the lock operations would be diverted into the basins, and would later be pumped back into the upper levels of the locks. Pump stations would be required by 2060. Depending on the option selected, these would pump 1,459 to 1,890 MCM of water back into the lake each year.

Table ES-1

Breakdown of Excavation Volumes in MCM
High Rise Canal Alternative

Excavation Zone	150,000 DWT Option	200,000 DWT Option
Caribbean Approach	46.9	54.2
Gatun Lake	134.8	160.3
Gaillard Cut	125.2	142.6
Miraflores	138.3	153.2
Pacific Approach	66.9	89.2
Total Volumes	512.1	599.5

MCM = Million Cubic Meters

With the single lane canal options, the total volume of excavation for 200,000 DWT ships would be reduced to 403 MCM which corresponds to 100 MCM of dry excavation and 303 MCM of dredging. For 150,000 DWT ships, the single lane option would reduce the total volume of excavation to 337 MCM, comprised of 90 MCM of dry excavation and 247 MCM of dredging.

SEA-LEVEL CANAL

The Sea-Level Canal alternative is planned for ships up to 250,000 DWT, and would require the construction of a new canal, located between 8 and 18 kilometers (km) west of the existing canal. The Caribbean Sea entrance would be located east of the town of Palmas Bellas. The Pacific Ocean entrance would be located east of Puerto Caimito. As the proposed alignment of the Sea-Level Canal will cut through the western portion of Gatun Lake, this alternative will require construction of a set of barrier dams to hold back the lake waters. The water between the dams would be drained to allow the canal to remain at sea level. Dividing Gatun Lake would reduce the amount of water available for the operation of the existing canal, but, based on traffic projections, the canal would still be able to operate. However, a regulator dam would be required on the Gatun River. This Upper Gatun dam would be constructed by the year 2060.

The tidal fluctuations in the Caribbean Sea are about 30 centimeters (cm), while those in the Pacific Ocean can range between 5 and 6 m. Due to the difference in these fluctuations, it is expected that the net flow of seawater would be from the Pacific Ocean, into the Caribbean Sea. This would cause oscillating currents that would make navigation unsafe and would promote the movement of Pacific fauna and flora into the Caribbean. To control this condition, the design of the Sea Level canal alternative will incorporate one of the following options: a) A single tidal lock on the Pacific entrance; b) Two tidal gates, one located at the Pacific entrance and one near the town of Escobal, on the north shore of Gatun Lake; and c) One tidal lock located at the Pacific entrance and one tidal lock near the town of Lagarterita, on the south shore of Gatun Lake. Also, in order to prevent migration of Pacific Ocean biota, a fresh-water barrier has been proposed. This barrier would consist of introducing fresh-water from the western impoundment of Gatun Lake (Impoundment E in the engineering report) and/or intercepted rivers, into the sea-level canal between tidal gates, and/or into the tidal lock structures.

If the Case b option is selected, the Sea-Level Canal will require excavations of 1,385 MCM, or more than twice the volume required for the High-Rise Lock Canal. This option represents 1,034 MCM of dry excavation and 351 MCM of dredging. The total volume of excavation will be reduced to 1,252 MCM in Cases (a) and (c). Either of the two latter options will require 948 MCM of dry excavation and 304 MCM of dredging. A breakdown of the excavation volumes by zones is presented in Table ES-2.

The ECE Annex also evaluated single lane tidal locks for Case (a) and a single lane Atlantic approach channel between the coast line and the Atlantic tidal gate for Case (b).With the single lane approach canal option, the total volume of excavation would be reduced to 1,228 MCM which corresponds to 950 MCM of dry excavation and 278 MCM of dredging. The

spoil from the dry excavation operations would be deposited in placement areas primarily located to the east of the canal. Dredging spoil would be placed west of the canal.

Table ES-2

Breakdown of Excavation Volumes in MCM
Sea Level Canal Alternative

Excavation Zone	250,000 DWT Cases a & c	250,000 DWT Case b
Caribbean Approach	16.3	17.5
Queblado	234.5	398.4
Gatun Lake	234.2	234.2
Continental Divide	646.6	637.2
Pacific Approach	121.0	97.8
Total Volumes	1,252.6	1,385.1

MCM = Million Cubic Meters

BIOLOGICAL BASELINE INFORMATION

In order to obtain the necessary baseline information to evaluate environmental impacts in the project areas, the CAS commissioned the BD/BI Study to the University of Panama Consortium -ANCON Consortium (UNIPAN-ANCON). Their initial study area covered the basin of the existing canal, which stretches from Lake Alajuela to the east, to the end of Gatun Lake on the west. To the north and south, it extended beyond the breakwaters outside of Limon Bay and the Gulf of Panama, respectively. As the route for the Sea-Level Canal was added after the BD/BI Study began, the available data for an environmental analysis of this area is very scarce.

The Biological Data Background phase of the BD/BI Study was a bibliographic search and survey of the available literature regarding environmental resources within the study area. The objective of the subsequent Biological Inventory study was to provide an up-to-date survey of the biota within the study area, to be used for input to the present Environmental Analysis Component. UNIPAN-ANCON collected samples of flora and fauna, from terrestrial and aquatic environments, as well as water quality and sediment samples from the aquatic environments.

The BD/BI Study was designed to consist of four quarterly sampling events and reports, together with a Final Report, which were to be used for the Environmental Analysis. However, due to time constraints set forth by CAS, the schedule of the Environmental Analysis was accelerated. Consequently, the present analysis was based on information provided in the reports available during the study period which excluded the fourth quarter and final reports.

HABITAT CHARACTERIZATION

As the first three reports of the BD/BI Study did not include descriptions of habitats within the impact zones of each alternative, color aerial photographs were used to identify areas of different ecological characteristics (habitats). The color photographs covered entirely the alignment of the High Rise Lock canal and the central and southern portions of the Sea Level Canal. Other areas of interest, such as the northern portion of the Sea-Level Canal, and portions of the Indio and Trinidad rivers were covered only by black and white aerial photographs taken from isolated flight lines.

On the basis of the information provided in the BD/BI Study, together with the aerial photographs, additional bibliographic material, and the personal experience of the project team, a generalized habitat classification was prepared by for the purposes of this study. These included wetlands, mangroves, mature tropical forest, secondary tropical forests, grasslands, pastures, agricultural lands, open areas, lakes & rivers, mudflats, sandy beaches, rocky shores, subtidal and pelagic habitats.

ENVIRONMENTAL IMPACTS

The following sections include discussions of potential impacts on various environmental resources due to the construction, operation, and maintenance activities associated with each of the proposed project alternatives. Anticipated impacts are first categorized and described on resources in general, followed by a more detailed, alternative-specific and site-specific description of anticipated impacts.

Impacts Common to Both Alternatives

Regardless of the alternative selected for construction, a new canal will have both temporary and permanent effects on the environment. Habitats will be temporarily or permanently disturbed by equipment staging areas, materials and stock pile locations; work space requirements; and infrastructure such as worker camps, villages, electrical transmission lines, quarries, and roads. Permanent losses will occur along the sites and in the immediate vicinity of excavations and construction.

The following impacts were identified as applicable to both alternatives:

- Destruction and fragmentation of forests will produce the loss of terrestrial ecosystems, particular species, and genetic diversity of flora and fauna. Fragmentation of a particular habitat will not only reduce the total area of the habitat, but also will reduce biological diversity by direct elimination of locally-adapted populations in the newly created non-forest habitats. A significant threshold appears when the amount of forest habitat decreases below 50 percent. Species that are associated with the old mature and young successional tropical forests will be affected directly or indirectly by forest destruction. Examples include 378 species of birds that have been reported in the old mature forest, which represents over 50 percent of the 512 species reported in the project area.

- Sediments and suspended materials introduced into waters from dredging and spoils deposition will affect water transparency, reducing visibility and affecting food gathering for aquatic animals. Erosion will cause soils disturbed by construction to reach bodies of water, causing physical changes through sedimentation and alteration of water flows. Sedimentation may also impede sunlight penetration, affecting the growth of aquatic plants. The heaviest particles will settle on the bottom, potentially destroying existing plant life and affecting the animals that rely on them.

- Changes in water quality may alter the trophic balance between producers and consumers. An increase in nutrients may cause an algal bloom, reducing the dissolved oxygen in the water and producing a die-off of aquatic fauna.

- Excavation and dredging will destroy benthic habitat. The suspension of sediments in the water column will lead to an increase in dissolved solids. Some of these may be toxic to the biota, either directly or indirectly from bioconcentration in edible species.

- Disposal of excavated materials in placing areas will destroy benthic fauna and terrestrial habitats as they are covered by the spoils.

- Dust generated at quarries and batching plants will subsequently pass into rivers and lakes. Limestone in these residues can also alter the Ph of these waters.

- Construction of new roads will have adverse impacts on adjacent wetlands. Roads built on raised levees or embankments which interfere with cross drainage or obstruct the movement of water can permanently impair the biological cycles and productivity of adjacent ecosystems. Roads can also

function as dams and cause flooding by blocking water flows and increasing runoff.

- The creation of new artificial lakes will affect water flow, aquatic biota, and sedimentation patterns. During dam construction and the filling of reservoirs, there will likely be an increase in the turbidity and quality of adjacent waters.

- Changes in water regime will affect the riverine fisheries and dependent terrestrial biota. Changes in water temperature and quality, loss of spawning habitat, and creation of barriers to fish movements are all likely impacts.

- The creation of fisheries habitat in the new reservoir will benefit waterfowl and other species that forage in lentic (lake) rather than lotic (river) habitats. However, marine species which feed or spend part of their life cycle in estuaries will be negatively impacted. Alterations in watercourses, will amplify these impacts.

- Maritime development (jetties, approach channels, canals, waterways, quays, and breakwaters) will generate localized environmental impacts. The impacts of maritime development will differ by location, based on the type of facility and variations in geography, hydrology, and ecology. Mangrove swamps, salt marshes, estuaries, seagrass beds, and coral reefs are particularly susceptible to disturbance.

- Dredging and spoil disposal activities for port development and maintenance will induce short- and long-term impacts on aquatic systems, including: degradation of marine resources (beaches, estuaries, coral reefs, fisheries), resuspension and settlement of sediments, partitioning of toxic contaminants and reintroduction to the water column, contaminant uptake by and accumulation in fish and shellfish, increased turbidity causing decrease in light penetration and associated photosynthetic activity, short-term depletions of dissolved oxygen, modified bathymetry causing changes in circulation, possible saltwater intrusion to ground-water and inland surface water, altered species diversity and structure of benthic communities, fluctuations in water chemistry, changes in shoreline structure, and loss of habitat and fisheries resources.

- General construction operations for the canal, locks, dams, impoundments, roadways, spillways, construction villages and camps, as well as other activities have the potential of increasing the breeding areas for nuisance insect pests and disease vectors. Vectors that are related to water may find suitable conditions, such as malaria vectors like *Anopheles albimanus*, and the proliferation of artificial containers, which are breeding sites of *Aedes aegypti*,

vector of Dengue Fever and of Urban Yellow Fever. After construction, other water related vectors may have suitable conditions for proliferation, increasing the potential to transmit diseases. Measures to prevent outbreaks related must be considered and implemented prior to, and during construction and operation of either Canal alternative.

Impacts Associated with High-Rise Lock Canal

The estimated areas of direct impact on land and water for the excavation and spoil disposal operations, including road construction, was estimated to be approximately 76 km^2. Depending on the option chosen, the new dams and their associated watersheds would add 35 or 39 km^2 of affected areas. The placing sites for the majority of the excavated soils are currently proposed in areas that consist primarily of mature and young succesional tropical forests. It is estimated that approximately 19 km^2 of forests will be cleared and buried, with additional losses of grasslands of 1.2 km^2. Impacts will not be limited to the placement areas, but also will include the sites of access roads, bridges, and the required construction and operational infrastructure. Most of the disruption is anticipated to occur on the western area of the widening of Gaillard Cut, one of the most important remaining forested regions in the study area.

In general terms, it can be stated that, without appropriate mitigation measures, the most significant impact from the High-Rise Lock Canal alternative would be to the remaining forested areas west of Gaillard Cut as well of east of the Gatun Locks and across from Barro Colorado Island. With the current design, the spoil deposition areas would destroy important biological resources and would increase the effect of the biological barrier for animal dispersal. In addition, the construction of the dams on the Indio, Ciri, or Trinidad Rivers would have significant effects on the local environment. A recent government regulation has created the International Interoceanic Park, with the objective of protecting a stretch of forest that extends from the Pacific Ocean to the Caribbean Sea. This park will include much of the land west of Gaillard Cut, as well as the area west of Gatun Locks.

The following impacts were identified for the High-Rise Lock Canal alternative:

- Disposal of the dredged spoils in the Pacific Ocean may have greater effects than in the Caribbean Sea, as most of the commercial fisheries are located here. Disposal of dredged spoils inside of Gatun Lake are not expected to have as great an impact as in the marine placement areas.

- The construction of the Indio River dam, together with the Ciri or Trinidad rivers dams will flood 32 or 39 km^2, depending on the option selected. These areas primarily consist of pastures, with a mosaic of forest fragments. Forest coverage appears to be on the order of 50 percent in the Indio River basin,

and drops to less than 30 percent in the Ciri and Trinidad river basins. The population density in the Indio River basin appears to be lower than that of the Trinidad and Ciri River basins. The construction of the Trinidad River dam will also affect the wetlands located at the mouth of the river. It is estimated that most of the 1.4 km^2 wetland may be severely affected and progressively reduced. The loss of wetlands removes valuable feeding, breeding and nursery areas for a wide variety of fauna.

Other environmental impacts would occur when the spillway from the Indio River dam connects to Gatun Lake, allowing the migration of the Peacock Bass (*Cichla ocellaris*) into the Indio River watershed. This exotic species was accidentally introduced into Gatun Lake in the past. Due to its carnivorous habits, the Peacock Bass has severely reduced the population of native fishes at Gatun Lake.

The use of the proposed water recycling scheme will have the side effect of increasing the salinity of Gatun Lake. As the salinity increases, the probability of marine fauna surviving the crossing from one ocean to the other increases greatly. The interchange of marine biota, including fish, invertebrates, parasites, bacteria, virus, eggs and/or larval forms of any of these, have the possibility of causing major impacts on the habitat in Panama Bay, where the great majority of the Panamanian fishing industry is concentrated.

Impacts Associated With Sea Level Canal

The construction of the Sea-Level Canal is estimated to have a direct impact on approximately 176 km^2 of land. The Upper Gatun dam impoundment will add an additional 11 km^2, for a total of 187 km^2. The placing sites will cover an area of approximately 85.5 km^2 which includes about 54 km^2 on land and 31.5 km^2 in water. Except for the northern portion of the canal alignment, the placing areas are currently located in areas that consist primarily of pastures and grassland, with remnants of tropical forests.

The placing areas located between the Pacific Ocean and the south shore of Gatun Lake, cover 38.6 km^2 of land consisting mainly of pastures and open land with an estimated forest cover of 10 to 15 percent. The spoil areas located between the north shore of Gatun Lake and the Caribbean Sea will cover about 15.5 km^2 of land with an estimated forest cover of 30 to 50 percent. Spoil sites in Gatun Lake, used to construct the barrier dams, will cover an area of about 5 km^2. The remaining spoil areas in water will cover 17.6 km^2 in the Pacific Ocean and 8.8 km^2 in the Caribbean Sea.

In this alternative, most of the terrestrial disruption is anticipated to occur in the eastern area of the canal alignment. Much of this area has been subject to logging activities, slash and burn agriculture and overgrazing. The following impacts were identified for the Sea-Level Canal alternative:

- The construction of the barrier dams to divide Gatun Lake will have significant environmental impacts to the area. Upon dewatering of the proposed sections, more than 5 km^2 of wetlands from nine major systems will be lost. Chief among these areas are those of Los Hules and Pescado rivers, where each system covers approximately 1 km^2.

- The wetlands located at the mouth of the Trinidad River will be disturbed by the loss of water flow. This area currently covers approximately 1.5 km^2, and would probably be severely affected.

- The diversion scheme that will block surficial water from entering the areas separated by the barrier dams, and the construction area of the canal, will cut through and affect 15 major rivers and streams. In some cases, their waters will be diverted directly into the canal, while in others, they will be directed into the detached portion of Gatun Lake (Reservoir E).

- The diversion scheme also includes the cutting of the Caimito River. A small impoundment will be formed in this area, near the city of La Chorrera. The mangrove habitat at the mouth of the Caimito River will be severely affected, as it will be split into two portions. It currently occupies approximately 2 km^2. It is anticipated that it will lose more than 1 km^2 and will remain as two separate sections of less than 0.5 km^2 each.

- The dredging of the 26.1 km approach channel in the Pacific Ocean, together with the adjacent placement of the spoils, may have significant negative impacts on the commercial fisheries located there. Not only is it expected to affect the local fisheries, but due to the westward flow of the predominant ocean currents, it is likely that the suspended sediments may affect important breeding and nursery areas that are located in the major mangrove habitats found at Punta Chame.

- The construction of the Upper Gatun dam will flood approximately 11 km^2. This area consists primarily of pastures, grassland, logged-out areas and small farms, together with a mosaic of forest fragments. Forest coverage in this area appears to be less than 40 percent. The population density in the adjoining area appears to be much greater than what was observed in the Indio, Trinidad and Ciri river basins.

- Additional environmental impacts will occur when the spillway from Reservoir E connects to the Lagarto River. The increased volume of water onto this river may cause local erosion and sedimentation problems. In addition, the spillway will allow the migration of the Peacock Bass (*Cichla ocellaris*) into this watershed. As indicated above, this exotic species has severely reduced the population of native fishes in Gatun Lake.

- A serious consideration is the potential for Pacific Ocean biota crossing into the Caribbean Sea. One of the most serious potential problems involves the Crown of Thorns starfish (*Acanthaster planci*). Populations of this starfish have been responsible for wide-spread damage to coral reefs throughout the coral reefs of the South Pacific and the Great Barrier Reef in Australia. It has also been reported in the Gulf of Chiriquí,west of the Bay of Panama, where it reportedly has been able to consume 18 to 47 percent of the live cover of a 20 ha reef in four months. Consequently, should the starfish cross into the Caribbean Sea, the devastation to the coral reefs and resultant loss of marine biota are anticipated to cause regional impacts.

- Eastern Pacific Ocean corallivores are more specialized and voracious than the Caribbean species. Their presence in the Caribbean will increase predation on coral. In general, there is more grazing pressure in the Eastern Pacific. Low algae and sponge cover is maintained by voracious, specialized predators. As calcareous algae and sponges contribute greatly to reef formation, the health of the Caribbean reefs will also be affected.

- Other potential environmental problems may be the introduction of parasites and competing organisms that may destroy or displace Caribbean Sea biota. Conversely, viruses have been found in the Caribbean Sea, which are absent in the Pacific Ocean. The accidental transport of these could cause major damage to the Pacific Ocean biota.

- The construction of a Sea-Level Canal will also represent an additional disruption to migration of terrestrial flora and fauna. The removal of forested areas in the placement sites located on the north portion of the Sea-Level Canal will create a barrier for forest fauna. Although the existing canal has been a barrier to migration, an additional, seawater barrier will increase the obstacles. Organisms, plants or animals, that could survive crossing the existing fresh-water barrier may not survive or be completely deterred from crossing a sea-water canal.

- Another potential impact that the Sea-Level Canal may cause is seawater intrusion into the potable water supply aquifers and/or a drop in the phreatic

surface, as the groundwater drains toward the canal. The hydrogeology of this area is poorly understood. However, the available information indicates that inland populations, away from Lake Gatun, install potable water wells that range in depth between 24 to 36 m below land surface. The coquina is the basal member of the Chagres sandstone, and it is highly permeable, and thus, would easily serve as a conduit to seawater into the groundwater.

The preliminary engineering design of the Sea-Level Canal alternative hypothesizes the incorporation of a freshwater barrier system to address the problem of seawater biota movement between the two oceans. The ECE Report discusses the possible introduction of fresh-water into the tidal locks or between the tidal gates for the purpose of creating a fresh-water barrier. However, the report indicates that there is insufficient information to be able to provide definite conclusions. The alternatives considered include introducing fresh water into the Locks, the tidal gate structures and the central section between the proposed locks and tidal gates. Their evaluation of mixing conditions indicated that there may not be enough fresh-water available to create such a barrier during low rainfall years. Available fresh water during normal years may be marginal and therefore the fresh water barrier may have questionable effects to prevent organisms from crossing the isthmus.

Even if additional fresh-water was made available, there are other factors that may make this barrier unreliable. In the existing Canal, behavioral habits of fish and other marine organisms, act to restrict the movement from an open bay situation into the confined space of a lock. However, in the Sea-Level Canal, the locks and gates are many kilometers from the coast. Once these organisms find themselves within the open boundaries of the Sea-Level Canal, crossing an open lock or gate would not be a behavioral barrier.

Overall, the Sea-Level Canal Alternative appears to have greater impacts to both terrestrial and aquatic habitats, in comparison to the High-Rise Lock Canal Alternative. In general terms, it can be stated that the major terrestrial impacts of the Sea-Level Canal Alternative will be to the forested areas north of Lake Gatun, and the removal of the wetlands in La Laguna. The major aquatic impacts will be to the Bay of Panama. The removal of the remaining forested areas north of Gatun Lake may act as a barrier to the movement of terrestrial fauna. The placement areas on the southern portion of the canal will cover 33 km^2 of pastures, grasslands and relatively small forest fragments. The dredging of the Pacific Ocean approach channel, however, will have an impact on the commercial fishing industries. As presently designed, the fresh water barrier does not appear to represent an impassable barrier to marine biota.

The major terrestrial impacts of the High Rise Lock Canal appear to be associated with the spoil disposal areas in the forested areas west of Gaillard Cut. Additional terrestrial impacts are associated with the spoil deposition areas east of Gatun Locks and Barro

Colorado Island. Aquatic impacts are associated with the deposition of additional spoil materials within Lake Gatun.

Both alternatives open up new watershed areas for invasion by the peacock bass *(Cichla ocellaris)*. The High Rise Lock Canal may open the Rio Indio Basin, and the Sea Level Canal may open up the Lagarto River Basin to this exotic predator.

RECOMMENDED MITIGATION MEASURES

General mitigation measures have been developed to avoid or reduce significant impacts of the project alternatives on the biological environment. The flow chart presented in Table ES-1 was developed to illustrate the recommended mitigation strategy.

The level of detail provided for these measure is necessarily general, since much of the baseline information collected from surveys, studies, and reports were of a regional rather than site-specific nature. Therefore, the mitigation measures are applicable for construction activities and practices over the entire project area. The recommended mitigation strategy requires that prior to construction, biologists conduct surveys to determine the presence or absence of sensitive resources within the impact areas. The initial investigation should focus on identifying and quantifying the different types of habitats that are found within the impacted areas. Based on this information, a discrete survey plan can be designed, in order to be able to evaluate a statistically valid number of representative areas for each identified habitat.

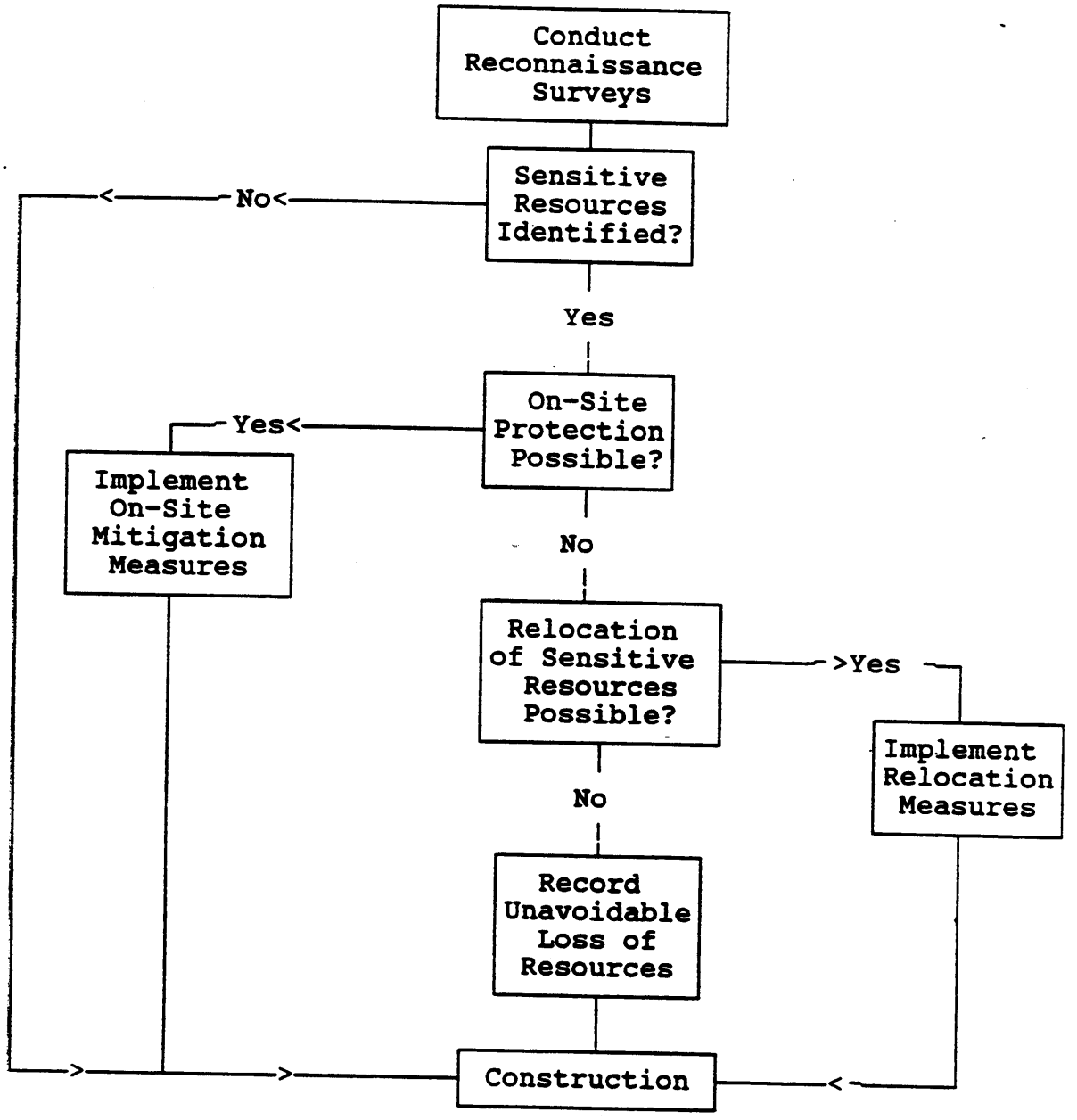
- If sensitive resources are not observed within the area of potential effect, construction activity using the general mitigation measures can commence.

- If it is determined that sensitive resources occur in the area of potential effect, then on-site protection should be evaluated. Measures that can protect on-site resources include: avoidance; establishment of buffer zones; marking, flagging, and posting of signs; scheduling construction to avoid sensitive time periods (e.g., crepuscular activity and/or breeding seasons) and; measures to encourage natural revegetation of temporarily disturbed habitats.

- Avoidance is the most effective way to reduce potential impacts to biological resources. In the cases where complete avoidance is not feasible, the possibility of partial avoidance should be evaluated. If on-site mitigation is not possible, then the possibility of relocating a sensitive resource should be considered.

Figure ES-1

Construction Mitigation Strategy
Biological Resources



If the projected impacts cannot be ameliorated on-site, then relocation options should be considered. However, relocation will not be a viable alternative if

suitable recipient habitat is not available. Examples where relocation is not feasible or realistic and where resources will be irreversibly damaged, should be documented prior to initiation of construction.

- In areas where sensitive resources cannot be salvaged, the type and extent of irrevocably committed biological resources should be recorded before construction proceeds utilizing standard mitigation measures. This record will be used as part of the documentation of the mitigation process, and also as a basis for determining the appropriate level of off-site compensation.

- Relocation of species should be combined with habitat compensation is recommended to ensure that there is no net loss of habitat quality and regional biological diversity. The purpose of such compensation is to prevent that species richness and diversity are diminished due to construction and operation of a new canal.

- When avoidance or reduction of impacts on biological resources within the project area are not possible, measures to offset unavoidable losses of habitat should be considered. The recommended strategy is to protect, when possible, similar (in-kind), unaffected habitat within the project area (on-site) or to replace those resources affected by the project.

- In the course of the project, biological resources like those in spoil deposition areas, will be irrevocably lost, with little or no chance for on-site rehabilitation. Losses which cannot be mitigated should be documented to determine the type and amount of habitat that should be acquired; however, as most other similar habitat within the project area has also already been lost or degraded from logging, agricultural clearing, and other activities, in-kind, on-site replacement of lost resources may not always be possible or practical. In these cases, calculations of unmitigated losses will be used to determine the appropriate level of compensation.

- The project Mitigation Plan should also include habitat compensation formulas. These formulas will assist design and value engineering in projecting costs to encourage the avoidance of particularly sensitive resources. Through this mechanism, a clear financial incentive to avoid biological assets will be established if, for example, the per hectare replacement ratio for mangrove forest is ten times that of agricultural lands.

Under certain circumstances, the acquisition, preservation, and maintenance of similar (in-kind) or different (out-of-kind) habitat in or near the study area may be the most practical means of compensating for a regional reduction in biological diversity caused by loss or

fragmentation of project area lands. Relatively large, contiguous blocks of habitat are required to avoid the adverse effects of habitat fragmentation on animal and plant populations.

The acquisition of undisturbed habitat adjacent to existing natural areas (i.e. Soberania National Park) may be the only way to provide for conservation of regional floral and faunal diversity. These newly acquired areas could then be placed under some form of legal protection, significantly reducing the possibility of future habitat loss or fragmentation in these areas. Even a landscape with impoverished remnants is better than one with none at all. Forest remnants can serve as important catalysts for forest regeneration and sources of botanical endemism. Ideally, smaller fragments should be connected by forest corridors and the landscape should include several large forest tracts of at least 1,000 ha (Daniel H. Janzen, University of Pennsylvania, personal communication). Locations of suitable habitat preservation areas within the study area were identified for potential acquisition and include:

1. A relatively large, contiguous block (approximately 14,000 ha) of mature tropical moist forest occurs south of Barro Colorado island, from the vicinity of Cerro Gigante eastward to the south shore of Gatun Lake, south of Gamboa.

2. An approximately 1,400 ha block of mature tropical moist forest east of Gatun locks.

3. Approximately 270 ha of freshwater wetlands at the mouth of the Trinidad River. This large wetland will possibly be lost by construction of the sea-level canal.

Other large areas of mature tropical moist forest and freshwater wetlands also still exist east of the existing canal, in the Districts of Colon and Chagres in the Province of Colon. A portion of the mitigation funds assigned for habitat preservation should be reserved in the form of an endowment. The endowment funds could be used to protect the acquired habitat, or to provide protection to existing reserved but unprotected lands. Endowment funds could also be applied to develop educational programs designed to increase local awareness of the value of the protected resources, and to develop "ecotourism" as a way to offset the financial implications of discontinuing consumptive resource exploitation in protected areas.

ADDITIONAL RECOMMENDATIONS

Because of the time frame, technical, and financial limitations associated with the performance of the Environmental Analysis component, a second phase combined Biological

Inventory and Environmental Analysis should be performed in parallel to proceeding to final design of either of the two canal alternatives.

The Phase II Environmental Analysis should include habitat mapping to obtain a relatively high degree of certainty with regards to the specific locations of sensitive resources within areas of impact. Sensitive species tend to be closely associated with a distinct community or habitat type. Therefore, studies designed to develop a map of the major and critical habitat types in the project area should be performed. Such maps will be critical for determining the least environmentally damaging alternatives for site disturbance and road alignments. These maps will also assist in determining potential resource relocation sites.

The information contained on resource maps will also be crucial for ascertaining potential site-specific impacts and for developing Mitigation Plans and Monitoring Programs. Habitat maps will document the existing environmental baseline conditions and provide a standard to measure the effectiveness of mitigation. These activities should be performed in all areas that may be affected by the construction or operation of the alternatives. Dames & Moore recommends that the area of impact to be studied include all land within a one (1) kilometer external radius from the boundary of the immediate construction, wet and dry deposition areas, roadways and all other canal related facilities.

Additional aerial photographs should be obtained to supplement the available photo coverage in the project areas. A full set of color aerial photographs, at a recommended scale of 1:18,000 should be commissioned. These should cover the entire areas of the High-Rise Lock and Sea-Level Canal routes, all deposition areas, as well as all proposed impoundment areas (Upper Gatun, Indio, Ciri and Trinidad), all diversion channels, minor impoundments and spillways.

Due to the low level of useful information regarding the areas for construction of the dams on the Indio, Trinidad and Ciri rivers, it is important that complete baseline studies be commissioned to obtain the necessary information for the Phase II Environmental Analysis. Without this information, it is not possible to adequately assess the magnitude of potential impacts to these areas.

The Sea-Level Canal Alternative presents a series of unresolved issues, such as the evaluation and design for a secure biological barrier to the marine biota and the movement of terrestrial fauna in the northern portion. These issues, among others, must be further investigated and resolved in order to properly evaluate this alternative. The existing conditions in this area are uncertain, as little site-specific information is available. Although the aerial inspection of the proposed canal route revealed that much of the southern portion has been severely affected by human activities, the northern portion still has significant areas of forest cover. In a similar fashion, insufficient information exists to assess the potential effects that the marine approaches may have to the surrounding ecosystems.

Specific studies should be performed in the proposed spoil placement areas along the route. Evaluations of the existing wetlands in the area of La Laguna should be also be commissioned. This area appears to have the greatest concentration of wetlands in Gatun Lake. The effects of the construction of the breakwater on both the Pacific and Caribbean approaches have the potential to significantly alter currents in these areas. This will have noticeable effects on current velocity, sedimentation rates, erosion and littoral drift. In order to evaluate these potential effects, it is necessary to obtain information regarding bathymetry, composition of the bottom sediments, current direction, rates and seasonal variations, to model the conditions in Panama Bay and in the Caribbean Approach areas.

As a Sea-Level Canal has the potential to affect the marine flora and fauna of the Caribbean basin and the Bay of Panama, a baseline study should be performed to establish regional marine biological conditions. Due to the large number of uncertainties regarding the possible effects of migrating Pacific marine biota to the Caribbean, it is important that existing conditions throughout the basin be properly tabulated.

Issues such as information regarding existing and historical fisheries (commercial, sport and subsistence), breeding grounds, current patterns, erosion and littoral drift, flora and fauna (both vertebrate and invertebrate), coral reef health, known contamination problems and any additional information that may serve to establish the historical and existing biological conditions within the Caribbean basin as well as the Pacific coastal countries extending from Ecuador through Mexico should be compiled.

A biological inventory, similar to the one performed for the High-Rise Lock Canal alternatives, should be performed for the areas that may be affected by the construction of a Sea-Level Canal. However, future biological inventories should be structured to provide information in areas that will be affected by the construction activities. Information regarding the local climate, geology, hydrogeology and hydrology should also be included, and additional information regarding local use of natural resources should be obtained, as this information will also be useful for future socioeconomic studies.

A recent declaration of May 25, 1993 created the Interoceanic Park of the Americas. The area that this park encompasses includes all of Gatun Lake and parts of the forested areas west of Gaillard Cut. An evaluation of the limitations on the usage of park areas should be performed, as these may have severe impacts on the activities associated with the construction of either of the two alternatives. An initial evaluation of the Park boundaries indicates that it may affect the various placement areas west of Gaillard Cut, as well as construction operations in La Laguna and the barrier dams.

LIMITATIONS OF THE PRESENT STUDY

The present study has been performed on the basis of biological information provided to Dames & Moore by CAS. The main references included the Biological Data Background Report, and the first three of four quarterly reports from the Biological Inventory. These documents included a large amount of significant information. However, due to their structure, certain limitations affected their usage. Among these conditions were the location of the sampling sites that were selected. Although most of these were within the operational areas of the existing canal, areas that would be directly affected by construction or operational impacts of either of the two alternatives were limited. As indicated before, the Biological Inventory did not provide information regarding the conditions in the area of the Sea-Level Canal alternative, nor were there any stations near any of the four proposed dam and impoundment areas.

In many cases, notably for insects, mammals, fish and birds, the methodology used did not provide a representative sample of these organisms. The reports reviewed for this study did not present descriptions of habitats, or other suitable information to relate species found with specific habitats. Certain habitats, such as mudflats, were not sampled at all. The absence of complete identifications had a large effect on the evaluation of insects, which had been classified only to the level of families, increasing the difficulty in evaluating organisms of medical importance. Other limiting conditions were encountered in the forestry data, where certain parameters, such as chest-height diameter were presented, without an estimate of tree height.

As indicated previously, aerial photograph coverage was incomplete, and certain areas, such as the Indio River basin, were only available in black & white photographs. If the Phase II Environmental Analysis is initiated within a 12 month period from the completion of this component, photographing only the missing areas may be sufficient. If the delay in performing the additional studies extends significantly beyond this period, it is recommended that full photographic coverage of the project areas be obtained.

The process to complete the recommendations for further study can require more than five years of continuous study, in order to establish patterns in areas where information is scarce or lacking. The information obtained in this fashion would be used to document existing conditions and potential impacts associated with the construction of a Sea-Level canal.

The Environmental Analysis did not provide a thorough evaluation of the design modifications set forth in the June 1993 Annex to the ECE Report, as this document was made available for review after completion of the Draft Final Report. However, the Final Report includes a limited evaluation of the impacts associated with the more significant design modifications for the High Rise Lock canal alternative.

**nte, esclusas de
deposición D-1.
n Locks, Gatun
e located.**

Foto 2. Cerro del contratista, Corte Culebra. Obsérvese los taludes de excavación.
Photo 2. Contractor Hill at Gaillard Cut showing the excavation faces.

Foto 3. Esclusas de Pedro Miguel entre los lagos Gatún y Miraflores.
Photo 3. Pedro Miguel Locks conecting Gatun and Miraflores lakes.

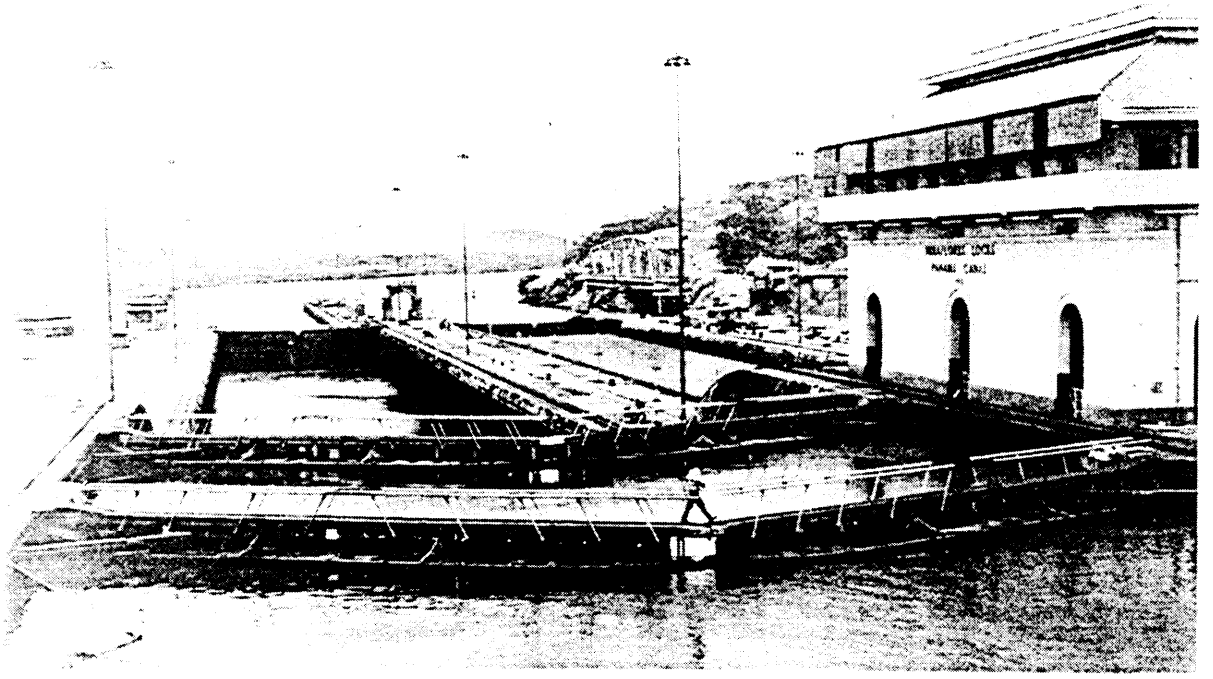


Foto 4. Esclusa de Miraflores entre el Lago Miraflores y el Océano Pacífico.
Photo 4. Miraflores Locks connecting Lake Miraflores and the Pacific Ocean.

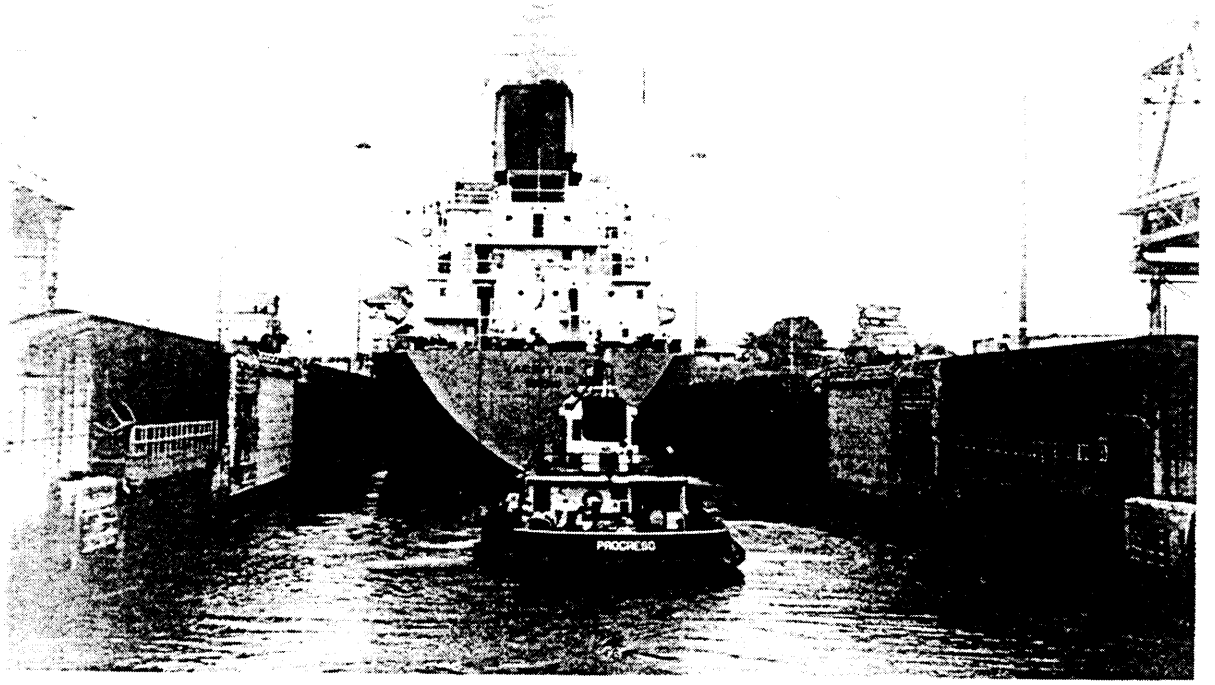
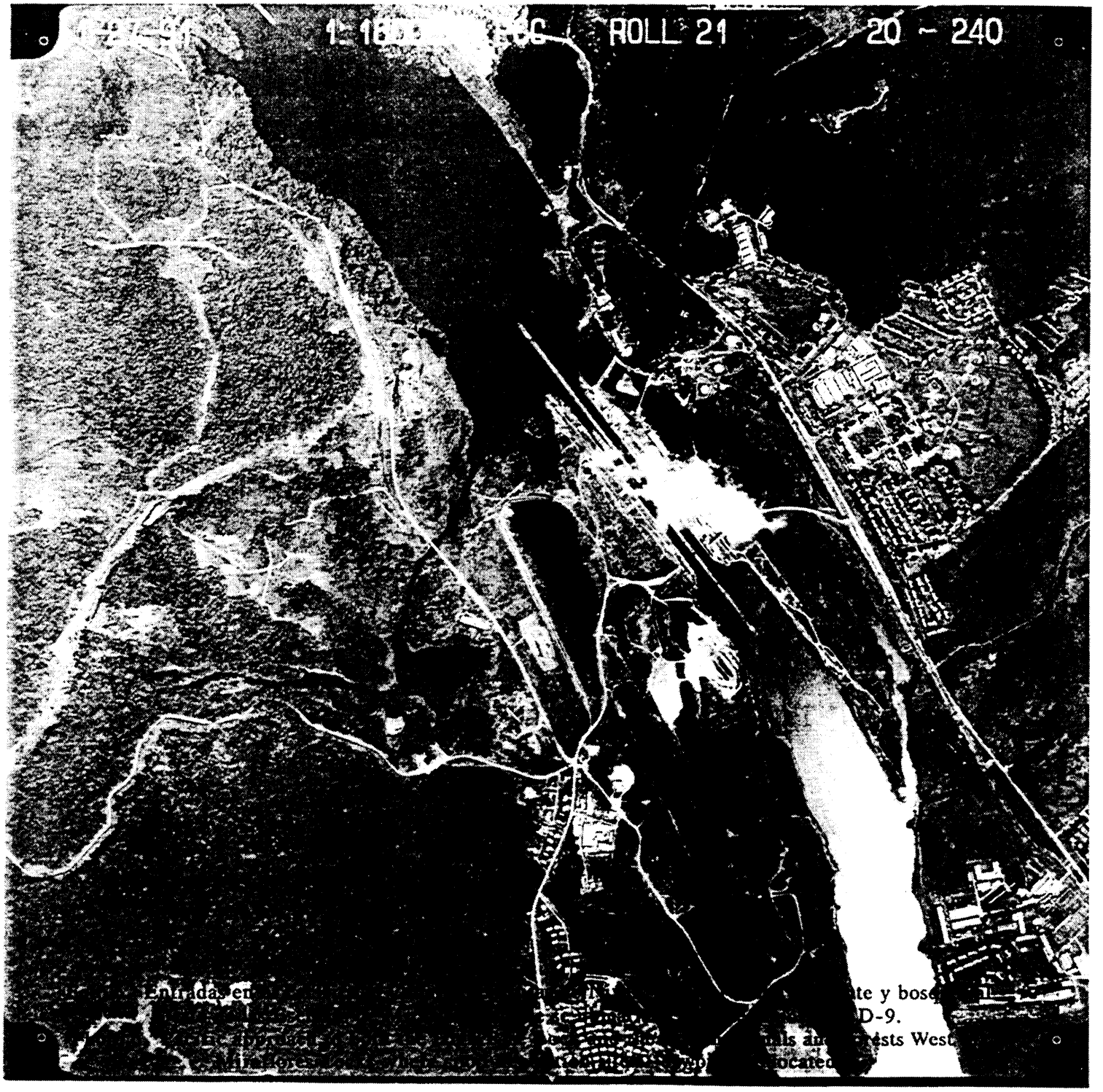


Foto 5. Remolcador asistiendo a un barco al entrar a las Esclusas de Miraflores.
Photo 5. Towboat assisting ship entering Miraflores Locks.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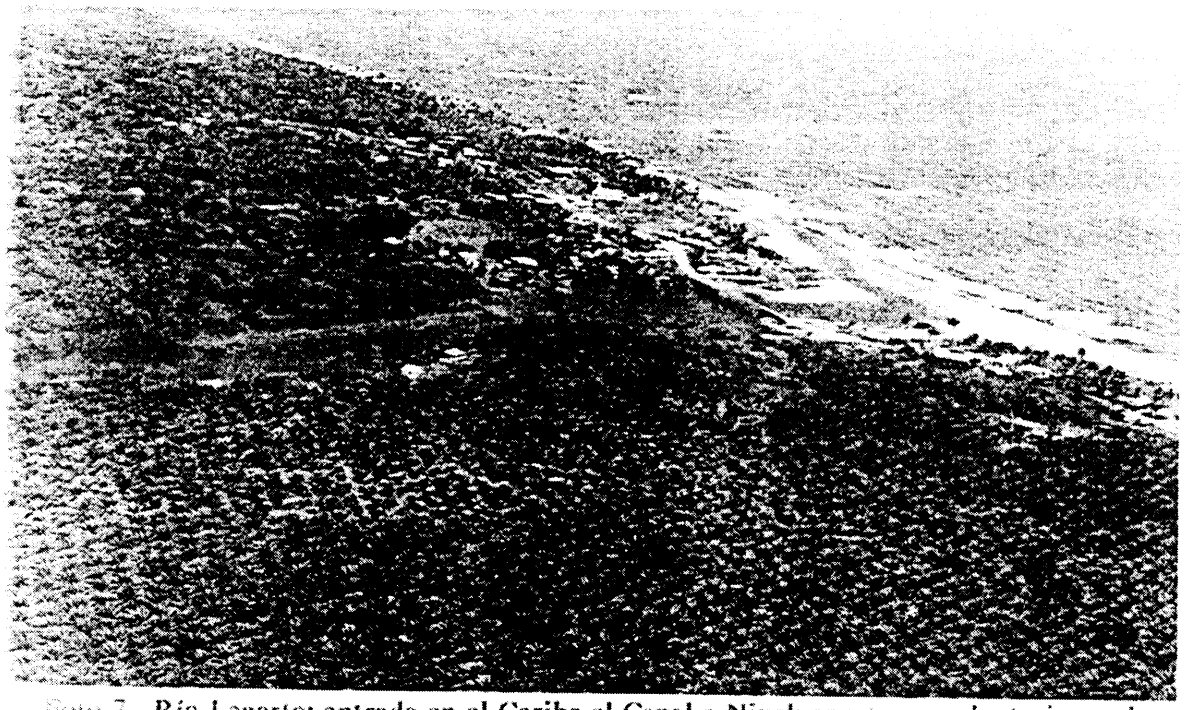


Foto 7. Río Lagarto: entrada en el Caribe al Canal a Nivel; consta con plantaciones de palma aceitera africana.
Photo 7. Lagarto River: Caribbean approach to Sea Level Canal adjacent to african oil palm plantation.

Foto 8. Area deforestada al Sur del Lago Gatún que seria atravezada por el Canal a Nivel.
Photo 8. Deforested area South of Lake Gatun which would be crossed by Sea Level Canal.

Foto 9. Fragmento de bosque al sur del Lago Gatún que sería afectado por el Canal a Nivel.
Photo 9. Forest fragment South of Lake Gatún which would be affected by Sea Level Canal.

Foto 10. Quema de herbazales junto a fragmentos de bosque al sur del Lago Gatún.
Photo 10. Grassland burning adjacent to forest fragments south of Lake Gatún.

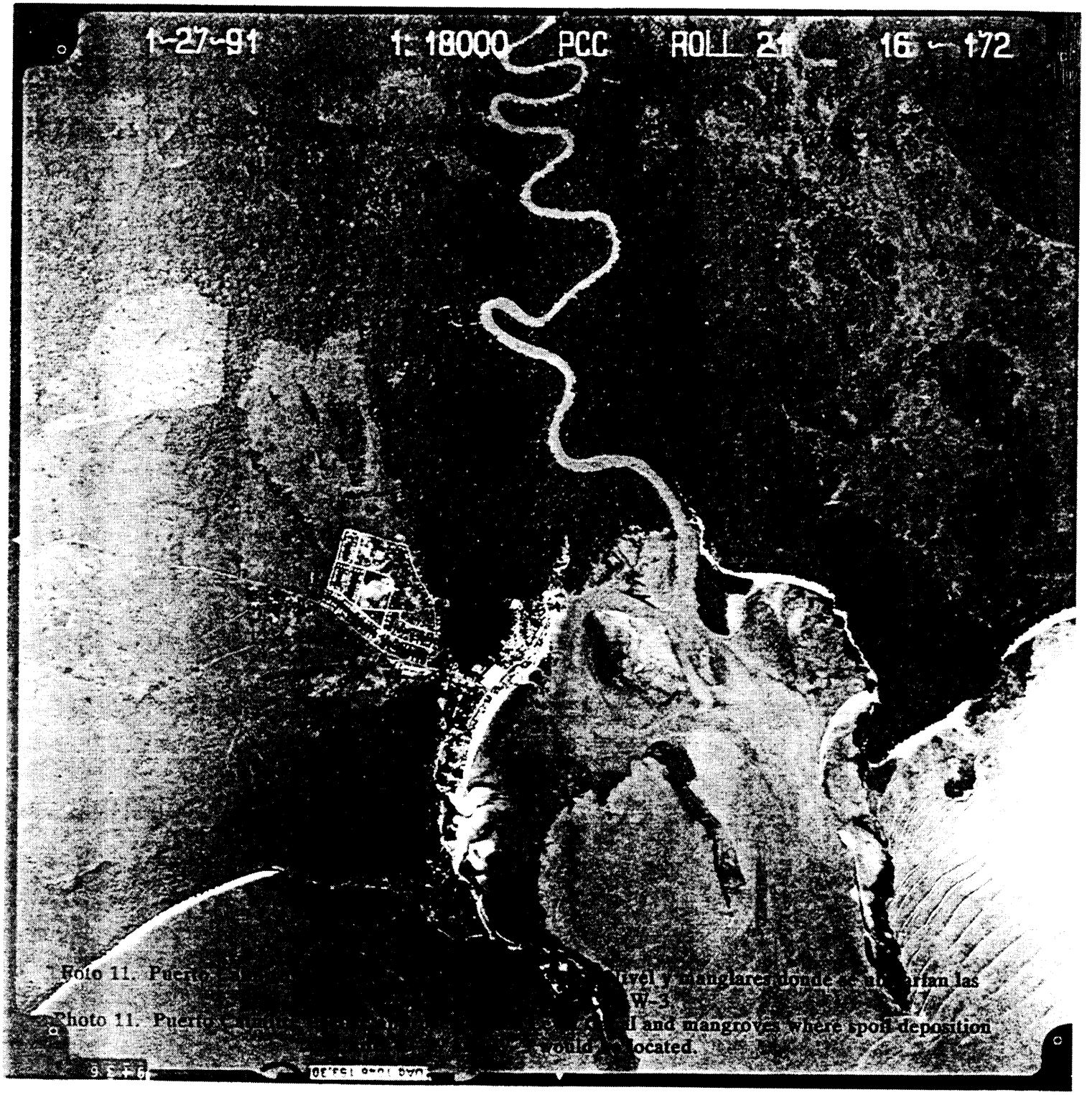


Foto 11. Puerto [illegible] ivel y manglares donde se [illegible]rían las [illegible] W-3 [illegible]

Photo 11. Puerto [illegible] l and mangroves where spoil deposition [illegible] would [illegible] located.

Foto 12. Area boscosa en las riberas de Corte Culebra.
Photo 12. Forested area adjacent to Gaillard Cut.

Foto 13. Area impactada por la expansión actual de Corte Culebra.
Photo 13. Impacted area by the current expansion of Gaillard Cut.

Foto 14. Bosque sucesional joven ubicado en el área de Gamboa.
Photo 14. Young successional forest localized in the vicinity of Gamboa.

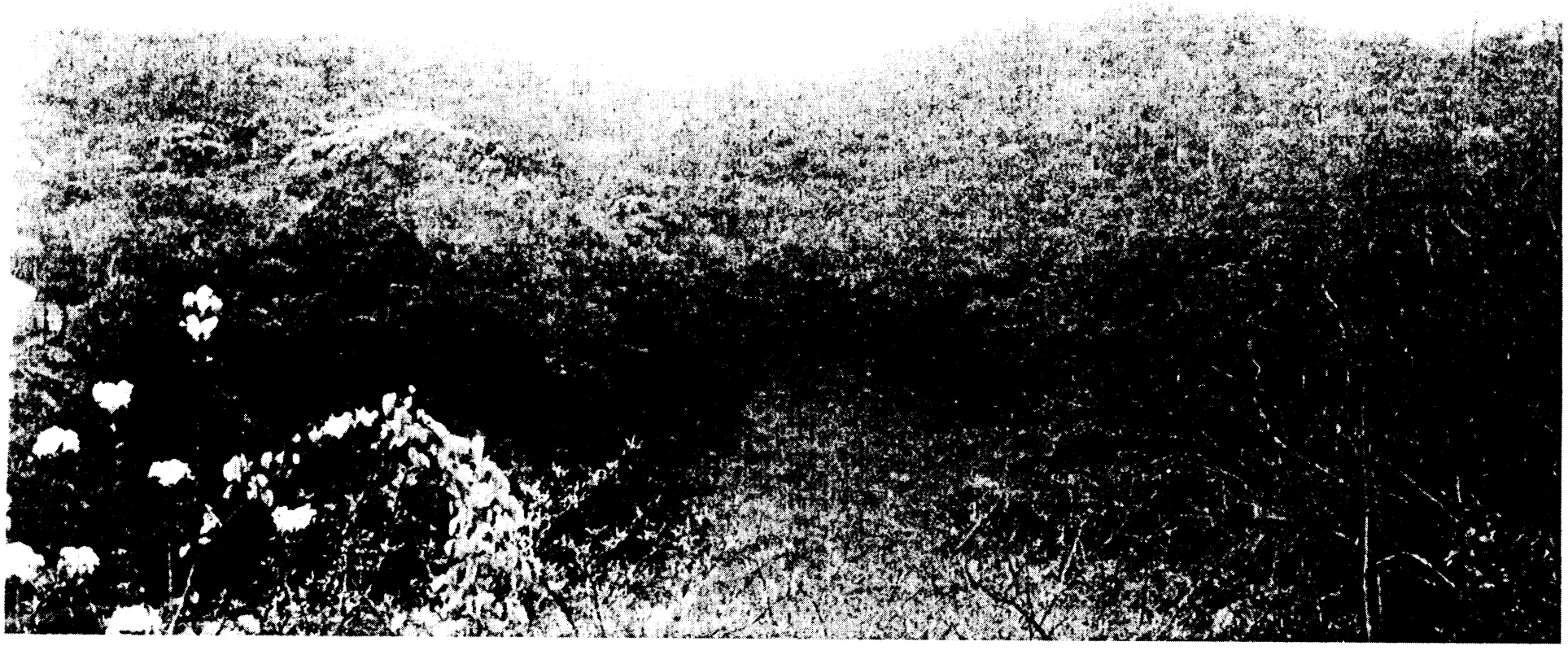


Foto 15. Bosque tropical ubicado en las riberas del Río Chagres en al área de Chilibre.
Photo 15. Tropical forest adjacent to Chagres River in the vicinity of Chilibre.

Foto 16. Bosque tropical en la desembocadura del Río Chagres al Lago Gatún, Gamboa.
Photo 16. Tropical forest adjacent to the mouth of Chagres River at Lake Gatun, Gamboa.

Foto 17. Vista de un arrecife de coral en el Caribe de Panamá (Archipielago de San Blas).
Photo 17. Caribbean coral reef of Panama (San Blas Archipielago).
Foto cortesía de Marco Díaz. Photo courtesy of Marco Díaz.

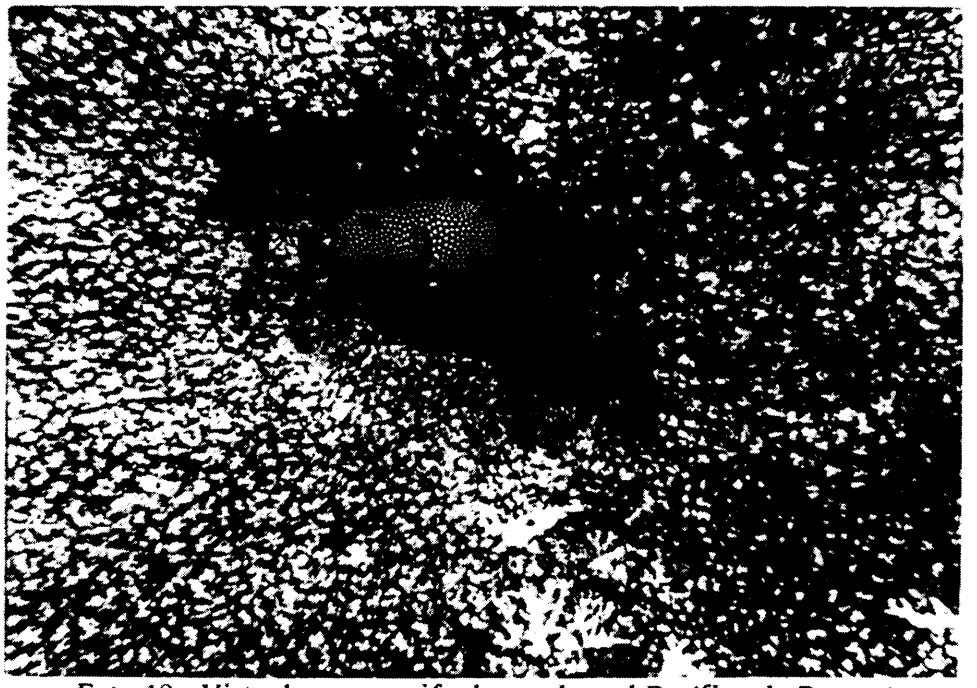


Foto 18. Vista de un arrecife de coral en el Pacífico de Panamá.
Photo 18. Pacific coral reef of Panama (Iguana Island, Pedasí).
Foto cortesía de Marco Díaz. Photo courtesy of Marco Díaz.

FINAL REPORT
ENVIRONMENTAL ANALYSIS COMPONENT
STUDY OF ALTERNATIVES TO THE PANAMA CANAL

PREPARED FOR THE COMMISSION FOR THE STUDY OF ALTERNATIVES TO THE PANAMA CANAL

1.0 INTRODUCTION

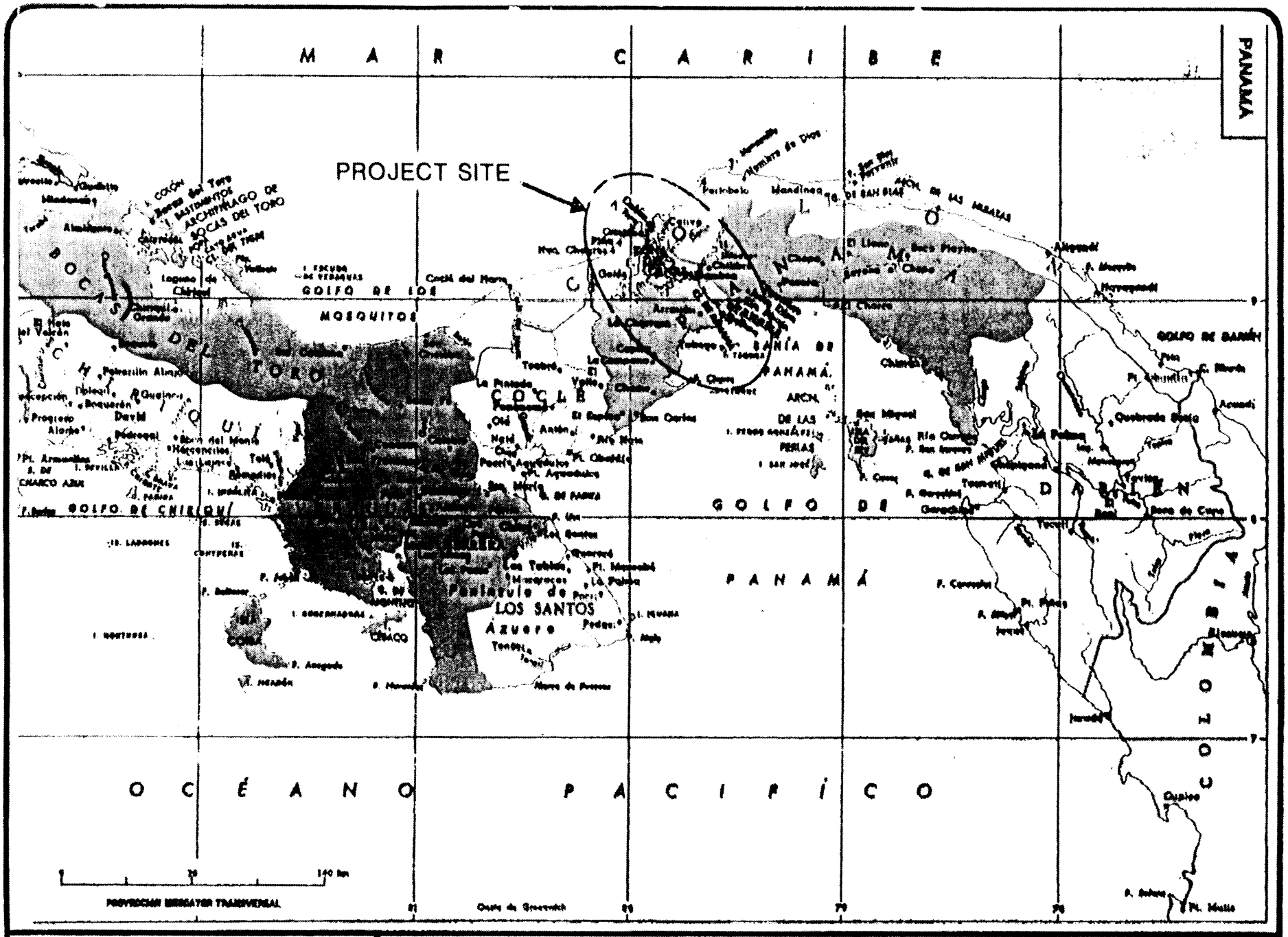
The existing Panama Canal was completed in 1914, and is recognized as one of the great engineering feats of the Century. Its completion opened vast improvements in world-wide trade expediting the journey of ships capable of transporting up to 65,000 Dead Weight Tons (DWT). However, ever since its inception, operators and users alike have been evaluating different methods for increasing its capacity. Many commissions have studied shipping and engineering requirements as well as physical conditions of the canal study areas. A map of the Republic of Panama showing the location of the canal is included as Figure 1.1.

As part of the Torrijos-Carter Treaties of 1977, Article XII mandated that the feasibility of a sea-level canal be studied by the Republic of Panama and the United States. This mandate created the Commission for the Study of Alternatives to the Panama Canal (CAS). With the association of Japan, a three-country commission was later established. The purpose of this commission has been to evaluate the different alternatives that could be implemented to enhance and improve the existing facility. As part of the feasibility study of different alternatives, CAS mandated various engineering, economic and environmental studies to evaluate potential options to upgrade the canal system.

After the evaluation of several canal upgrading schemes, two final alternatives remain: the construction of a third set of locks parallel to the existing system, and the construction of a new sea-level canal to the west of the existing canal along what is known as Route 10. The alternatives selected for final evaluation would complement the existing system, and not replace it. In addition to the actual construction operations related to building a canal, either alternative will require additional infrastructure support. This will include roadways, bridges, quarries, crushing plants, cement batching plants, temporary docks and/or jetties, equipment laydown areas, worker camps and villages.

The present report details the activities performed and the results of the Environmental Analysis Component of the Study of Alternatives to the Panama Canal. The purpose of this analysis was to review the available biological information, evaluate the environmental impacts anticipated from each of the two alternatives, identify data gaps, and recommend mitigation measures and additional environmental studies if deemed necessary. The study evaluated the effects of different activities associated with the construction, operation, and maintenance of canal alternatives.

The Environmental Analysis was based on information provided by CAS, which consisted of the Preliminary Engineering and Cost Estimate (ECE) report, dated April 1993, prepared by Yachiyo Engineering Co., Ltd.; the first three of four quarterly reports of the Biological Data Background and Biological Inventory (BD/BI) component, prepared by the Consortium Universidad de Panama-ANCON Consortium (UNIPAN-ANCON); Operating Characteristics and Capacity Evaluation Study, Phase 2 (OCCES), prepared by TAMS Consultants, Inc.; partial aerial photographic coverage of the study areas, and other available information located in the Information Center of the Commission. Additional information for review was obtained from the Smithsonian Tropical Research Institute (STRI), the Panama Canal Commission (PCC) library, the Tommy Guardia Geographic Institute, and the personal libraries of professionals and scientists associated with the Dames & Moore team.



ENVIRONMENTAL ANALYSIS
STUDY OF THE ALTERNATIVES
TO THE PANAMA CANAL

REGIONAL LOCATION MAP

DAMES & MOORE

FIGURE 1.1

BY BEHAE DATE 06-21-93 REVISIONS
CHECKED BY. D & M JOB NO. 26437-001-5552 BY DATE

2.0 PROJECT BACKGROUND

Soon after the founding of the city of Panama by the Spanish conquerors in 1519, the Emperor Carlos V ordered studies to build a canal that joined the Pacific and Atlantic oceans. The Licenciado Espinoza, who explored the region in 1534, recommended to the Crown to open a canal using the course of the Chagres River. However, the project was abandoned and during the three centuries that followed, until 1850, the Camino Real, an overland trade route that joined the two oceans, was used by the Spanish conquerers to transport goods. The Camino de Cruces, which used the river Chagres to navigate until its mouth in the Caribbean was also utilized for the same purpose (Mack, 1971).

Between 1850 and 1855, the Panama Trans-isthmus Railway was built with a length of only 80 kilometers (km), joining the city of Panama and the new city of Colon. Only 25 years later, the railway would serve as base for the fruitless efforts as the French attempted to build a sea-level interoceanic canal. The construction of the Panama Canal was begun by the Universal Company for the Interoceanic Canal in 1880 with the intention of opening a canal at sea level for the international navigation. The works were paralyzed nine years afterwards due to severe health problems, along with engineering and financial difficulties (Bouvier, 1964).

In 1903, after the signing of a treaty between the U.S. and the Republic of Panama, recently separated from Colombia, the French sold their canal rights to the United States (Teran, 1979). A year later, the U.S. began the construction of the canal. In 1906, the U.S. Congress approved a plan to modify the original design of the Panama Canal. Under the direction of the American engineer John Stephens, the U.S. proceeded to build the interoceanic canal using a lock system which was successfully completed in 1914. The original notion of a lock canal to control the rising of the Chagres River was proposed 25 years before by the French engineer Godin de Lepinay (McCullough, 1977). During 10 years of construction more than 100,000 workers were contracted for all activities (Newton, 1984).

Due to the constant increase in the canal traffic after its opening, the American government empowered the U.S. Army Corps of Engineers to perform studies to expand the capacity of the canal. In 1931, the group proposed three solutions: to add a third set of locks to the existing canal, to convert the existing canal into a sea-level canal, or to build a new lock canal in Nicaragua. These solutions constitute, in part, the origin of the alternatives that are considered at present. In 1936, the President of the Panama Canal Company and, Governor of the Panama Canal Zone, was instructed by the U.S. government to propose a plan that increased the traffic capacity of the canal in order to satisfy future demand.

The governor presented a plan based on the construction of a third set of locks proposed by the Army Corps of Engineers (Cooley, 1972). The U.S. Congress accepted the plan and approved the construction of the third set of locks. The objective was to increase the capacity of the canal and, at the same time, improve the defensive condition of the canal.

However, the U.S. was already committed to the approaching World War. In 1942, when the excavation for the new locks and the design of the new structures had already been performed, the construction projects were discontinued and never restarted.

The present American system of two Navy fleets, one in each ocean, has made canal crossings for military reasons unnecessary. In 1945, after the war, the U.S. again ordered the Governor of the former Panama Canal Zone to design the best means to increase the capacity of the canal. The Studies included the possibility of building other canals that offered easier defense (SINBOL, 1992). As a result of this study, 30 alternative routes to the existing canal were proposed. "The Study of the Isthmus Canal," dated 1947, concluded that the most desirable and viable solution would be a sea-level canal.

Several years later, in 1955, almost simultaneously to the diplomatic agreements which opened up duty-free zones to the Panamanian economy, the Stanford Research Institute published a study on the impact of a sea-level canal on the economy of Panama. In 1958 the Board of Consultants in the studies of the Isthmus Canal investigated a plan for long-term improvements to increase the capacity of the existing canal.

Due to the confrontations produced in January of 1964 among the U.S. Army and a Panamanian popular movement, diplomatic relations between the two countries were discontinued. When these were re-established, the two governments agreed to begin new discussions on the Panama Canal (Yao, 1972). In the same year, a report titled "Studies of the Isthmus Canal" analyzed the available methods for improving the lock canal, increasing its capacity and meeting the traffic demands of the canal. The report proposed alternatives detailed on the following plans:

- Plan for a third set of locks
- Terminal lake plan
- Plan for a sea-level canal along the existing route.

The report also evaluated the projected capacity for traffic on the canal, a pre-requisite to design a new alternative plan. That year, the U.S. President obtained approval for legislation to finance the study for a sea-level canal. The study concluded in 1970 that the construction of a sea-level canal was viable, selected potential routes and presented cost estimates. The results of the study were summarized in the document "Report of the Interoceanic Canal Commission" (known also as the Anderson Report). This report recommended the then Route 10 (west of the existing canal) as the most feasible alternative and route 14S (through the existing canal) as a possible alternative (SINBOL, 1990).

In 1972, the Economic Commission for Latin America of the United Nations, delivered to the Panamanian government a report on the economy of the former Panama Canal Zone, which recommended a large-scale study to establish the relationship between alternatives to the existing canal and shipping demands at world level (CEPAL, 1972). A study to determine the viability of pumping seawater into Gatun Lake, to complement the reserves from the rivers and lakes that feed the canal, was performed in 1973.

The canal consumes the equivalent of 2.2 million acre-feet of fresh water on an annual basis (14,000 lock operations). The hydrologic basin produces 4.3 million acre-feet of water. Thirty percent of this quantity is used in ancillary functions to the canal. It is calculated that water demand could grow to 3.7 million acre-feet if the number of traffic reaches a maximum of 26,800 crossings per year. With a third set of locks, the number of crossings could reach 35 thousand with a demand of 6.6 million acre-feet of water. To cover this hypothetical deficit, three alternatives were recommended in 1977: 1) deepen the canal route, 2) create new areas for water reserves and 3) create a system to pump water (Panama Canal Company, 1973).

Alternative 3 was considered as a last resort. In 1987, the Panama Canal Commission presented the conclusion of its study on the widening of Gaillard Cut. The project consists of broadening the nine miles (15 Kms) of the Gaillard Cut to permit the simultaneous crossing of two Panamax type ships (built to the maximum specifications of the locks). This would increase the capacity of the Canal by 15 percent. In addition, it would offer greater safety to the largest ships. The construction cost was estimated between $310 and 380 million.

Article XII of the 1977 Panama Canal Treaty between the Republic of Panama and the U.S. included the mandate that both countries perform a study on the viability of a sea-level canal crossing the isthmus. It was required that the study be completed prior to the year 2000. In May 1982, the U.S. President requested that the study include the sea-level canal and also other alternatives, in addition to the sea-level canal.

In September of the same year, the Preparatory Committee for the Study of the Alternatives to the Panama Canal between the U.S. and Panama was established. Japan joined the Committee soon after to participate in canal feasibility studies that would benefit the three countries. In October of 1982, the U.S. Department of State sponsored a meeting to discuss future alternatives for transportation through the Panama isthmus.

The preparatory committee, with the participation of the three countries, was gathered for the first time in December, 1982. During the sixth meeting of the Committee, held in Tokyo in 1984, an agreement was reached on the scope of the study to evaluate alternatives to the existing canal. In September of 1985, the Terms of Reference for the studies were formally accepted (SINBOL, 1992).

The objectives of the study were defined as follows:

- To study the possible alternatives to the existing Panama Canal.
- To recommend the best alternative to the participating governments.

The studies began approximately seven years ago. Due to political upheavals, the completion of various components was delayed. The present study for the Environmental Analyses Component began on March 19, 1993. CAS is currently planning to complete all work and make its recommendations to the three member countries in September 1993.

3.0 PROJECT DESCRIPTION

The results of the previous studies of alternatives to the Panama Canal have reduced the considered alternatives to two. After the evaluation of several canal upgrading schemes, the final alternatives under consideration by CAS are: the High-Rise Lock Canal, and the Sea-Level Canal through Route 10. A site vicinity map showing the general alignments of the two alternatives is presented in Figure 3.1 The alternatives selected for evaluation would complement the existing system, and not replace it.

This section presents a summary of the design features of each of the two alternatives as described in the Final ECE Report. Although the June 1993 Annex to the ECE Report became available for review after completion of the Environmental Analysis Final Draft Report, appropriate sections were updated for the Final Report, when possible, to reflect some of the most significant design modifications associated with the alternate single lane options considered in the ECE Annex for both the High-Rise Lock Canal and the Sea Level Canal.

3.1 HIGH-RISE LOCK CANAL

The High-Rise Lock Canal will widen, deepen, bifurcate at few locations and provide new two-lift locks at the Gatun and Miraflores locations. A layout of this alternative is shown on Figure 3.2.

The proposed alignment of this alternative follows most of its route along the existing canal. It coincides with the existing canal from the Pacific coast to the port of Balboa. The canal then changes its direction to the west of the existing canal, at a point 2 kilometers (km) north of the port of Balboa where two new locks are proposed. A new channel excavated 2.5 km west of Cerro Aguadulce joins the existing canal 2.5 km northwest of the existing Pedro Miguel locks.

The canal continues along the existing route through the Gaillard Cut section and then proceeds along Route-I, through Gatun Lake. The canal then shifts to the east, about 3 km before the Gatun dam, where the new locks are provided. The canal extends 1.5 km east from Gatun locks and is parallel to the existing canal. The canal then rejoins the existing route at Limon Bay and continues as the existing canal. The proposed layout of the new locks on the Pacific side and associated facilities are shown on Figure 3.3 while the Caribbean side new lock system is shown on Figure 3.4.

Two sizes of ships, 150,000 DWT and 200,000 DWT, are under consideration for the alternative designs. The proposed canal is a two-lane canal, 322 meters (m) in width and 21 m deep for the 150,000 DWT ship alternative and 350 m wide and 22 m deep for the 200,000 DWT alternative. Additional general information regarding the General Characteristics of the two Panama Canal alternatives including the High-Rise Lock Canal is presented in Table 3.1.

The overall construction schedule for the High-Rise Canal alternative is estimated at 10.5 years. Final engineering design and tender for the High-Rise Canal alternative is expected to last 2.5 years. Presently, the project schedule requires the construction of supporting structures for a period of one year.

Table 3.1 General Characteristics of Panama Canal Alternatives

ALTERNATIVE		HIGH-RISE LOCK CANAL		SEA LEVEL CANAL		
Alignment		Along Existing Canal		Route 10 from IOCS Study		
Maximum Ship Size		150,000	200,000	250,000 DWT		
Number of Ship Transit	(2020) Existing C.	16,200	16,200	16,200		
	New Canal	2,000	2,000	2,100		
	Total	18,200	18,200	18,300		
	(2060) Existing C.	20,000	20,000	19,400		
	New Canal	4,600	4,600	5,100		
	Total	24,600	24,600	24,500		
Number of Lanes		2		1 (approach 2)		
Number of Lifts		2		0		
Water Level		85 feet		Sea Level		
Tidal Lock & Gate		N/A		Case a	Case b	Case c
				parallel 4 locks	1 lane 2 gates	parallel 4 locks & 1 gate

N/A: Not Available

Two additional variations of the High-Rise Lock Canal were evaluated in the ECE Annex to study single lane canal options through the Culebra Cut section for both the 150,000 and the 200,000 DWT alternatives. Except by this variation, the ECE Annex canal alternatives are similar to the original designs considered in the ECE Final Report.

In view of the proposed canal structure, existing topography and geology, proposed construction methods and excavation volumes, the High-Rise canal alignment was divided for the purposes of the ECE Report into five zones. The zone map for the High-Rise Lock canal is shown on Figure 3.5. Table 3.2 provides zoning scheme data for the 200,000 DWT option.

Table 3.2

Zoning Scheme - High Rise Lock Canal

ZONE NO.	HIGH-RISE CANAL	INITIAL STATION	FINAL STATION	LENGTH (km)	CANAL BOTTOM (m)*1	WATER LEVEL (m)*1
I	Atlantic Approach	-12.80	+2.00	14.8	-21.3	-0.3
II	Gatun Lake	+2.00	+42.00	40.0	+3.1	+25.1
III	Culebra	+42.00	+52.00	10.0	+3.1	+25.1
IV	Miraflores	+52.00	+60.00	8.0	+3.1	+25.1
V	Pacific Approach	+60.00	+79.20	19.2	-25.4	-3.4

*1 Reference datum is Precise Level Datum (PLD) as adopted by the Panama Canal Commission and corresponds to Elevation (El.) -0.30m Mean Sea Level datum (MSL)

The design modifications of the single lane High Rise Canal can be summarized as follows:

- There is no widening of the Culebra Cut Zone beyond the widening now being carried out by PCC to 630 feet on straight sections and 730 feet in curves.
- The Culebra Cut is deepened to 21m for 150,000 DWT design ships and to 22m for 200,000 DWT.
- The deepening is required only over the width necessary to allow one way passage of the design ship which corresponds to 160m for 150,000 DWT and 175m for 200,000 DWT.
- The two lanes of new locks are reduced to only one lane of High-Rise Locks.

3.1.1 Proposed Roads and Bridges

Access roads are aimed to provide at least the same level of service and convenience after implementation of the canal improvements as is now available. Since the High-Rise Lock

Canal closely follows the alignment of the existing canal, access roads generally already exist and the extent of new access and permanent roads is much less than for the Sea-Level Canal alternative. The Boyd Roosevelt or Trans-isthmic highway provides convenient access across the isthmus.

Construction of new locks and approach channel will cut off the existing road from Colon to Fort Sherman and to Escobal, and Nuevo Chagres. New two-lane paved roads are planned to connect the town of Gatun with Fort Sherman, Escobal, and Nuevo Chagres. New roads will also be built on the east side of the locks to have access to Fort William Davis and Dock 45 on Gatun Lake.

Access to the town of Gatun is provided by means of a new high level bridge and existing movable bridge immediately below the existing locks. No access roads are planned for Gatun Lake. Access to the Gamboa Reach area will be provided by extending the road from Miraflores on the west and south side of the widened canal. Due to the widening of the canal on the southwest side of Gaillard Cut, a significant portion of the existing Borinquen Highway will be lost. Table 3.3 presents a summary of the proposed new access roads for the High-Rise Lock canal alternative.

Van Dam bypass bridge is planned for extension of the Highway from Arraijan to Panama City north in the Miraflores zone. The Bridge of Americas will be widened with a new bridge crossing. All bridge crossings will be provided with a clear span of 350 to 380 m in width and 60 m in height. The bridges will be either two-lane or four-lane and paved. Table 3.4 is a summary of the proposed bridges for the High-Rise Lock Canal alternative.

3.1.2 Excavation and Dredging

Construction of the High-Rise Lock Canal will require excavation of approximately 600 million cubic meters (MCM) of soils for 200,000 DWT and 512 MCM for the 150,000 DWT, including both dry excavation and dredging. The breakdown of estimated excavation volumes assuming the level of Gatun Lake is maintained at 85 feet are presented on Table 3.5. With the single lane canal options, the total volume of excavation would be reduced to 403 MCM for 200,000 DWT ships and 337 MCM for 150,000 DWT.

The material to be excavated at the proposed alignment is highly variable. In addition, topographic conditions also differ greatly from zone to zone. Therefore, the excavation method to be used in each zone will be varied to accommodate the different site conditions and minimize the trafficability in the existing canal.

Table 3.3

Summary of New Access Roads - High Rise Lock Canal

LOCATION	NO. OF LANES	TYPICAL X-SECTION	APPROXIMATE LENGTH	COMMENTS
Gatun				
Approaches to new bridge	2	Paved	1 km *2	Provides access to west of canal
Access to New Locks & Fort Davis	2	Paved	3 km	Also serves Dock 45 on Gatun Lake
Gaillard Cut				
Borinquen Highway	2	Paved	27 km	Replaces existing Borinquen Highway
Panama				
Pan American Highway	4	Undivided, paved	2 km *2	Approaches to new bridge
Access to New Dams				
Rio Indio, Ciri* and Trinidad	2	Paved	27 km	No existing roads
TOTAL			**60 km**	

*2 Excludes length of bridge structure.

The excavation and dredging for the five different zones are planned as follows.

ZONE I - Caribbean Approach Zone: This is a 14.8 km section between Stations -12.8 to +2.00, which consists mainly of unconsolidated deposits, that will be entirely excavated by the dredging method. The excavation will be initiated with dredging on one half of the canal only to allow the passage of ships on the other half. Once dredging in the first portion is finished, dredging on the other side will be started. During this period the ships can use the newly widened portion.

ZONE II - Gatun Lake Zone: This is a 40 km section that extends from Stations 2.00 to 42.00. Except for ground excavation of several small islands along the alignment, the dredging method of excavation will be used in the Gatun Lake zone which is mainly located below elevation +29.0 m. Strong rock is encountered in this zone. The dredging plan will be similar to the one carried out for Zone I.

Table 3.4 Summary of Bridges - High Rise Lock Canal

LOCATION OF BRIDGE	CANAL WIDTH (M)	BRIDGE		MAIN SPANS BRIDGE LENGTH (M)				APPROACH LENGTH
		LANES NO.	WIDTH (M)	L	L1	L2	L3	L4
(a) 150,000 DWT								
Atlantic	320	4	20.5	740	410	165	165	1500
Middle	320	2	10.0	850	470	190	190	600
Van Dam (1)	320	4	20.5	850	470	190	190	490
Van Dam (2)	Exit.	4	20.5	900	500	200	200	430
Pacific	320	2	10.0	810	450	180	180	850
(b) 200,000 DWT								
Atlantic	350	4	20.5	770	430	170	170	1500
Middle	350	2	10.0	900	500	200	200	600
Van Dam (1)	350	4	20.5	900	500	200	200	490
Van Dam (2)	Exit.	4	20.5	900	500	200	200	430
Pacific	350	2	10.0	860	480	190	190	800

Table 3.5 Excavation Volumes (MCM) - High Rise Lock Canal

METHOD	150,000 DWT SHIP	200,000 DWT SHIP
Dry Excavation	216.69	241.79
Dredging	295.43	357.66
Total	512.12	599.46

MCM = Million Cubic Meters

ZONE III - Gaillard Zone: This is a 10 km section that extends from Station 42.00 to 52.00. Widening of the existing Gaillard Cut is planned to expand the canal into the southwest bank while preserving the northeastern bank. The dredging method

will be used to excavate in the canal while both the dredging and dry excavation methods will be used to widen the canal. In the mixed excavation areas, dry excavation will be conducted first and dredging will be conducted in the second stage to remove the remaining underwater material.

ZONE IV - Miraflores Zone: This is an 8 km section extending between Stations 52.00 to 60.00. Since this section is diverted from the existing canal to avoid the Miraflores Lake, the excavation is entirely on dry ground. Therefore the dry excavation method will take place along the entire Zone IV. Since this section is separated from the existing canal, no shifting of canal lanes during construction will be required.

ZONE V - Pacific Approach Zone: This is an 19.2 km section that extends from Stations 60.00 to 79.20. This section will be excavated entirely by the dredging method. The dredging procedure will be similar to the one carried out for Zone I.

3.1.3 Spoil Areas

The following construction procedures will be employed to dispose of the excavated material and mitigate surface run-off into the excavated areas:

1) Materials from the dry excavation will be used for banking at designated placing areas which are located along the canal. The hauling distance from the dry excavation areas to the placing areas typically range from 2 to 20 km. In order to avoid disruption of the surface waters in the proposed placing areas, streams and creeks will be piped through the placing areas. Drainage during construction will be handled by sedimentation ponds. In addition, vegetation and surface drainage will be provided upon completion of banking at the designated placing areas.

2) In order to provide temporary in-situ earth plugs to prevent large amounts of rainfall from flowing into the excavation areas, dry excavation will generally be carried out in 2 km sections. Large capacity pumps will be used for dewatering operations to maintain the ground excavation area dry.

3) Dredged materials will be disposed at designated placing areas located along the existing Pacific and Caribbean breakwaters and within the Gatun Lake area.

Locations of spoil areas for the High-Rise Lock canal alternative are shown on Figure 3.6.

3.1.4 Reservoirs, Dams and Pump Stations

In order to adequately meet the amount of lockage water required for the proper operation of the High-Rise Lock Canal, new dams and reservoirs will be constructed. The proposed dams will be designed as rockfill gravity dams and material for dam construction will be obtained from local quarries. The sites selected as the preferred dam location choices are on the Indio River and the Ciri or Trinidad rivers, depending on the maximum ship size option.

As presented in Table 3.6, except for the Indio river dam, all other dams are scheduled for constructed in the year 2060. Figures 3.7 through 3.9 show the location and layout of the proposed Indio, Ciri and Trinidad rivers reservoirs. Figure 3.10 shows the Indio-Ciri rivers reservoir arrangement for the 150,000 DWT option while Figure 3.11 shows the Indio-Trinidad rivers reservoirs for the 200,000 DWT option.

Although concerns have been raised regarding the mixing of recycled lockage water and seawater, recycling basins and pump stations are planned to be constructed in the vicinity of the two lock structures. The purpose of this pumping scheme is to supplement the volume of water available for the lock operations and to mitigate the hydrodynamic impacts associated with opening of the locks. A summary of the proposed dam and pump stations is provided in Table 3.6.

Table 3.6 Proposed Dam Plan - High Rise Lock Canal

DESIGN SHIP ALTERNATIVE	PROPOSED DAM	YEAR 2020 (VOL, MCM)	YEAR 2060 (VOL, MCM)
150,000 DWT	Ciri	-	102
	Indio	-	461
	Pump Station	-	1459
200,000 DWT	Trinidad	-	396
	Indio	116	591
	Pump Station	-	1890

It is evident from the table that, for a ship size of 150,000 DWT, the Indio and Ciri rivers dams will be necessary, together with a pump station, in the year 2060. For the 200,000 DWT ship alternative, the Indio river dam will be needed in 2020 and the Trinidad river dam, supplemented with a pump station, will be required in 2060.

3.1.5 Locks

Each lock consists of three Operating Gates, eight Culvert Gates, and an Emergency Gate to fulfill its lockage function. The three Operation Gates are named the Upper Operating Gate which is located at the upstream ends of the upper chamber, Middle Operating Gate, located at the downstream end of the upper chamber, and the Lower Operating Gate, located at the down stream end of the lower chamber in the lock.

The four Culvert Gates are installed in the culvert tunnel in each lock wall; i.e., one just upstream of the Upper Operating Gate, one just upstream of the Middle Operating Gate, and two just down stream of the Lower Operating Gate. One of the last two are for the culvert heading for the recycling pond and the other is for water discharge to an ocean. The Emergency Gate is located far ahead of the Upper Operating Gate.

In addition to the gates described above, each lock has maintenance gate seals in the vicinity of both lock ends on the lake side and the sea side, and also has a pair of culvert gate maintenance gate slots on the upstream and downstream side of each Culvert Gate. These provisions allow the draining of the whole lock or a Culvert Gate alone when necessary for lock maintenance work in a dry condition. For this purpose, a Maintenance Gate and four sets of the Culvert Gate Maintenance Gates are provided for the locks on both ocean sides.

3.1.6 Other Facilities

The project will require mobilization of huge volumes of construction equipment and materials to the construction site. The enormous volumes of cement, fuel, lubricants and equipment will require the construction of logistic bases with wharfs on both the Caribbean and Pacific sides. These bases will serve for unloading, storing, and transporting main construction equipment and materials imported from abroad.

In addition, three logistics facilities will be constructed in connection at Pilon Port and Colon on the Caribbean side and at Panama City on the Pacific side. Finally, two construction villages and five labor camps will be constructed for providing accommodations for approximately 10,000 workers and 800 staff and family members. The transport of the construction equipment and materials will be through an access road which is to be constructed for that purpose.

Other structures to be constructed include five jetties for berthing small boats along the approaches, two tie-up stations at the Gatun Lake and inside of the new lock on the Pacific Side for mooring the vessels, and anchorage areas at the Pacific and Caribbean Sea. Existing breakwaters are considered adequate for the proposed High-Rise Lock Canal. Incidental facilities which include surge basins in the Cocoli River Valley, recycling pond

storing mainly fresh water in the vicinity of the Caribbean and Pacific locks are also planned.

3.2 SEA-LEVEL CANAL

The proposed Sea-Level Canal follows Route 10 of the pre-screening alternatives and is being planned for a maximum ship size of 250,000 DWT. The alignment for this alternative is located between 8 to 16 km west of, and approximately parallel to the existing canal. A layout of the Sea-Level Canal alternative is shown on Figure 3.12.

The southern end of the proposed Sea-Level Canal alignment, on the Pacific Coast, is at the town of Puerto Caimito at the mouth of the Caimito River. The Sea-Level Canal alignment follows the Caimito river north-westward for approximately 8 km, crossing the Pan American Highway about 4.8 km north-east of La Chorrera. It continues to the north through generally open and rolling terrain; crosses the Continental Divide through the Chorrera Gap; and parallels the Pescado River until it reaches an arm of Gatun Lake at La Laguna.

Turning in a more westerly direction, the Sea-Level Canal alignment continues over relatively flat terrain and crosses the Trinidad arm of Gatun Lake, to Escobal. From there it runs north-westerly through low ridges that become more open towards the coast. It meets the Caribbean Sea near the town of Lagarto. The canal will be a one-lane pathway across the isthmus, with two-lane approaches on the Caribbean and Pacific sides. The ECE Annex also evaluated single lane tidal locks for Case (a) and a single lane Atlantic approach channel between the coast line and the Atlantic tidal gate for Case (b).

Construction of the Sea-Level Canal will require diversion of rivers flowing across the proposed alignment and construction of barrier dams in Lake Gatun. The Sea-Level Canal alternative will divide Gatun Lake in three sections and the water elevation of the central section will be drained to accommodate the design water elevation of the new canal. The western and eastern sections of the lake, named Reservoir E and New Gatun Lake, will be fragmented by barrier dams E and F, respectively. As a result of this construction feature, Gatun Lake will loose 80 km^2 in Reservoir E and approximately 26 km^2 in the central section.

The proposed Sea-Level Canal will also intersect the southern portion of Gatun Lake in the vicinity of La Laguna village which will result in an additional loss of approximately 12 km^2 after Barrier Dam G is constructed. Figure 3.13 shows the location of the barrier dams. The water elevation of Gatun Lake will continue to be +26 m and the proposed design water elevation for the Sea-Level Canal is 1.1 m.

Presently, the Sea-Level Canal alternative considers three different scenarios for tidal gates and tidal locks arrangement. The tidal gates and locks together with the injection of

freshwater from diverted rivers are also intended to act as a freshwater barrier to reduce migration of marine biota. A layout of the Sea-Level Canal showing the three tidal gate/lock scenarios is shown on Figure 3.14.

The estimated construction schedule for the Sea-Level Canal alternative is 15 years. Final engineering design and tender is expected to last 3.5 years. Construction of supporting structures is planned to occur over the first year of construction. Following construction of the supporting structures, the sequence of construction of the Sea-Level Canal alternative is as follows:

1) construction of the diversion dams and channels to re-route rivers flowing into the proposed canal alignment would be initiated six months prior to the start of the,

2) construction of barriers dams E, F and G to allow lowering of the existing Gatun Lake water elevation, construction of the spillway, the excavation of the five zones, and construction of the breakwaters.

A general layout of the diversion scheme is presented on Figure 3.15, with additional details for the northern, central, and southern portions shown on Figures 3.16 through 3.18. The diversion dams and channels will re-route freshwater from the rivers Los Hules, Chico and Cano to Reservoir E. Construction of the diversion scheme is expected to last 2.5 years and to start approximately 6 months after construction of the supporting structures.

Construction of the three barrier dams, E, F and G will ensure maintaining of the present water level of Gatun Lake while allowing lowering of the water level between them to the seawater level. The entrapped water between the barrier dams will be drained via a diversion channel provided on the Caribbean side while excavation is in progress.

A spillway control structure with a capacity of 100 cubic meters per second when the Gatun Lake water elevation is at 26 m is planned to be constructed at a distance of about 12 km upstream from the left abutment of the barrier dam E, to regulate the water elevation of Reservoir E. Spillway construction is scheduled to occur during construction of the barrier dams.

Based on traffic projections, it is estimated that the existing canal would still be able to operate with the reduced New Gatun Lake. However, a new regulator dam and reservoir would be constructed on the Gatun River, as shown on Figures 3.19 and 3.20.

In view of the proposed canal structure, existing topography and geology, proposed construction methods and excavation volumes; the Sea-Level canal alignment was divided

for the purposes of the ECE Report into five zones, as shown on Figure 3.21. Table 3.7 gives zoning scheme data for the Sea-Level Canal alternative.

Table 3.7 Zoning Scheme - Sea Level Canal

ZONE NO.	HIGH-RISE CANAL	INITIAL STATION (M)	FINAL STATION (M)	LENGTH (KM)	CANAL BOTTOM (M)*3	WATER LEVEL (M)*3
I	Atlantic Approach	-2.80	+0.50	4.4	-24.3	-0.3
II	Queblado Zone	+0.50	+17.00	16.5	-24.3	-0.3
III	Gatun Lake	+17.00	+38.00	21.0	-24.3	-0.3
IV	Continental Divide	+38.00	+60.50	22.5	-24.3	-0.3
V	Pacific Approach	+60.50	+85.60	25.1	-27.40	-3.4

*3 Reference datum is Precise Level Datum (PLD) as adopted by the Panama Canal Commission and corresponds to Elevation (El.) -0.30m Mean Sea Level datum (MSL)

3.2.1 Roads

Access roads necessary for the construction work will be located and designed to become part of the road network improvements required in any case to provide permanent access to both sides of the canal and/or for operation and maintenance of the canal. This will help reduce costs and also reduce disturbance to the environment.

Permanent access road requirements are more significant for the Sea-Level Canal than for the High-Rise Lock Canal. This is due to the fact that there are more existing roads crossing the Route 10 alignment. Since the construction of the Sea-Level Canal would create two barriers to the movement of traffic, compared to one in the case of the High-Rise Lock Canal, the Sea-Level Canal alternative will double the number of bridges required to cross both canal alignments.

The Sea-Level Canal will include four bridges over the proposed canal and three bridges over the existing canal at Gatun, Gamboa and Miraflores (Van Dam Bypass). The fourth bridge over the existing canal for the Pan American Highway is not included since the existing canal will not be widened and the existing Bridge of the Americas can remain.

(1) **Trans-Isthmic Road:** Since there is no existing trans-isthmic road along the proposed Sea-Level Canal alignment, a new trans-isthmic road is considered essential for construction of the Sea-Level Canal and is considered highly desirable for an efficient operation and maintenance of the canal after completion. Therefore it has been proposed that a construction access/haul road be designed and located for conversion to a public road upon completion of the Sea-Level Canal. The trans-isthmic road would be used to provide access for operation and maintenance of the canal but would be open to the public for general usage and tourism.

(2) **Caribbean Sea to Gatun Lake:** Since alternative access is not available for some villages on the Caribbean side of the proposed Sea-Level Canal alignment, a canal crossing will be constructed at 1.5 km inland from the Caribbean Coast. The road between Escobal and Cuipo on the north side of Gatun Lake will also be cut by the alignment. Based on available data and site observations, this road is more important and carries more traffic than other roads north of the La Chorrera - Nuevo Emperador road. A bridge crossing has therefore been proposed at this location.

(3) **Gatun Lake Region:** Access to the small village of Las Pavas will be provided by connecting the village access road to the new trans-isthmic road. A permanent road across the barrier dam to the west of the canal is also proposed. This road will be required for maintenance of the dam and will also serve to improve the road network on the west side of the canal. The villages of Lagarterita and La Laguna are accessed by roads from the south and access is not affected by the canal construction. Minor works will be required where the proposed diversion dikes cross these access roads.

(4) **Gatun Lake to Rio Caimito:** The existing road between La Laguna and Santa Clara and between La Chorrera and Nuevo Emperador through Rio Congo will be cut by the proposed Sea-Level Canal alignment. However, a canal crossing is not required since a connection to the new trans-isthmic road on the east side of the canal will be provided.

(5) **Rio Caimito to Pacific Ocean:** In this section the Sea-Level Canal crosses two major roads, the Pan American Highway and the toll road which provides alternative access between La Chorrera and Arriajan. Both roads carry considerable traffic volumes and bridges over the canal are considered essential for both roads. The proposed canal crossing point for all cases is at the tidal structure, allowing effective use of hills on either side to reduce the length of approach structures.

(6) **Access to New Dams:** The Upper Gatun Dam is required for the year 2060 in the case of the Sea-Level Canal to maintain an adequate supply of lockage water for

the continued operation of the existing canal. A construction access road is required between the new dam site and the Boyd Roosevelt Highway and the road would be retained as paved two-lane road for operation and maintenance purposes after construction.

(7) **Access for Operation and Maintenance:** The proposed trans-isthmic road will provide the main access for operation and maintenance of the Sea-Level Canal. It passes adjacent to each of the tidal lock/tidal gate structures and also connects to the port facilities proposed inside the breakwaters on the Caribbean and Pacific sides. Proposed roads across all three barrier dams will provide the necessary access for maintaining the dams and associated spillway structures.

As described above, new bridges are proposed at the following locations for the Sea-Level Canal alternative:

(a) Across the Sea-Level Canal

(1) Caribbean Coast road at Nuevo Chagres
(2) Escobal Road
(3) Pan American Highway
(4) Autopista

(b) Across the existing canal

(1) Gatun
(2) Gamboa
(3) Van Dam Bypass

Details of the Sea-Level Canal alternative proposed roads and bridges are given in Tables 3.8 and 3.9.

3.2.2 Excavation and Dredging

If the Case b option is selected, the Sea-Level Canal will require excavations of 1,385 MCM, or more than twice the volume required for the High-Rise Lock Canal. This option represents 1,034 MCM of dry excavation and 351 MCM of dredging. The total volume of excavation will be reduced to 1,252 MCM in Cases (a) and (c). Either of the two latter options will require 948 MCM of dry excavation and 304 MCM of dredging.

With the single lane canal option, the total volume of excavation would be reduced to 1,228 MCM which corresponds to 950 MCM of dry excavation and 278 MCM of dredging. The

spoil from the dry excavation operations would be deposited in placement areas primarily located to the east of the canal.

Excavation at the different zones of the Sea-Level Canal alternative would start six months into the construction of the supporting structures. The following is the planned excavation and dredging procedures for each zone:

ZONE I - Caribbean Approach Zone: This is a 3.3 km section between Stations -2.80 and +0.50 which will be entirely dredged.

ZONE II - Queblado Zone: This is a 16.5 km section between Stations 0.50 and 17.00. The sub-section between Stations 0.50 and 14.50 will be excavated by the mixed method of ground excavation and dredging. Ground excavation will be used in the remaining section. A diversion channel will be constructed at the downstream crossing point of Queblado River to guide its flow to the Caribbean Sea, while a cut-off dike will be erected at the upstream crossing point to guide the flow to Gatun Lake via a diversion channel.

ZONE III - Gatun Lake Zone: This is a 21 km section between Stations 17.00 and 38.00. Dredging and dry excavation will be conducted at the sub-section between Stations 17.00 and 22.50. Dredging work will firstly be conducted below sea level while barrier dams are being constructed. With the completion of the barrier dams, the water inside the barrier dams will be drained, followed by ground excavation above sea level. Work for the sub-section between Stations 22.50 and 33.00 will entirely consists of dry excavation. Barrier dams will be erected for the sub-section between Stations 33.00 and 38.00. Ground excavation will be conducted in this sub-section after the water has been drained. Cut-off dikes will be constructed to guide the flow of Los Hules, Quebrado de Chica, Pescado and Cano rivers to Gatun Lake via diversion channels.

ZONE IV - Continental Divide Zone: This is a 22.5 km section between Stations 38.00 and 60.50. Mixed excavation consisting of ground excavation and dredging will be conducted at the sub-section between Stations 38.00 and 59.00. Ground excavation above sea level will firstly be conducted, followed by dredging below sea level. The sub-section between Stations 59.00 and 60.50 which is a swamp zone will be completely dredged.

ZONE V - Pacific Approach Zone: This is a 25.1 km [22.7 km for Option (b)] section between Stations 60.50 and 85.60 [83.20 for Option (b)]. This section will be dredged throughout.

Dredging and dry excavation volumes for the three tidal lock/gate alternatives are given on Table 3.10.

Table 3.8

Summary of New Access Roads - Sea Level Canal

LOCATION	NO. OF LANES	TYPICAL X-SECTION	APPROXIMATE LENGTH	COMMENTS
Trans-Isthmic Road	2	Paved	62.5 km	
Nuevo Chagres				
Approaches to new bridge	2	Paved	4 km *4	Provides access to west of canal.
Escobal Road				
Approaches to new bridge	2	Paved	2 km *4	Provides access to west of canal.
La Chorrera				
Pan American Highway	2	Undivided, paved	3 km *4	Approaches to new bridge.
Autopista	4	Divided, paved	3 km *4	Approaches to new bridge.
Access to New Dams				
Rio Gatun	2	Paved	3 km	No existing road
Total			**77.5 km**	

*4 Excludes length of bridge structure.

Table 3.9

Summary of Proposed Bridges - Sea Level Canal

LOCATION OF BRIDGE	CANAL WIDTH (M)	BRIDGE		MAIN SPANS BRIDGE LENGTH (M)				APPROACH LENGTH
		LANES NO.	WIDTH (M)	L	L1	L2	L3	L4
Sea Level Canal - Case (a) and Case (c)								
Over the Sea Level Canal:								
Atlantic	190	2	10.0	430	250	90	90	1600
Escobal Rd.	190	2	10.0	630	350	140	140	600
Pan American	190	2	10.0	430	250	90	90	0
Autopista	190	4	20.5	430	250	90	90	0
Over the Existing Canal:								
Atlantic	Exist.	2	10.0	410	230	90	90	1140
Gamboa	Exist.	2	10.0	360	200	80	80	600
Van Dam	Exist.	4	20.5	900	500	200	200	950
Sea Level Canal - Case (b)								
Over the Sea Level Canal:								
Atlantic	380	2	10.0	800	440	180	180	1600
Escobal	190	2	10.0	630	350	140	140	600
Autopista	190	4	20.5	430	250	90	90	0
Pan American	Exist.	2	10.0	430	250	90	90	0
Over the Existing Canal:								
Atlantic	Exist.	2	10.0	410	230	90	90	1140
Gamboa	Exist.	2	10.0	360	200	80	80	600
Van Dam	Exist.	4	20.5	900	500	200	200	950

Table 3.10

Excavation Volumes (MCM) - Sea Level Canal

METHOD	OPTIONS (a),(c)	OPTION (b)
Dry Excavation	948.3	1,033.6
Dredging	304.2	351.4
Total	1,252.5	1,385

MCM = Million Cubic Meters

3.2.3 Spoil Areas

Similar to the High-Rise Lock Canal alternative, the following construction procedure will be employed:

1) Materials from the dry excavation will be used for banking at designated placing areas which are located along the canal. The hauling distance from the dry excavation areas to the placing areas typically range from 2 to 20 km. In order to avoid disruption of the surface waters in the proposed placing areas, streams, creeks, will be piped through the placing areas. Drainage during construction will be handled by sedimentation ponds. In addition, vegetation and surface drainage will be provided upon completion of banking at the designated placing areas.

2) In order to provide temporary in-situ earth plugs to prevent large amounts of rainfall from flowing into the excavation areas, dry excavation will generally be carried out in 2 km sections. Dewatering by use of large capacity pumps are planned to be used to maintain the ground excavation area dry.

3) Dredged materials will be disposed at designated placing areas which are located along the proposed Pacific and Caribbean breakwaters and within the Gatun Lake area.

Proposed spoil area locations for the Sea-Level Canal alternative are shown on Figure 3.22.

3.2.4 Breakwaters

Breakwaters will be constructed for the Sea-Level Canal alternative on the Caribbean and Pacific coasts in Zones I and V. Dredging of Zone I will occur simultaneously with the breakwater construction on the Caribbean side and should last 5 years. Dredging and breakwater construction in Zone V (Pacific side) which is also expected to last 5 years will start upon completion of the same in Zone I. The construction method and equipment employed for breakwater construction are planned separately for above and below elevation -4.0 m MSL.

3.2.5 Barrier Dams

The main barrier dams consist of two almost parallel dams to be constructed in Gatun Lake, as shown on Figure 3.13. These dams would be built to ensure the present water level of Gatun lake while allowing the lowering of the water level between them to the seawater level. The Sea-Level Canal passing between these two dams can then be constructed with no adverse effects on the level of Gatun lake. These barrier dams will start near Escobal village at the southern tip of Gatun lake towards Cano Gigante situated on the opposite side of the lake. Apart from these main barrier dams, another barrier dam is planned on the opposite coast of La Laguna village to bring the total number of barrier dams to three.

Gatun lake will be divided into two reservoirs (New Gatun Lake and Reservoir E) by three Barrier dams (E, F and G). The barrier dam sites are as follows:

(1) **Dam Site E:** The dam site is selected at a location where the valley is at a relatively narrow part of the old Rio Trinidad, approximately 1 km south of the proposed alignment. Los Negros and Esperanza islands in the lake would be closed off by barrier dam. The barrier dam has a spillway to ensure the safety of the dam, and a waterway from the spillway to Rio Lagarto is also proposed in order to reduce the water raising of the lake.

(2) **Dam Site F:** The dam site F is selected at a location downstream of dam site E and north of the canal alignment. The axes of the dam are almost parallel and the dams are separated by approximately 3 km. La Punta de Ramon and Bajo Island in the Lake would be closed off by this barrier dam.

(3) **Dam Site G:** The dam site is selected at a location where the valley is very narrow, and downstream of the old Rio Pescado, approximately 7 km south of the canal, about 2 km north of the proposed alignment.

Considering the large crest length, the relatively small water head difference, and that the dam foundation treatment is almost underwater, a rockfill-type dam has been selected as the preferred alternative for construction.

3.2.6 Tidal Lock and Tidal Gates

Three tidal lock/gate arrangement schemes are under consideration for the Sea-Level Canal alternative. These schemes are depicted on Table 3.1 and Figure 3.14. For option (a), a tidal lock system would be constructed 5 km from the Bahia Chorrera on the Pacific side. A layout of this tidal lock facility is shown on Figure 3.23.

For study case (b), a pair of tidal gates shall be installed on both ocean sides. A tidal gate on the Pacific side is located at the same site where the tidal lock is planned for Case (a). A layout of this tidal gate is shown on Figure 3.24. A similar tidal gate is planned at a site 15 km southeast from the Caribbean coast. The village Escobal is located 6 km west of the site. The area is generally flat ranging from 20 to 30 m, with Brazito river and Arrieros river, located near the site. The distance between the two tidal gates is 40 km.

For study (c), a tidal lock of the same structure located on the Pacific side as mentioned for study case (a) and a tidal gate is planned at site N-617.5 and E-1005 km adjacent to the village "La Laguna," where a local road is connected to the village "Mendoza". The distance between them is 31 km.

3.2.7 Freshwater Barrier System

A freshwater barrier system was hypothesized to address the problem of seawater movement between the two oceans. Freshwater would be collected from rain water, mainly from the watershed on the west side of the canal, and poured into the canal or tidal lock chambers, forming a hydraulic barrier that would restrict the movement of seawater. However, because of its higher density, sea water is expected to ride under the freshwater and it is possible that a connective corridor could be formed, unless a sufficient flow of freshwater is maintained at all times. The freshwater barrier concept requires that freshwater be injected either directly into the tidal lock chamber or between the Pacific side tidal gate and Caribbean side tidal gate.

1) **Direct discharge to Tidal Lock Chamber:** Only the concept of this option was examined in the ECE Report. This concept would require that large volume of water must be injected into the lock chamber in a very short period of time. Such a system would require an elevated reservoir with one million cubic meter capacity constructed adjacent to the tidal locks. Water supply pipes would be needed to connect the elevated reservoir and the tidal locks.

2) **Injection Between Tidal Gates:** In this case, water is injected into the canal consecutively via reservoir (E) or the intake of dams W-3-D, W-4-D, W-6-D and W-7-D described later in the Diversion Scheme Section.

3.2.8 Spillway

A spillway is located at about 12 km upstream from the left abutment of barrier dàm (E). Once the barrier dams are completed and prior to construction of the canal, the spillway will be the only means to control the rising of the water level in the newly created Reservoir E (fragmented portion of Lake Gatun). During construction of the canal, the spillway will be used to control the water level in reservoir E. After construction, its use will occur only under unusual circumstances and it is anticipated to be used occasionally, on the order of once every five to ten years. The spillway control structure has a capacity of 100 m^3/s when the reservoir water level is 26.00 m. The spillway is equipped with two 6 x 3 m rectangular gates with sills at elevation 24.00 m. An orifice at the lower part of the main sills is equipped with one 3 x 2 m radial gate with a sill at elevation 22.00 m, and it is capable of discharging the annual mean discharge volume of 37 m^3/s with the reservoir water level at 26.00 m. The overfall and orifice spillway are both used for reservoir releases of the designed discharge volume.

3.2.9 Diversion Scheme

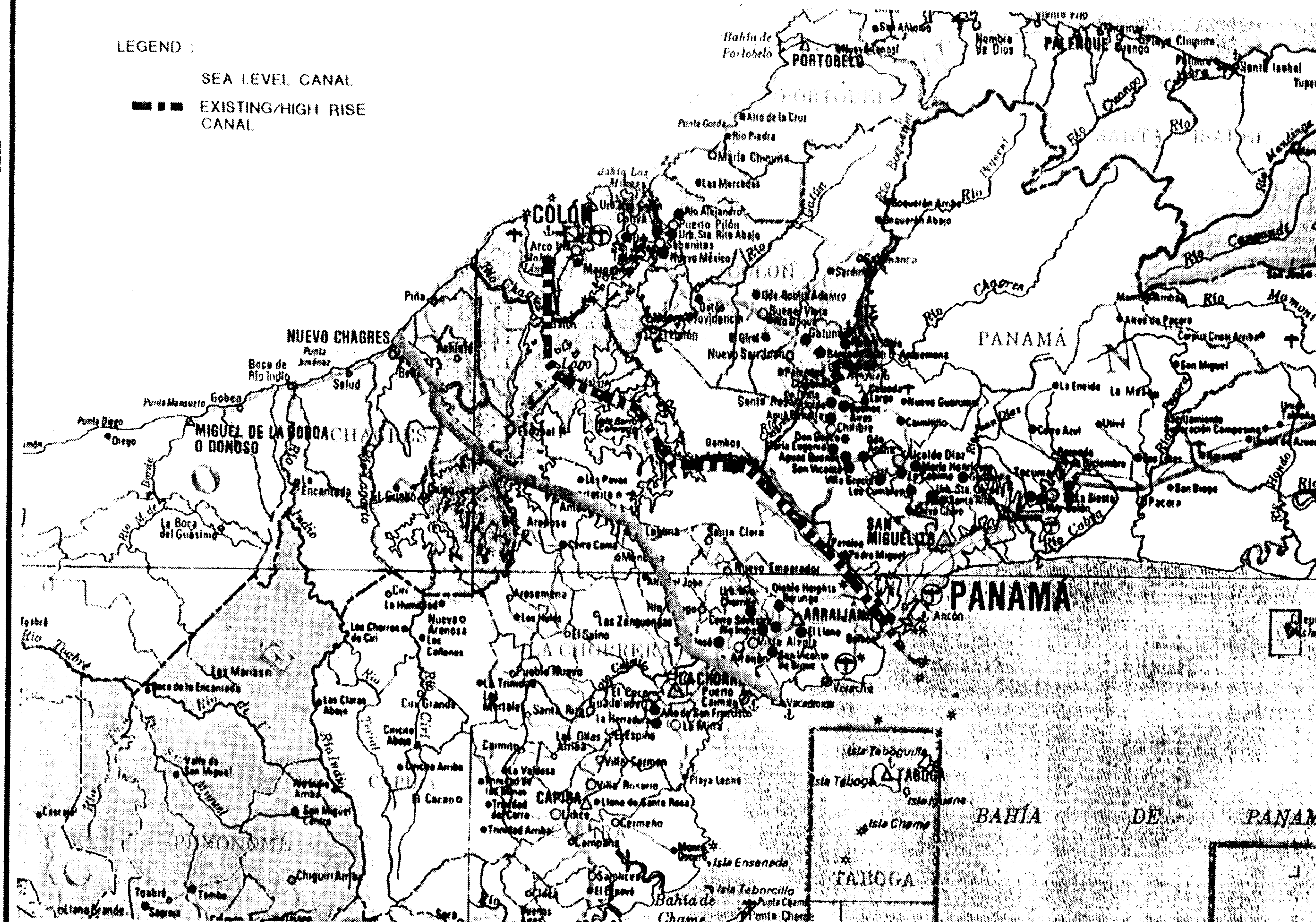
Injection of large amounts of water into the tidal lock chamber will make it necessary to temporarily store freshwater from rivers in a reservoir and other facilities so that freshwater can function as a freshwater barrier system. The diversion scheme layout are shown on Figures 3.15 through 3.18. Reservoir (E) is proposed for this purpose. Freshwater is obtainable from the Trinidad and Ciri rivers, both of which directly flow into Reservoir (E). In addition, the use of Los Hules, Chico and Cano rivers are proposed to provide water for Reservoir (E) via diversion channels.

The Caimito River, which is separate from the Gatun watershed, has a large runoff which can be used by the freshwater barrier system. As it is difficult to guide water from the Caimito river to Reservoir (E) due to topographical reasons, water from this river will be independently used. Any water discharge into the canal on the Pacific and Caribbean sides will come directly from rivers without using a reservoir. Main features of the diversion dams are given in Table 3.11.

Table 3.11

Main Features of Diversion Dams - Sea Level Canal

DAM	H.W.L. EL (M)	DAM CREST EL (M)	DAM CREST LENGTH (M)	DAM HEIGHT (M)
W-1-D	-	10	200	7
E-1-D	10	12	200	10
W-3-D	37.5	40	420	16
W-4-D	43.5	46	500	20
W-6-D	52.0	54	420	30
W-7-D	30.0	32	760	25
E-2-D	-	8	5,000	5



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	CANAL LOCATION MAP	DAMES & MOORE FIGURE 3.1

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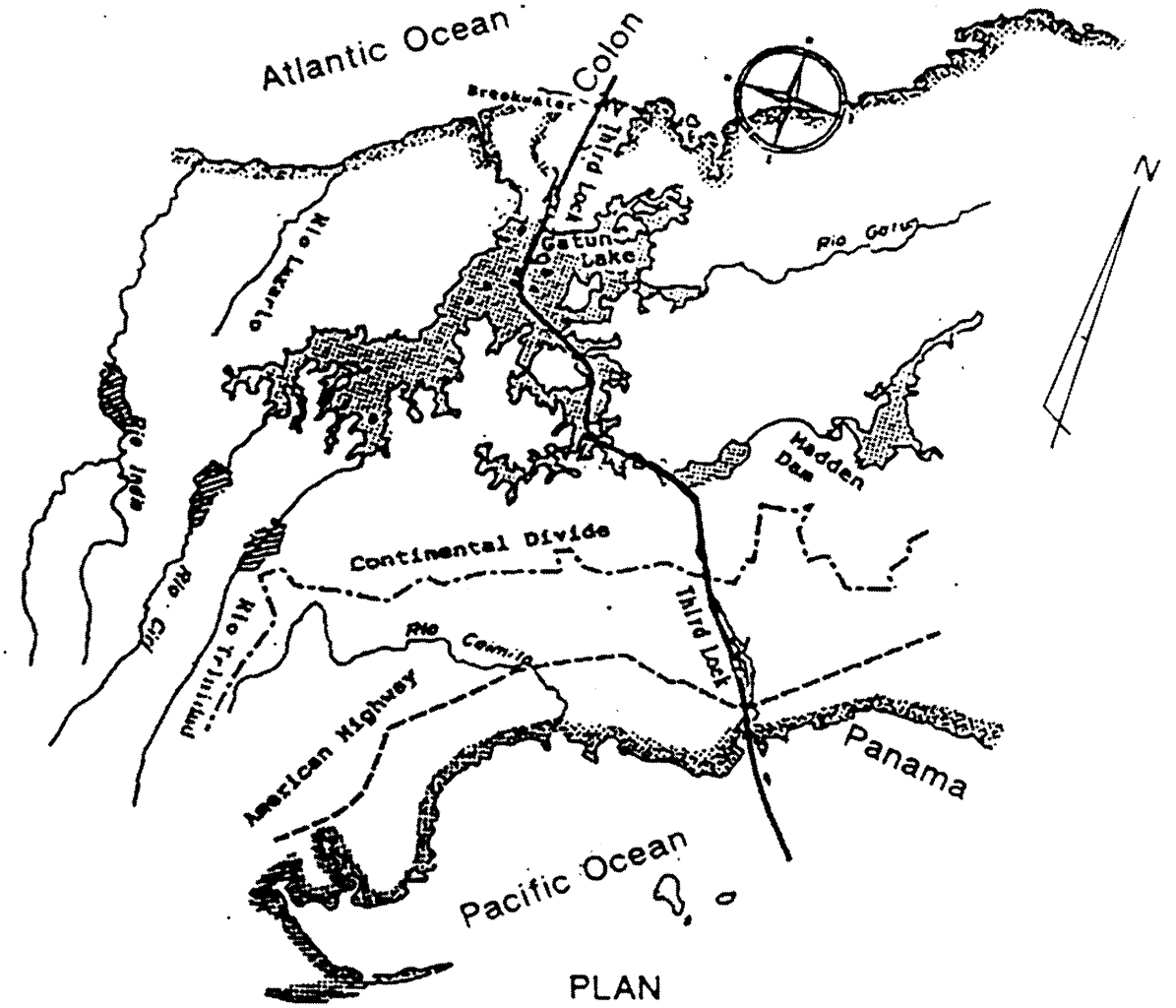
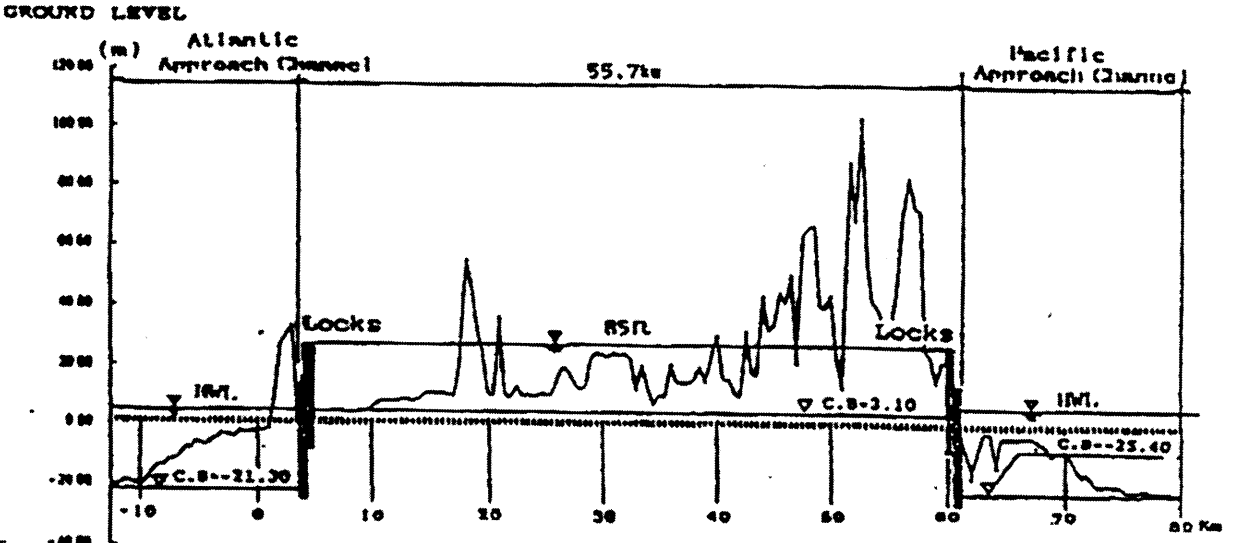


PLAN



PROFILE

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
FINAL REPORT, 1993
THE STUDY OF ALTERNATIVES
TO THE PANAMA CANAL
PHASE 2: PRELIMINARY ENGINEERING
AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF 200,000 DWT HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.2

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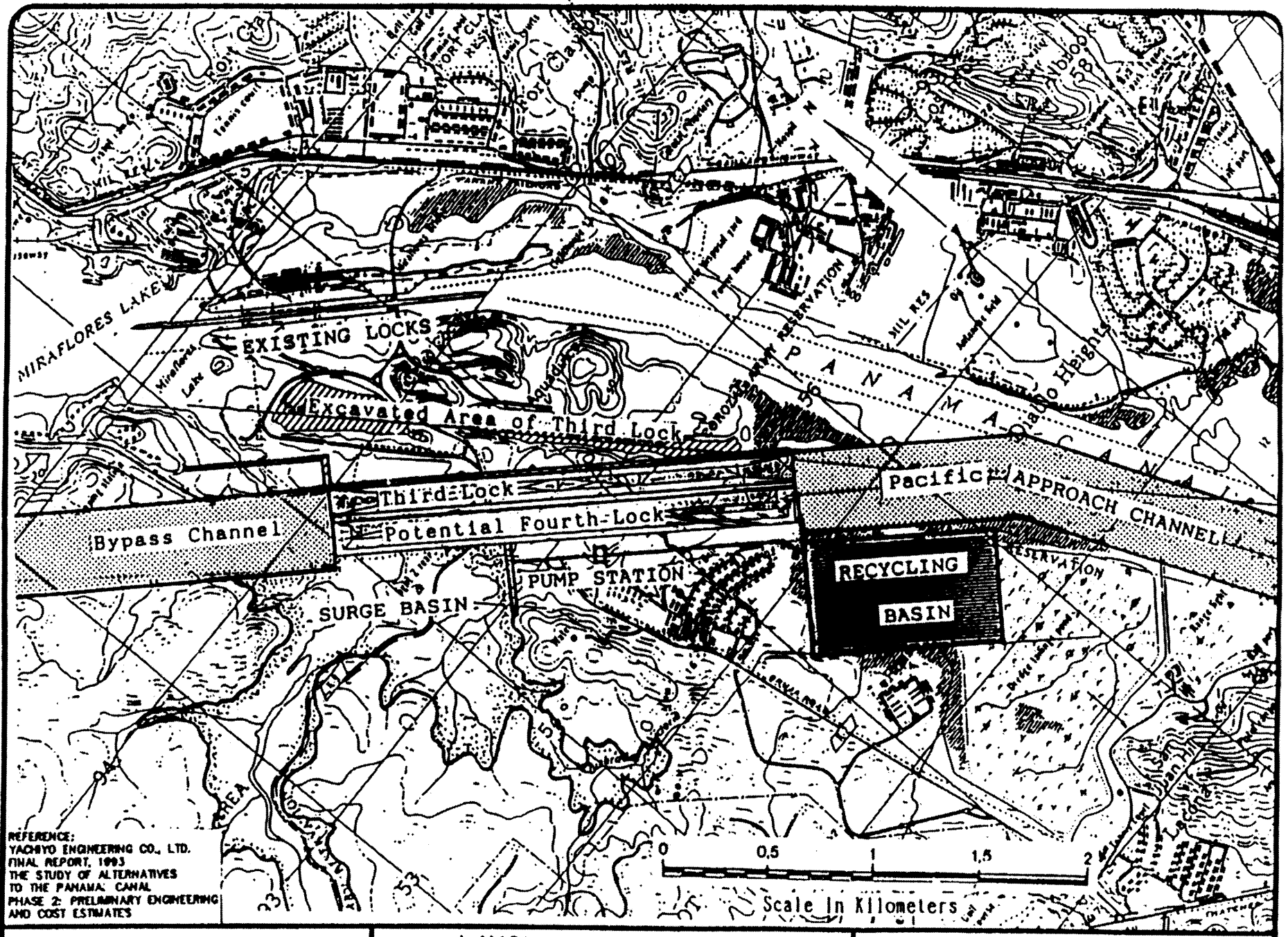
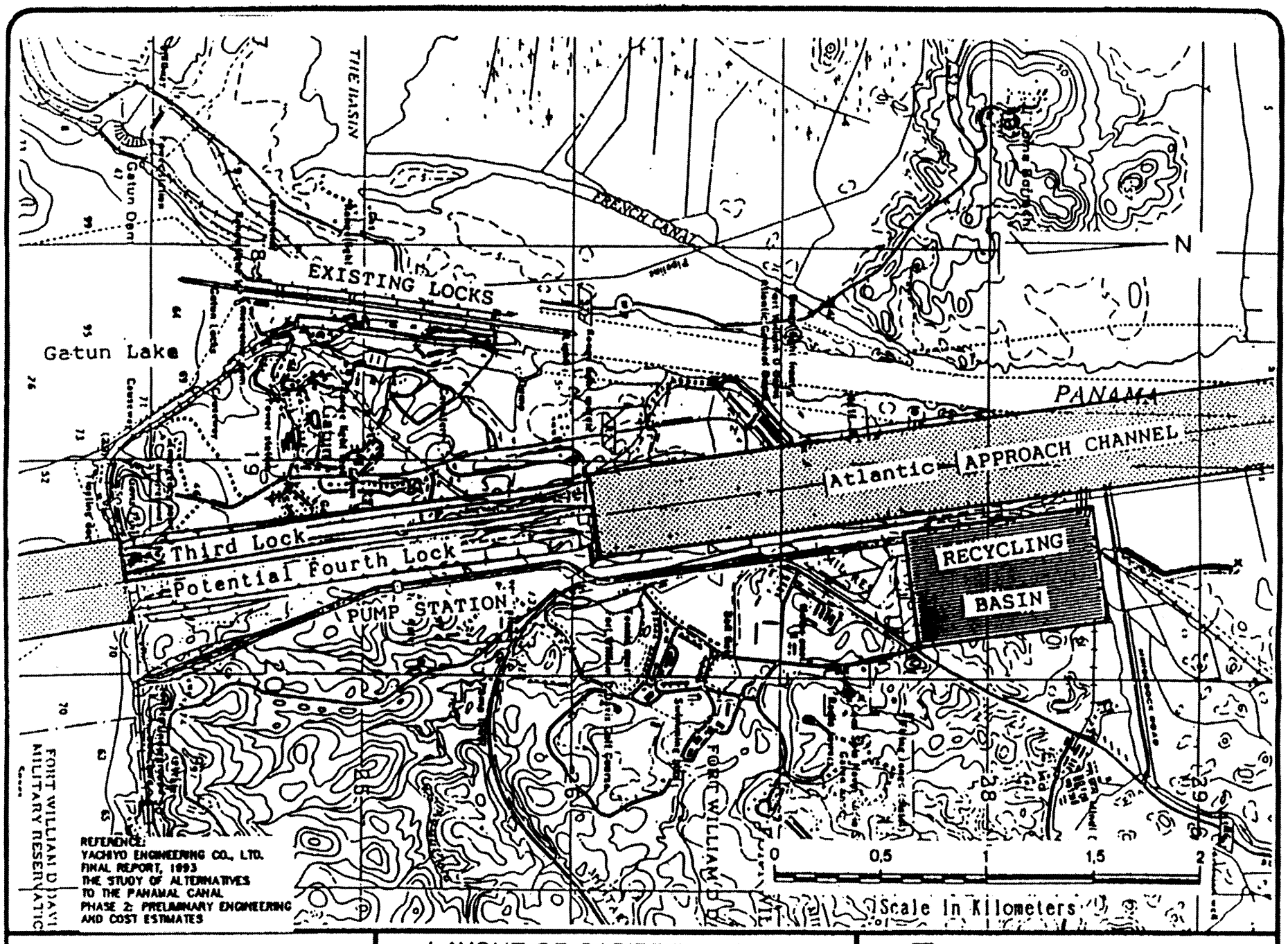


ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF PACIFIC SIDE LOCK FACILITIES HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.3

BY REHAR DATE 06-21-93 CHECKED BY D & M JOB NO. 28437-001-6552 BY DATE REVISIONS



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF CARIBBEAN SIDE LOCK FACILITIES HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.4

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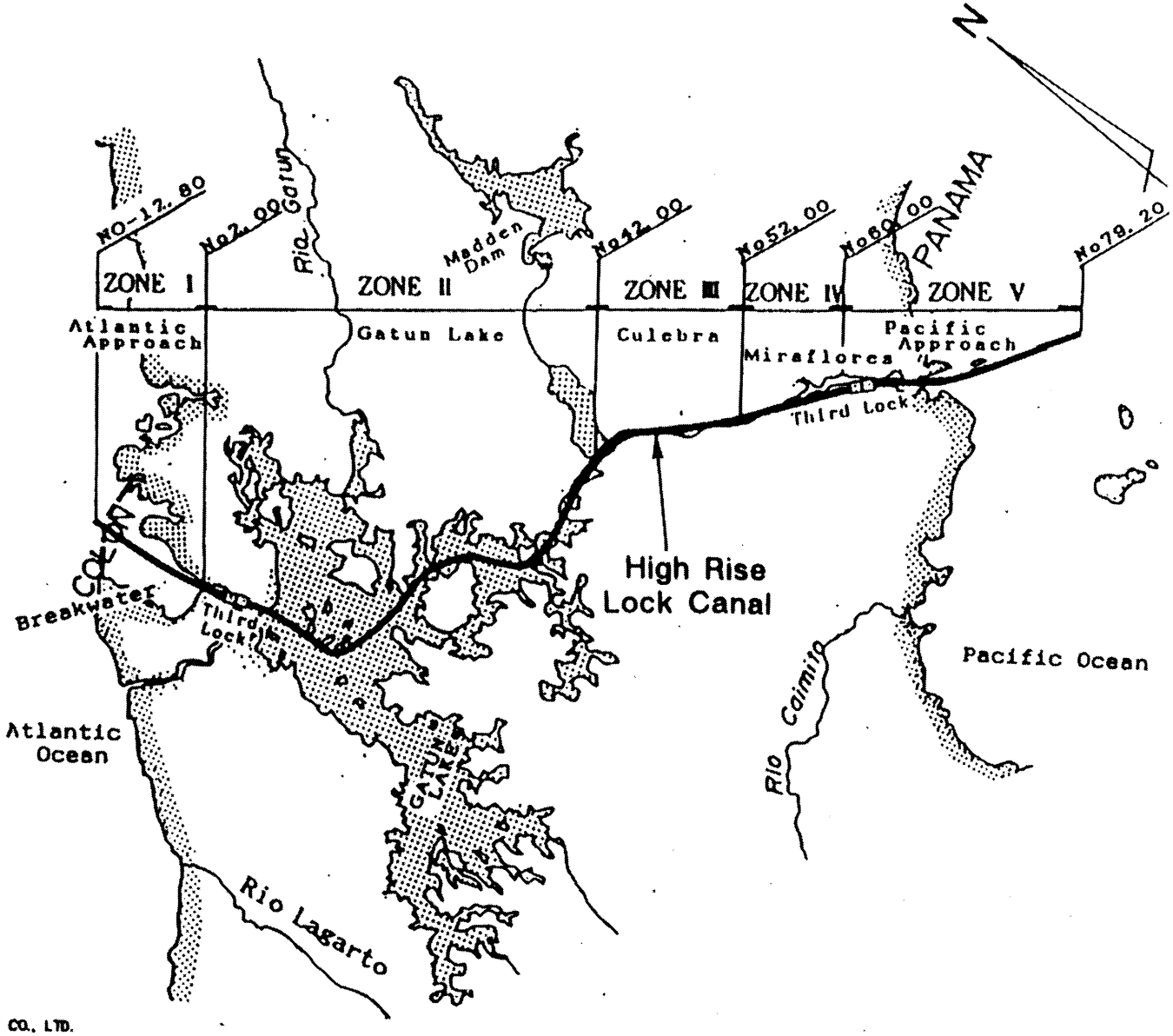

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
FINAL REPORT, 1993
THE STUDY OF ALTERNATIVES
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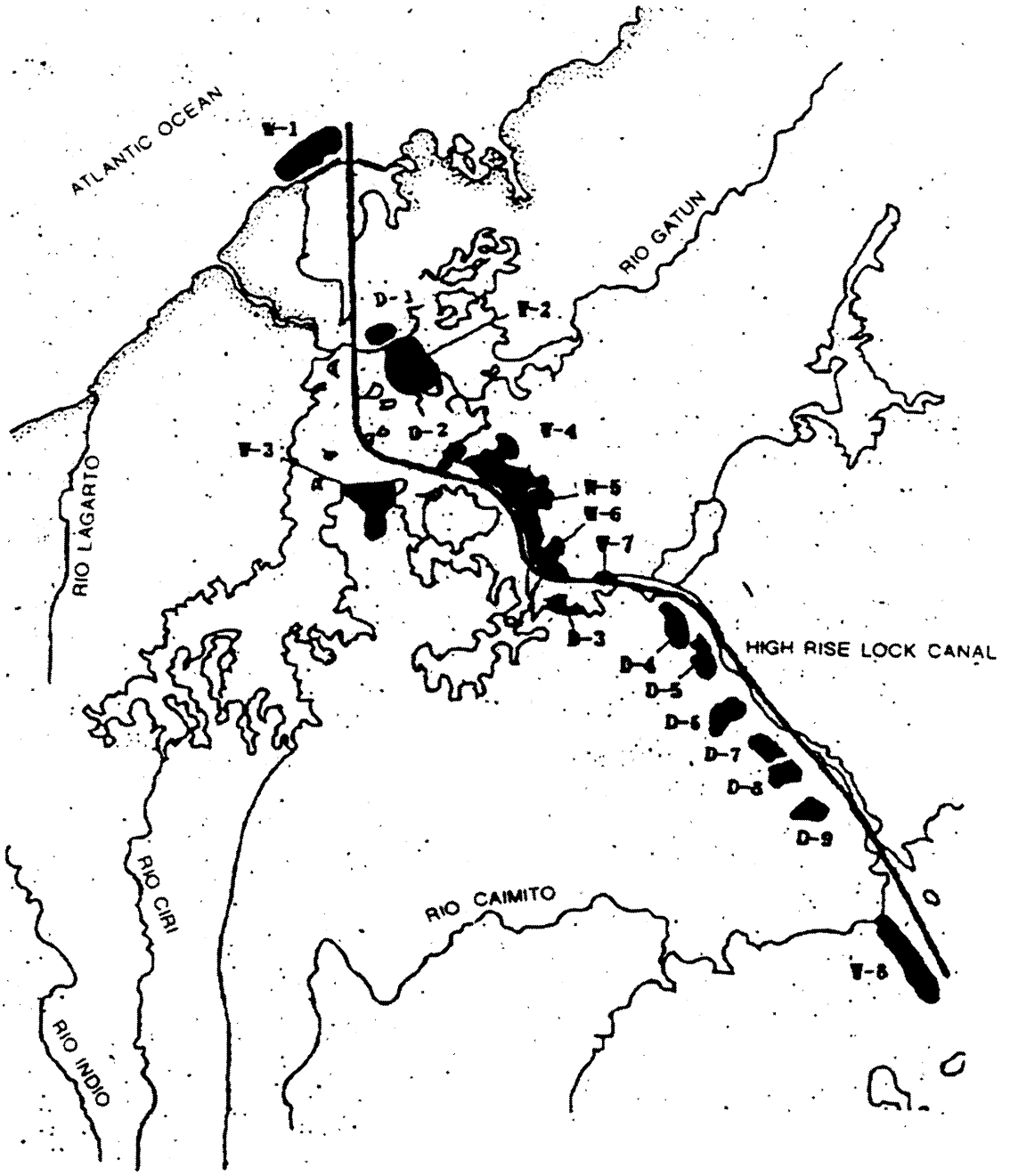
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	ZONE MAP OF HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.5

BY Ralph DATE 06-21-93 CHECKED BY D & M JOB NO. 29437-001-5552 BY DATE REVISIONS



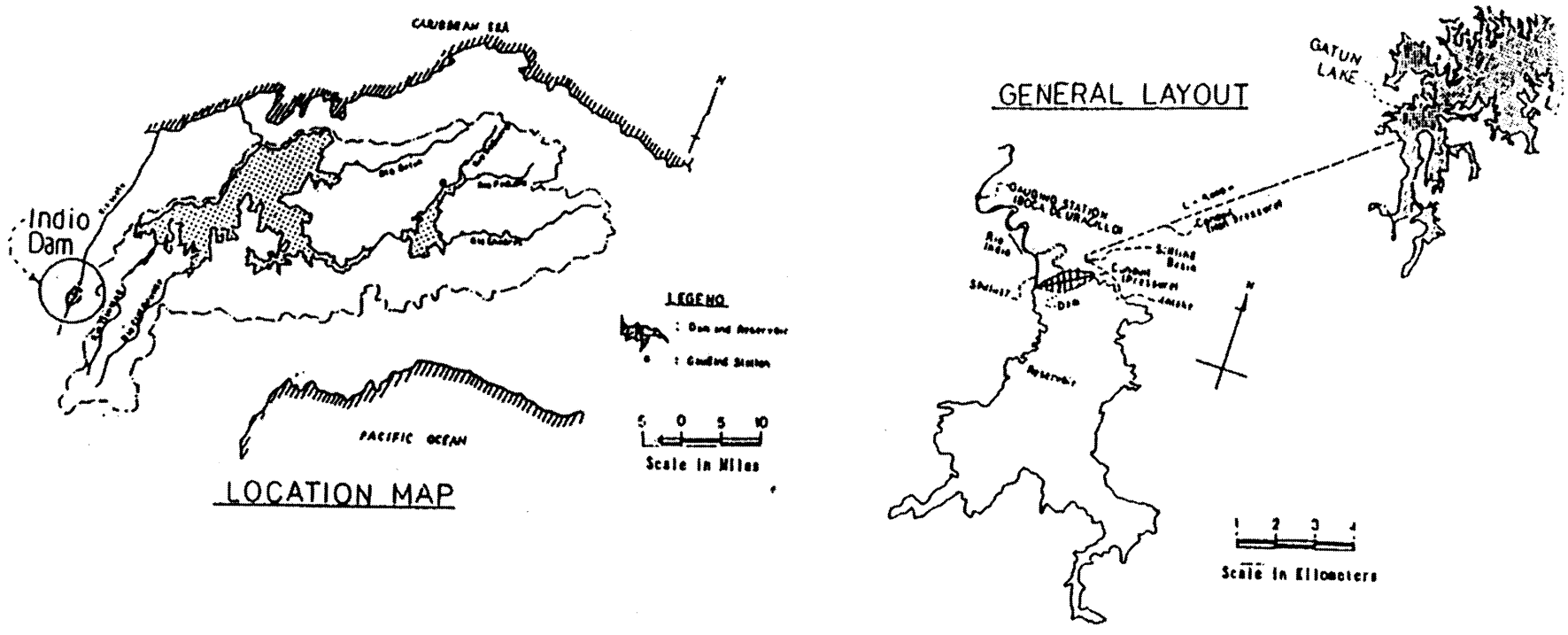
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

LOCATION OF PROPOSED SPOIL AREAS HIGH RISE LOCK CANAL

DAMES & MOORE

FIGURE 3.6

BY Ralph DATE 06-21-83 CHECKED BY D & M JOB NO. 8457-001-5858 REVISIONS BY DATE



REFERENCE:
YACHIYO ENGINEERING CO., LTD.
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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	PROPOSED INDIO RIVER RESERVOIR HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.7

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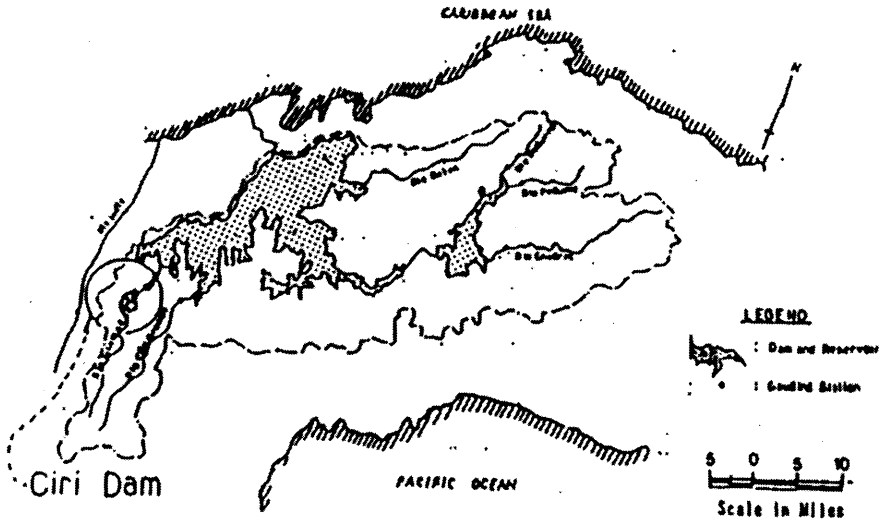
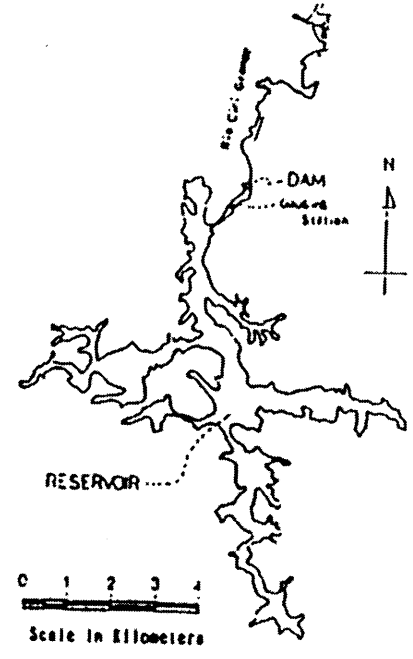


LOCATION MAP



GENERAL LAYOUT

REFERENCE:
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ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	PROPOSED CIRI RIVER RESERVOIR HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 3.8

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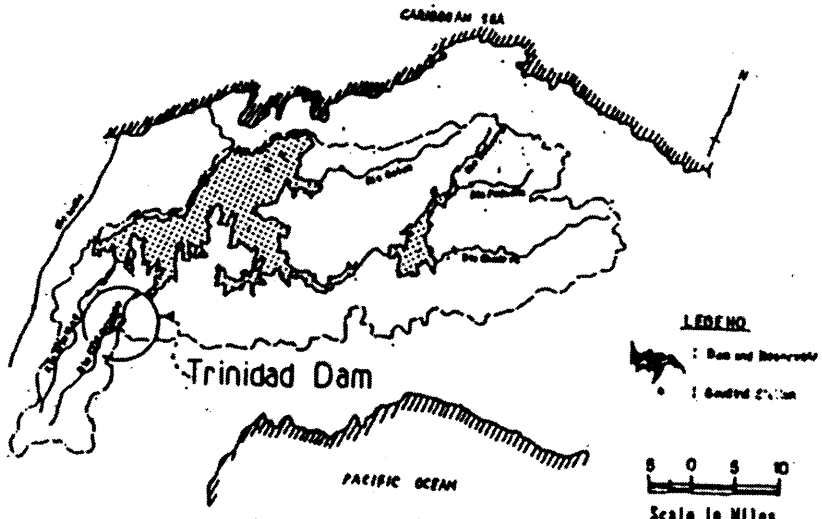
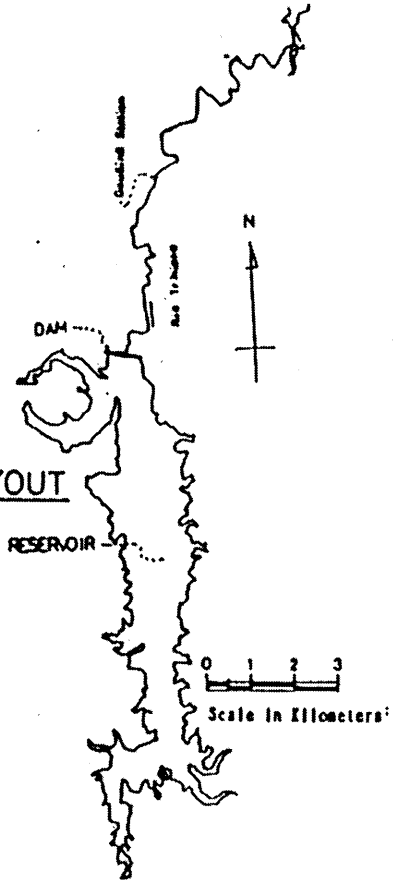


LOCATION MAP



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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	PROPOSED TRINIDAD RIVER RESERVOIR HIGH RISE LOCK CANAL	DAMES & MOORE FIGURE 39

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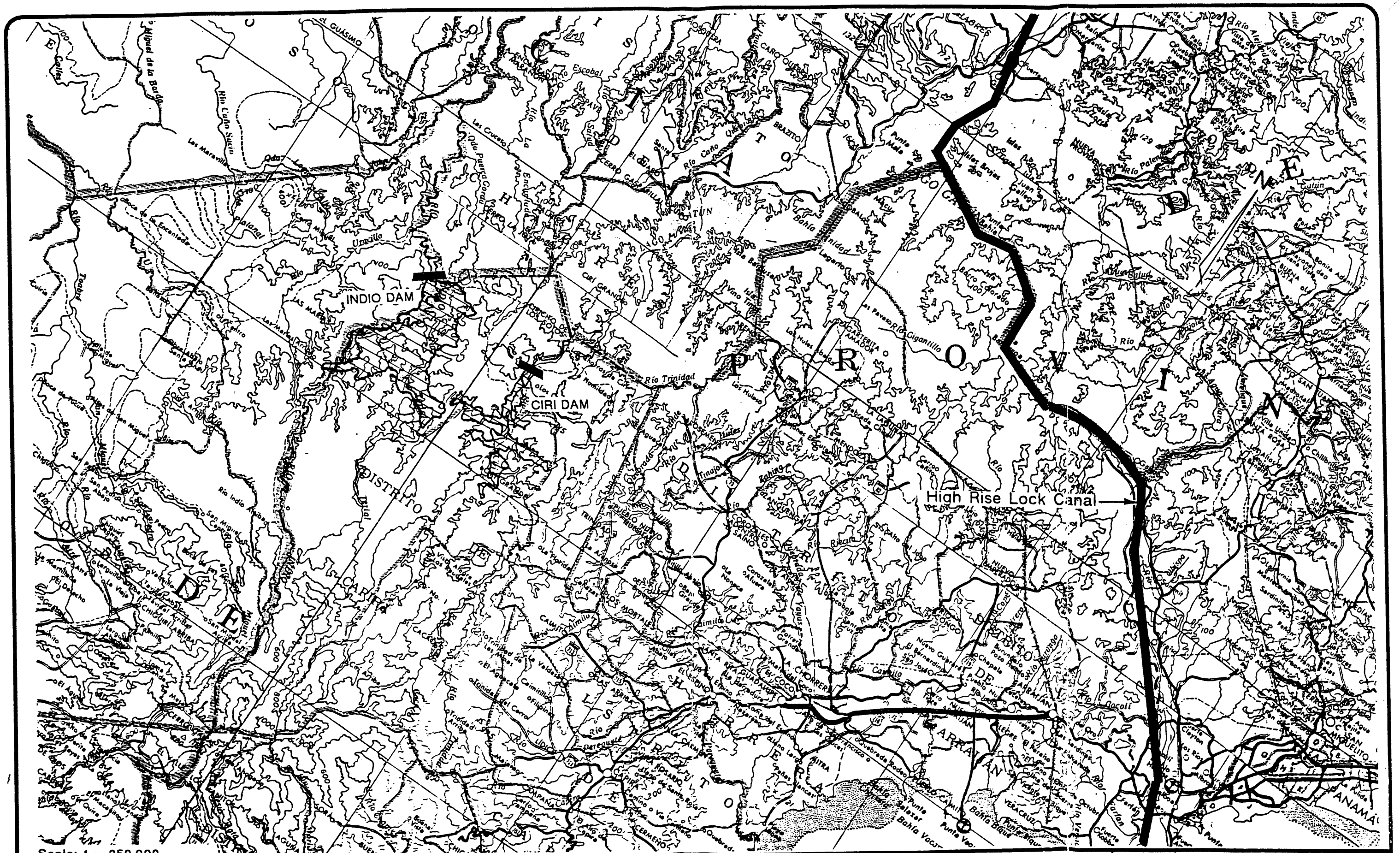

ENVIRONMENTAL ANALYSIS
STUDY OF THE ALTERNATIVES
TO THE PANAMA CANAL

PROPOSED RESERVOIRS FOR
150,000 DWT OPTION-HIGH RISE LOCK CANAL

DAMES & MOORE

FIGURE 3.10

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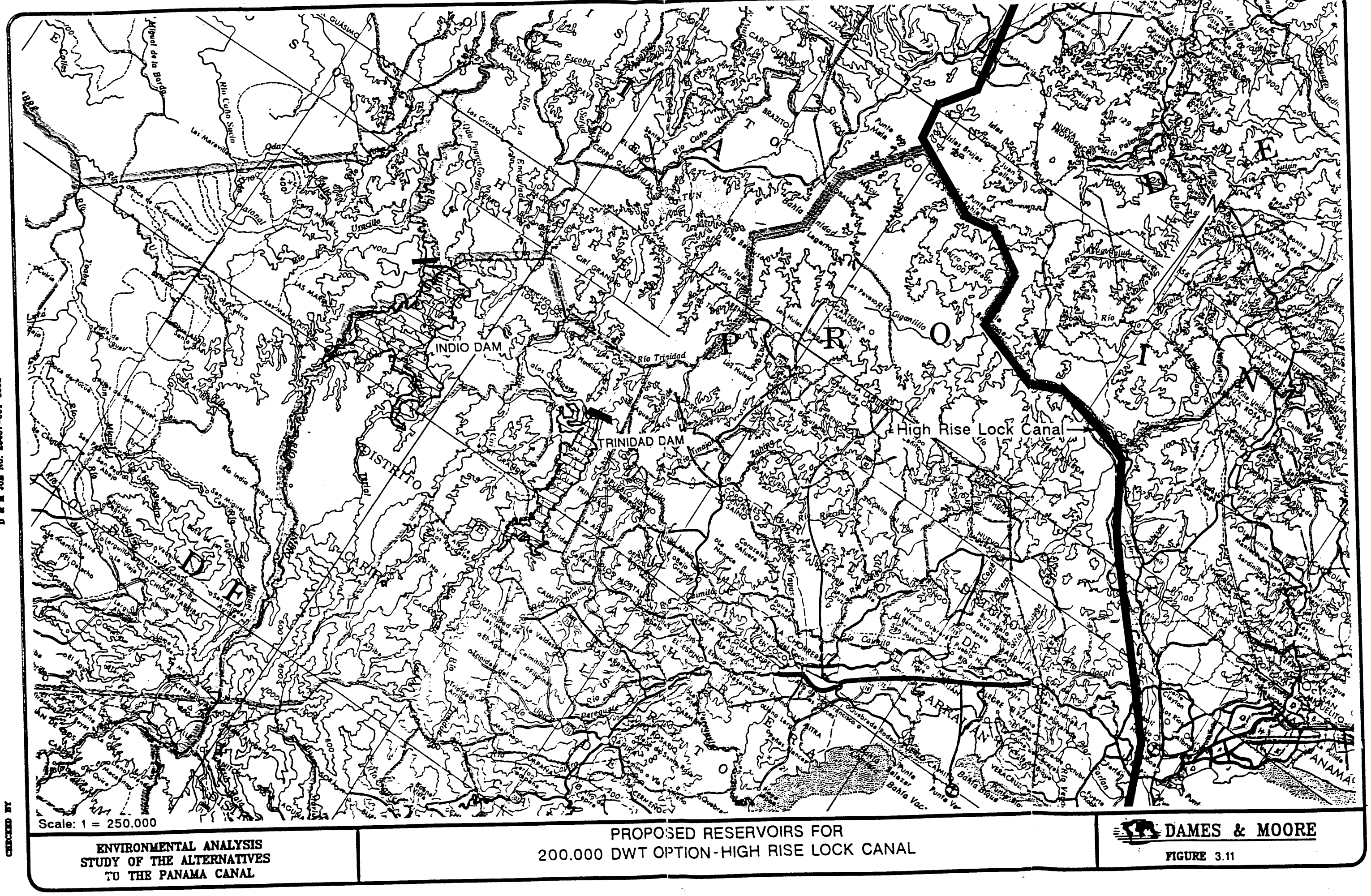

ENVIRONMENTAL ANALYSIS
STUDY OF THE ALTERNATIVES
TO THE PANAMA CANAL

PROPOSED RESERVOIRS FOR
200,000 DWT OPTION-HIGH RISE LOCK CANAL

DAMES & MOORE

FIGURE 3.11

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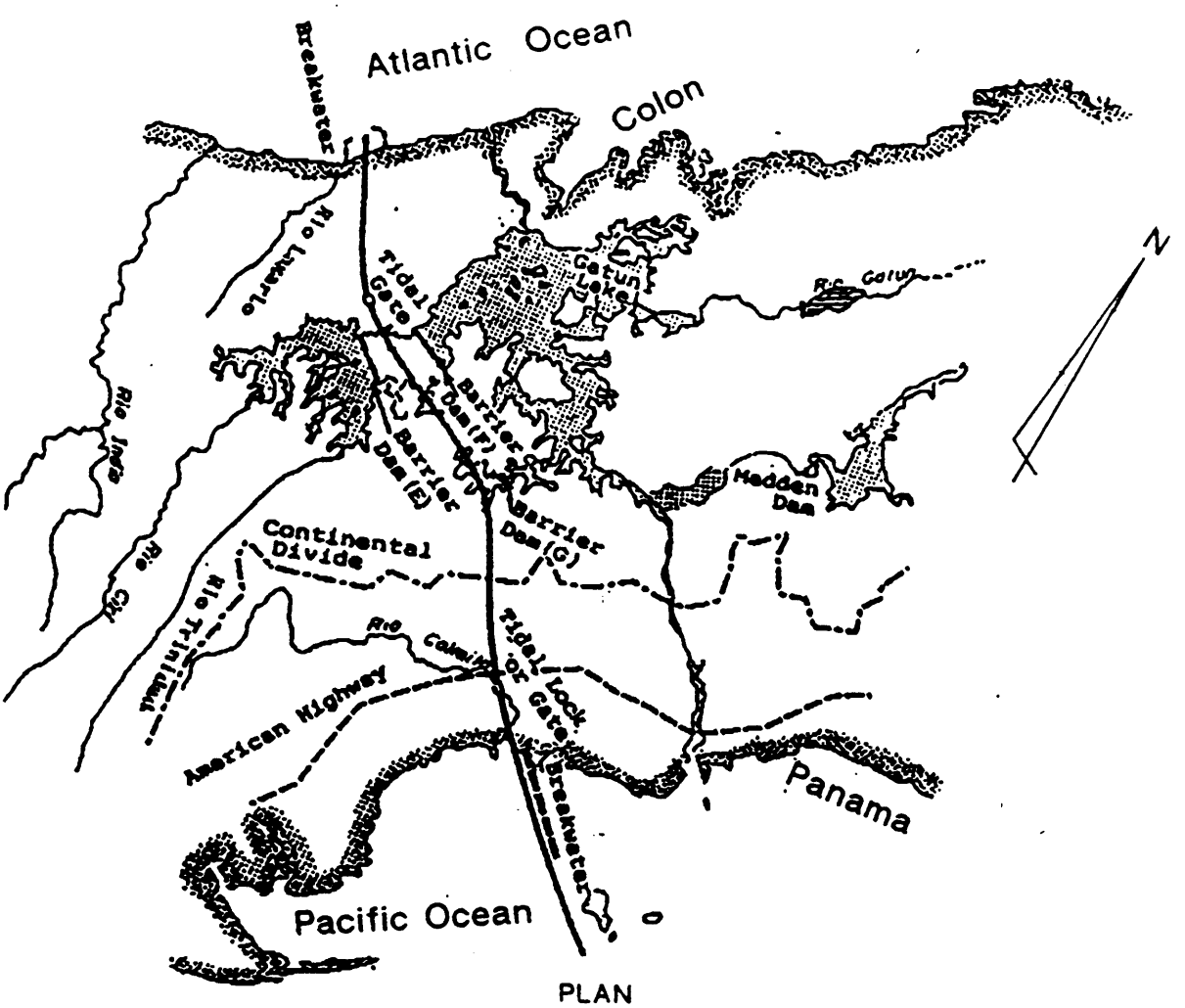

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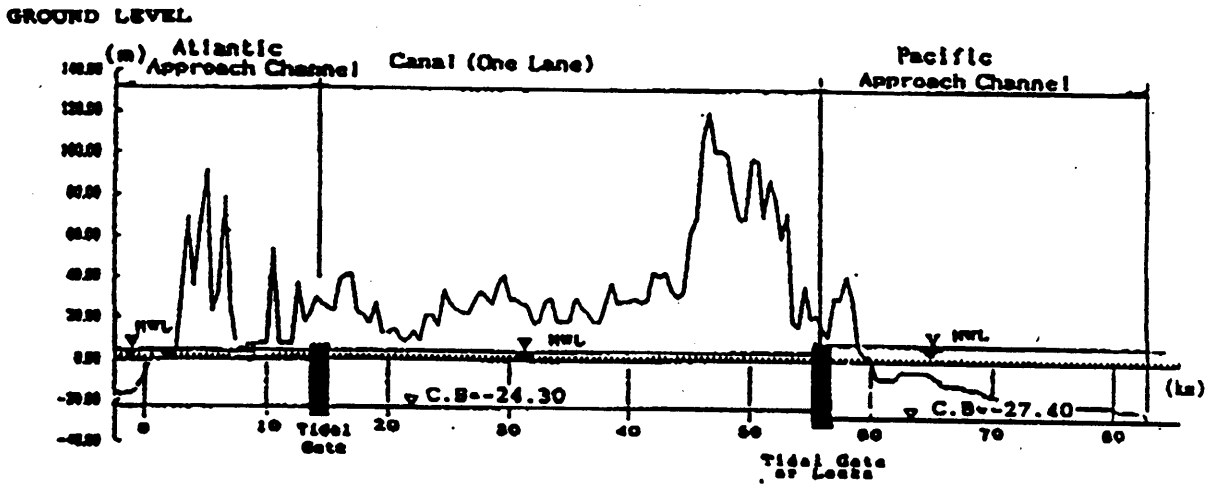

PROFILE

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
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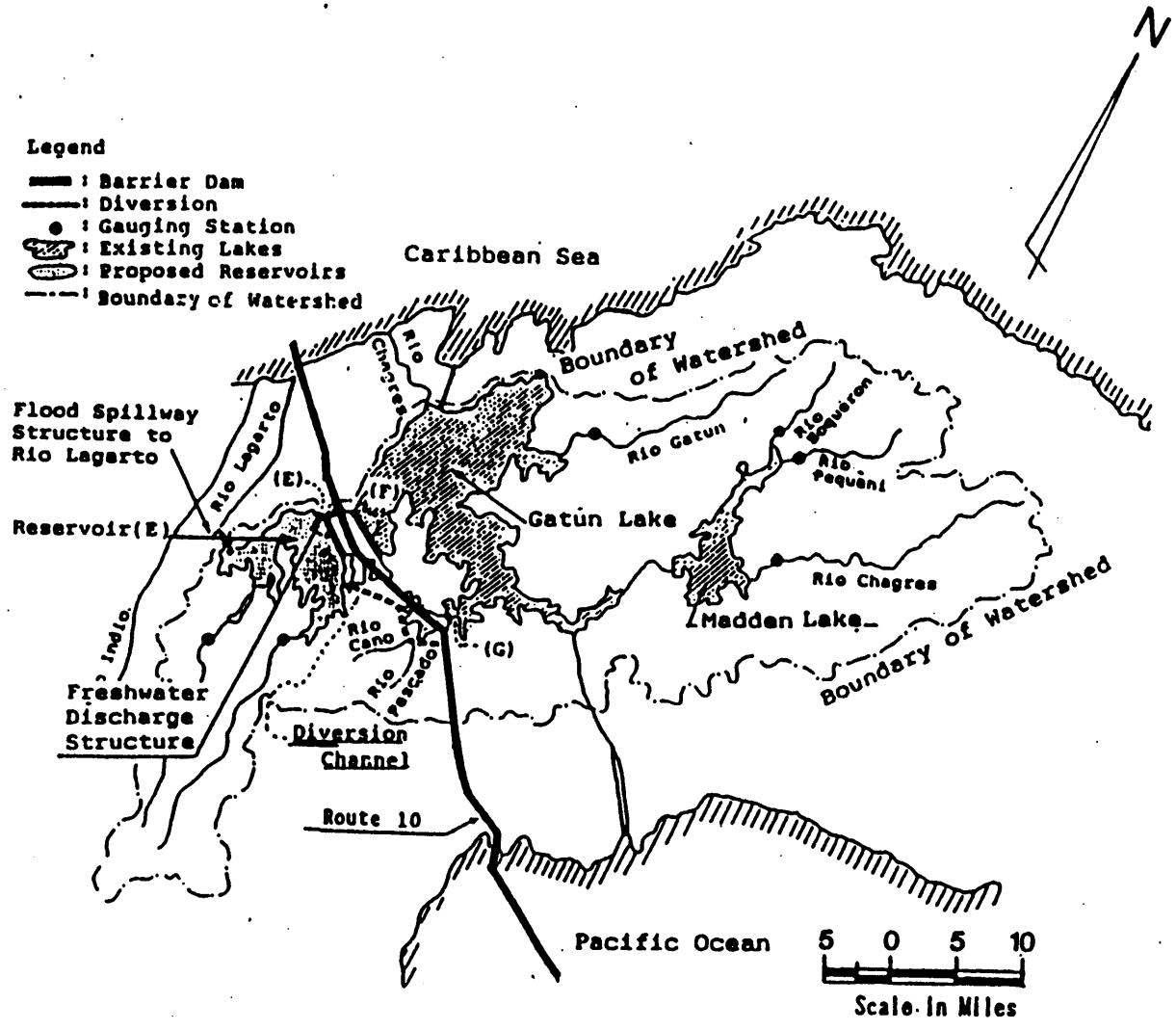
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF SEA LEVEL CANAL CASE (a)	DAMES & MOORE FIGURE 3.12

BY Ralph DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE



REFERENCE:
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TO THE PANAMAL CANAL
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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	BARRIER DAM LOCATIONS SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.13

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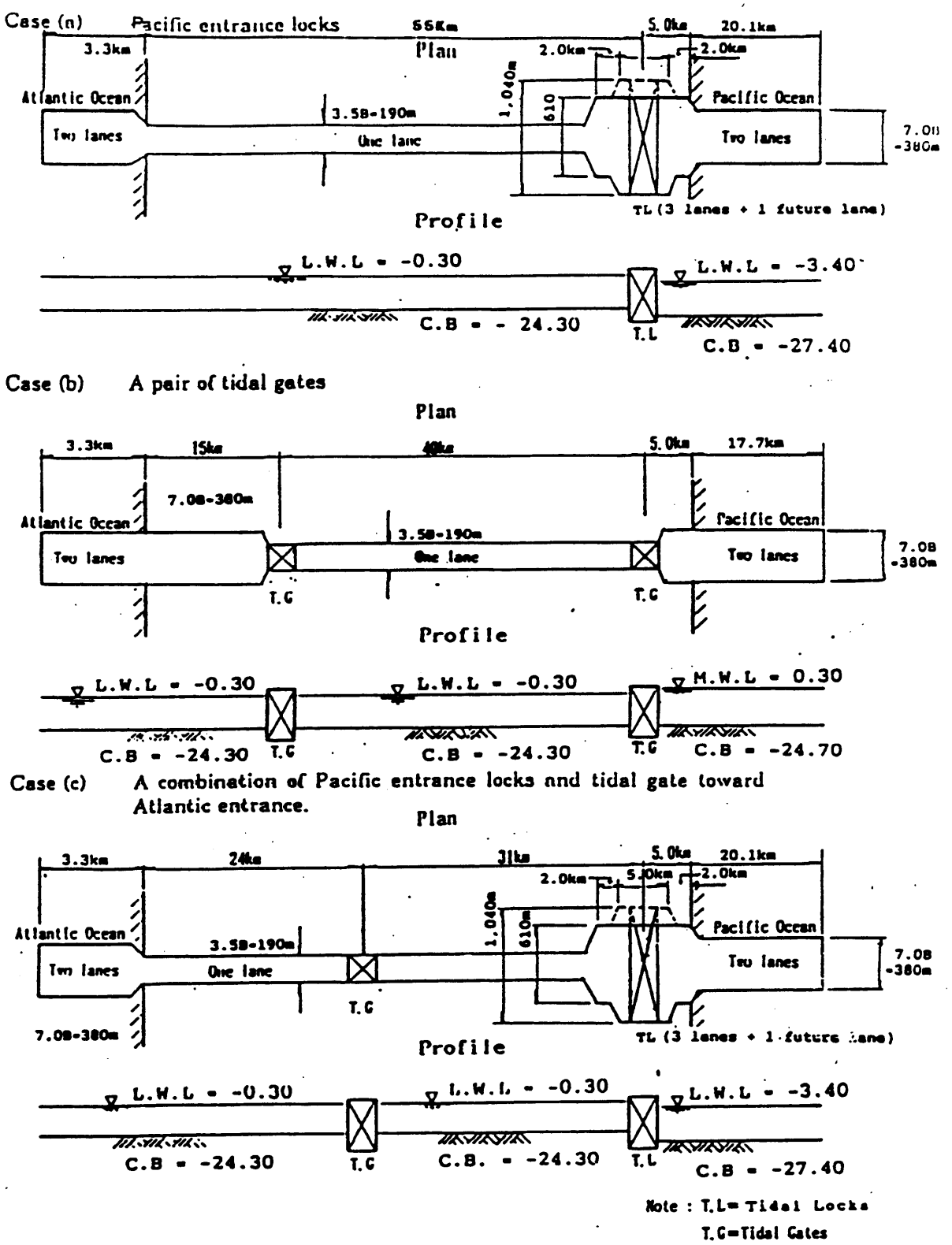

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
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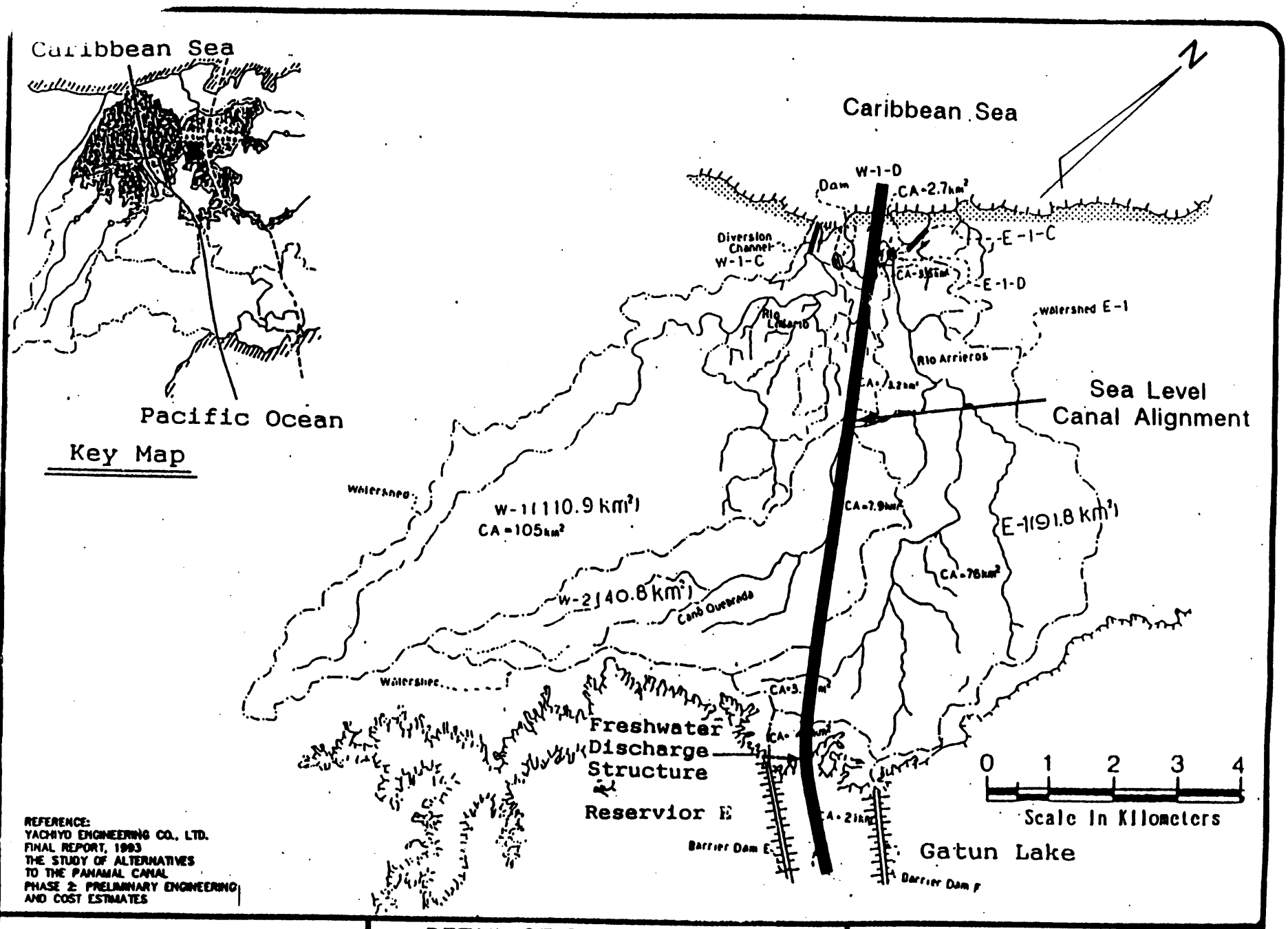
AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF TIDAL GATE/ LOCK OPTIONS SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.14



REFERENCE:
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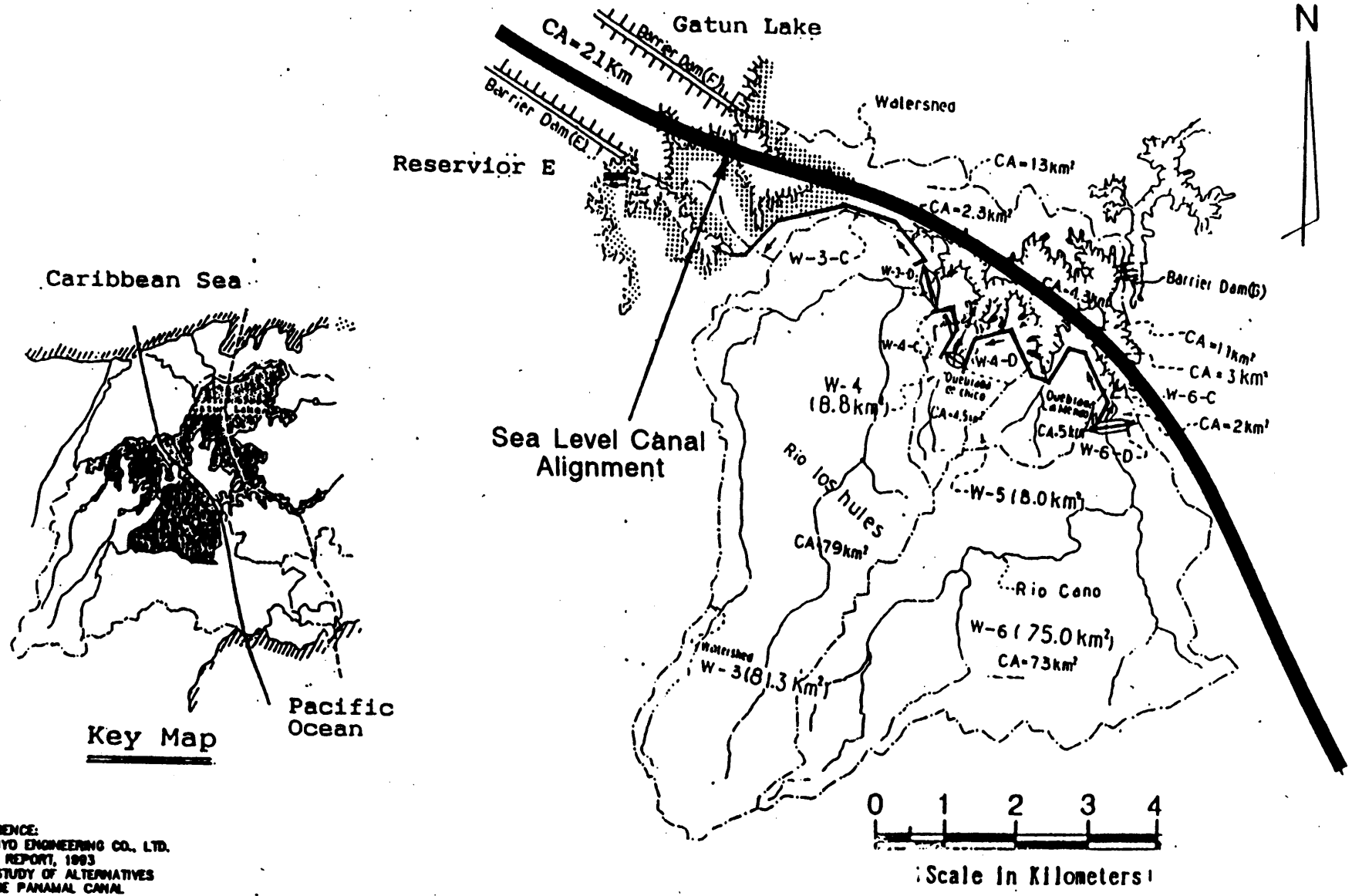
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	DETAIL OF CARIBBEAN SIDE DIVERSION SCHEME SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.16



REFERENCE:
YACHIYO ENGINEERING CO., LTD.
FINAL REPORT, 1993
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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	DETAIL OF CENTRAL PORTION OF DIVERSION SCHEME SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.17

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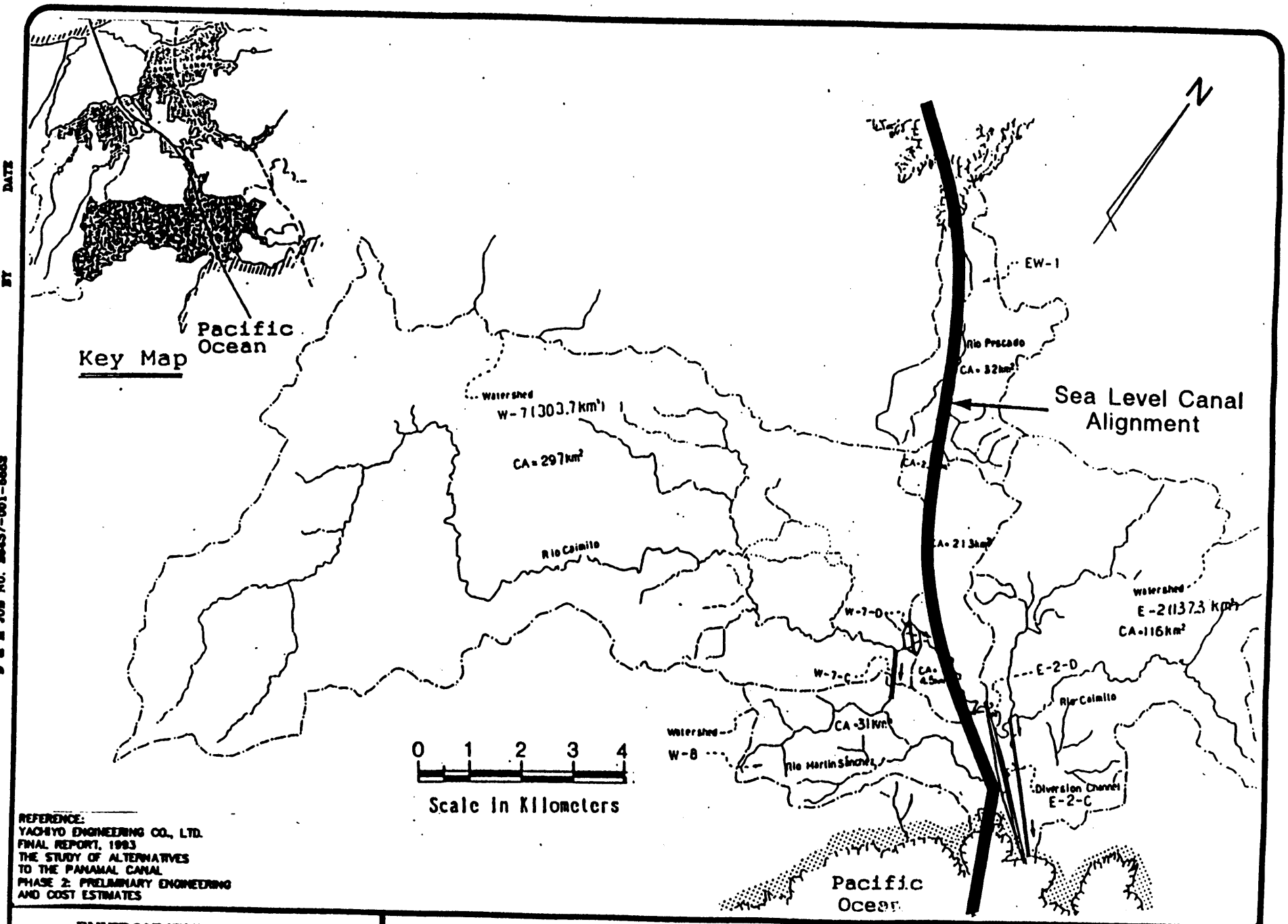

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
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TO THE PANAMAL CANAL
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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	DETAIL OF PACIFIC SIDE DIVERSION SCHEME SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.18

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D & M JOB NO. 26437-001-5553

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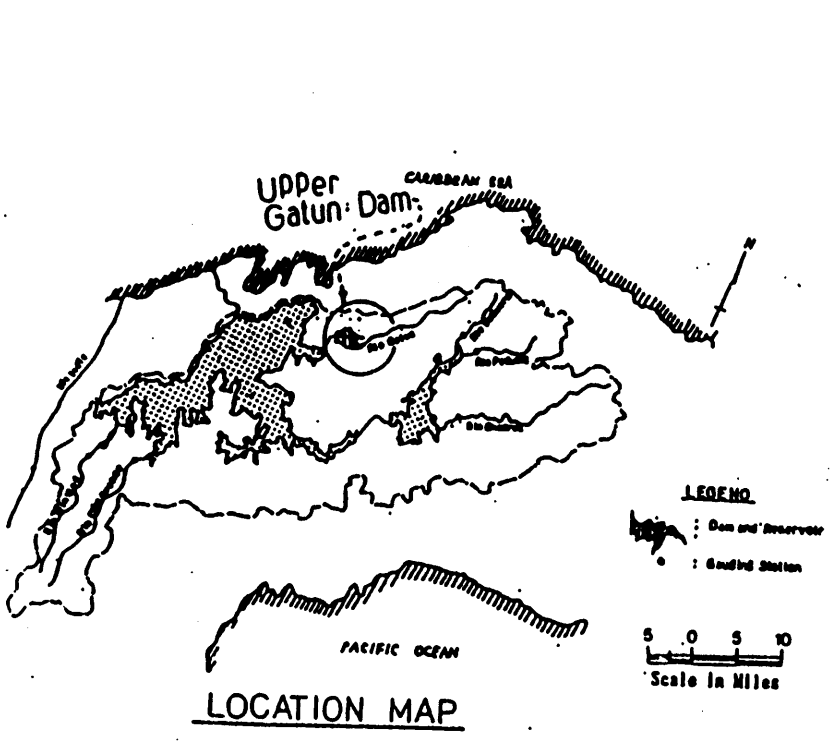
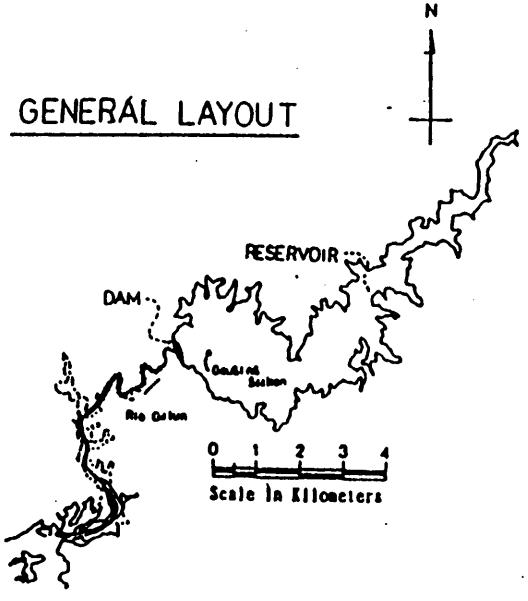


LOCATION MAP



GENERAL LAYOUT

REFERENCE:
YACHIYO ENGINEERING CO., LTD.
FINAL REPORT, 1993
THE STUDY OF ALTERNATIVES
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ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF UPPER GATUN RIVER RESERVOIR SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.19

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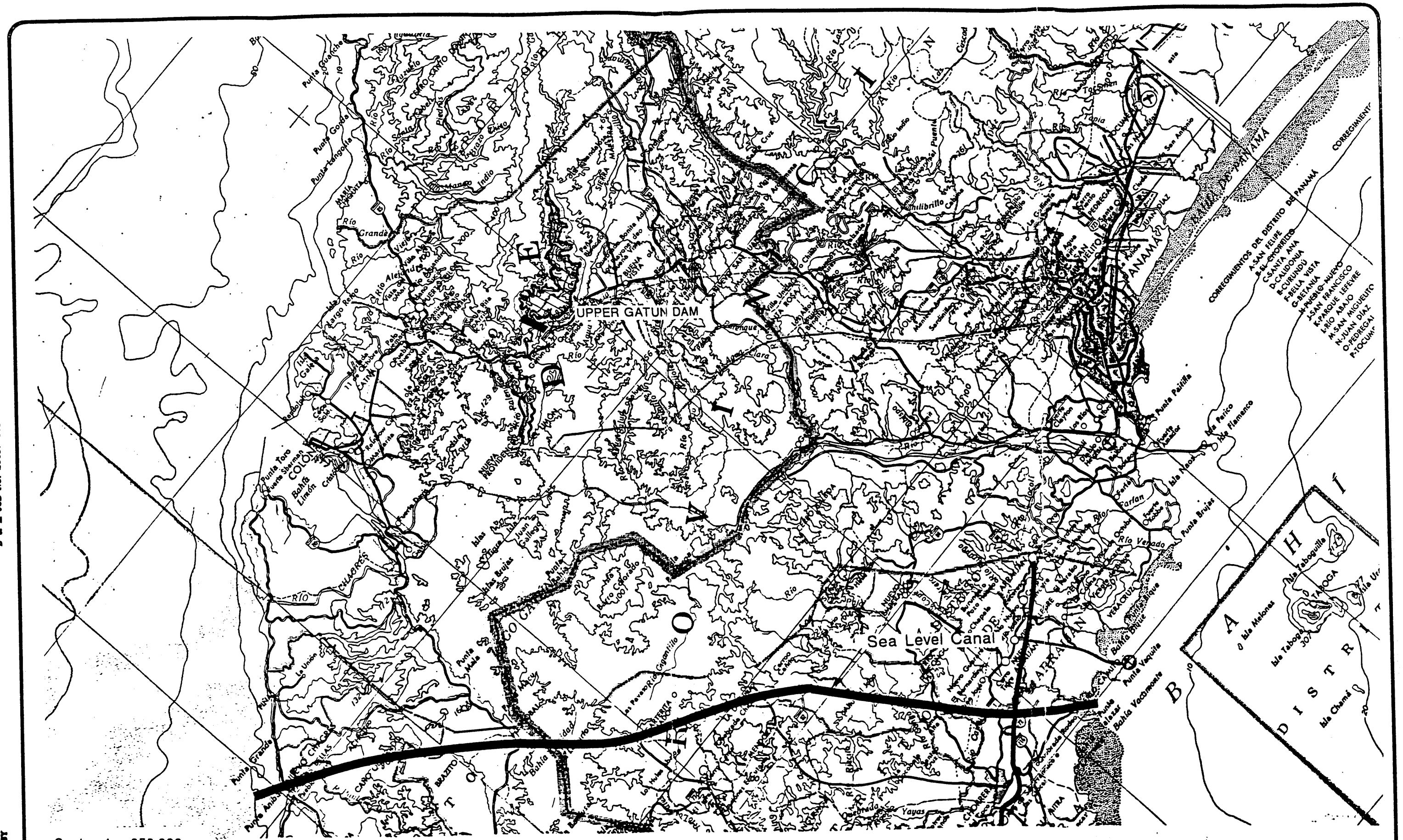

ENVIRONMENTAL ANALYSIS
STUDY OF THE ALTERNATIVES
TO THE PANAMA CANAL

ESTIMATED IMPACT AREAS OF
UPPER GATUN RIVER RESERVOIR

DAMES & MOORE

FIGURE 3.20

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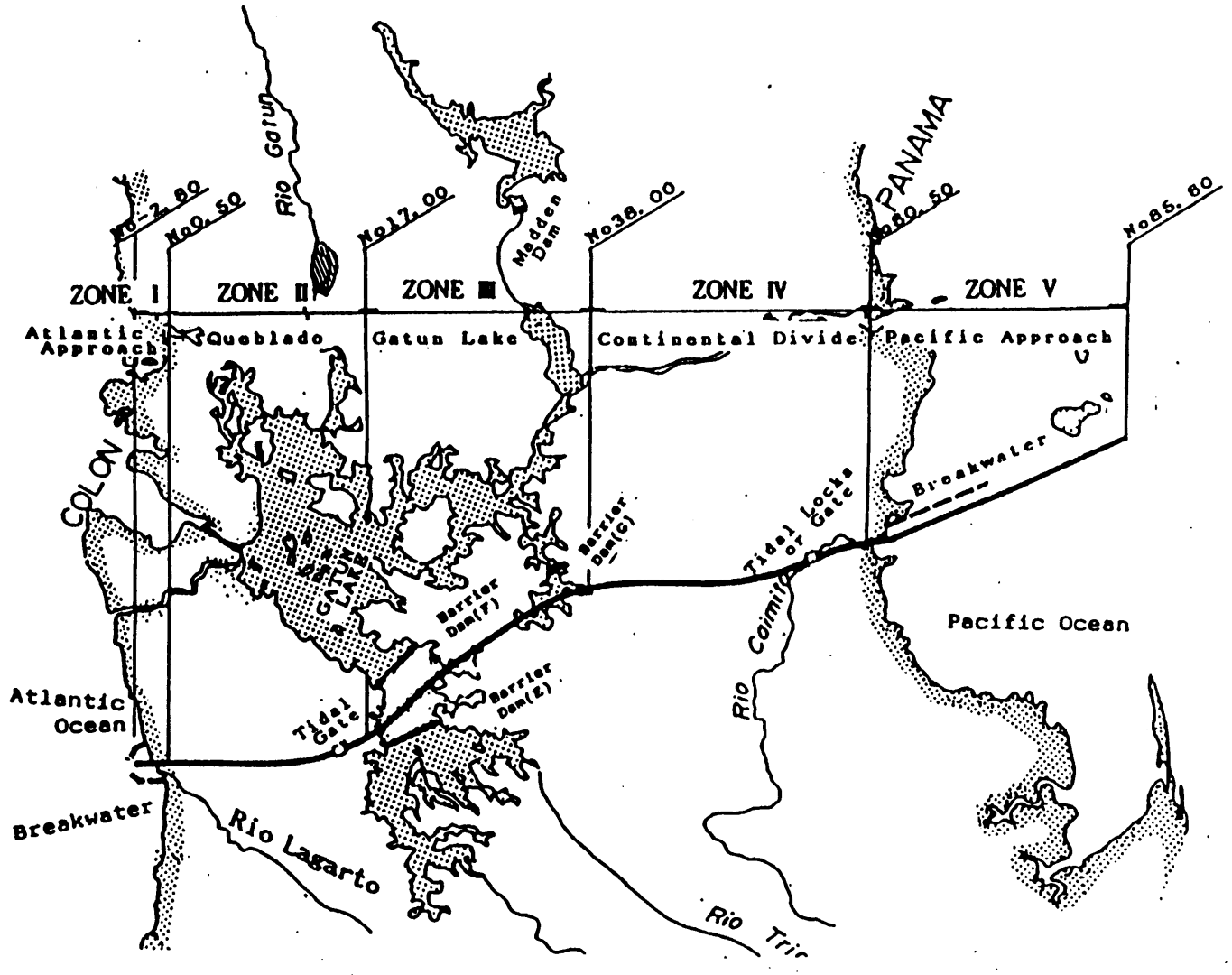

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TO THE PANAMAL CANAL
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ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	ZONE MAP OF SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.21

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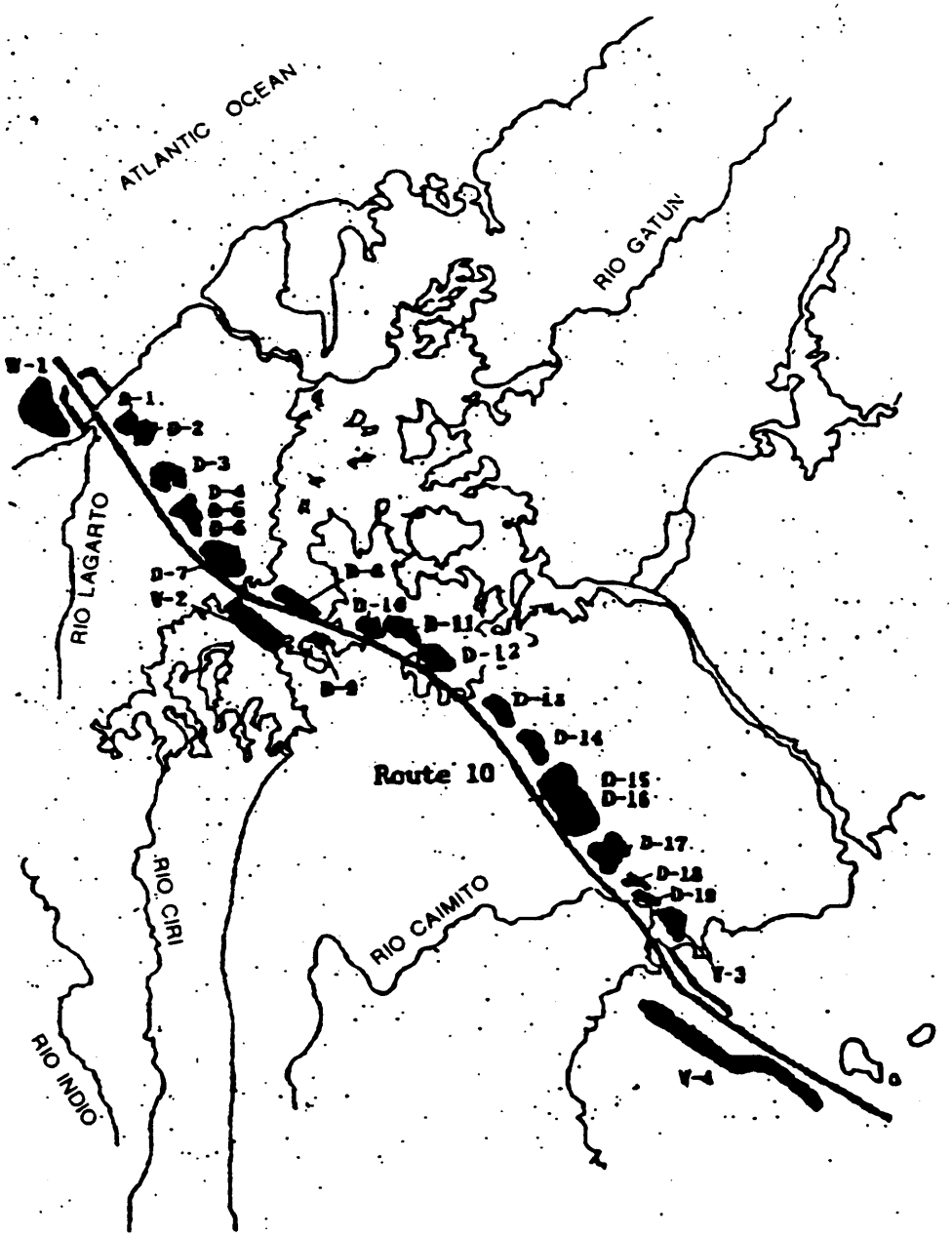
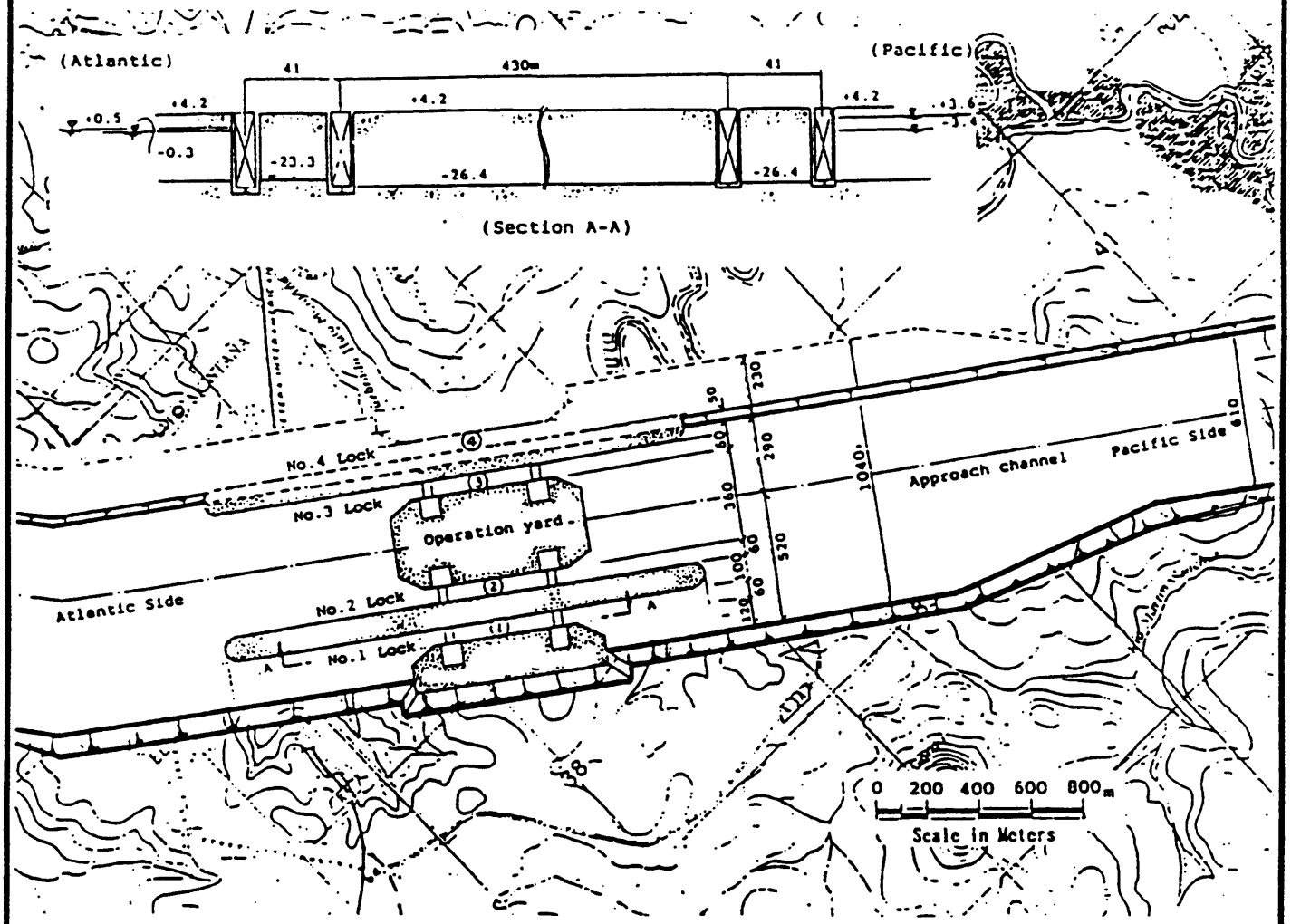


ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LOCATION OF PROPOSED SPOIL AREAS SEA LEVEL CANAL	DAMES & MOORE FIGURE 3.22

BY Ralph DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE



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TO THE PANAMA CANAL
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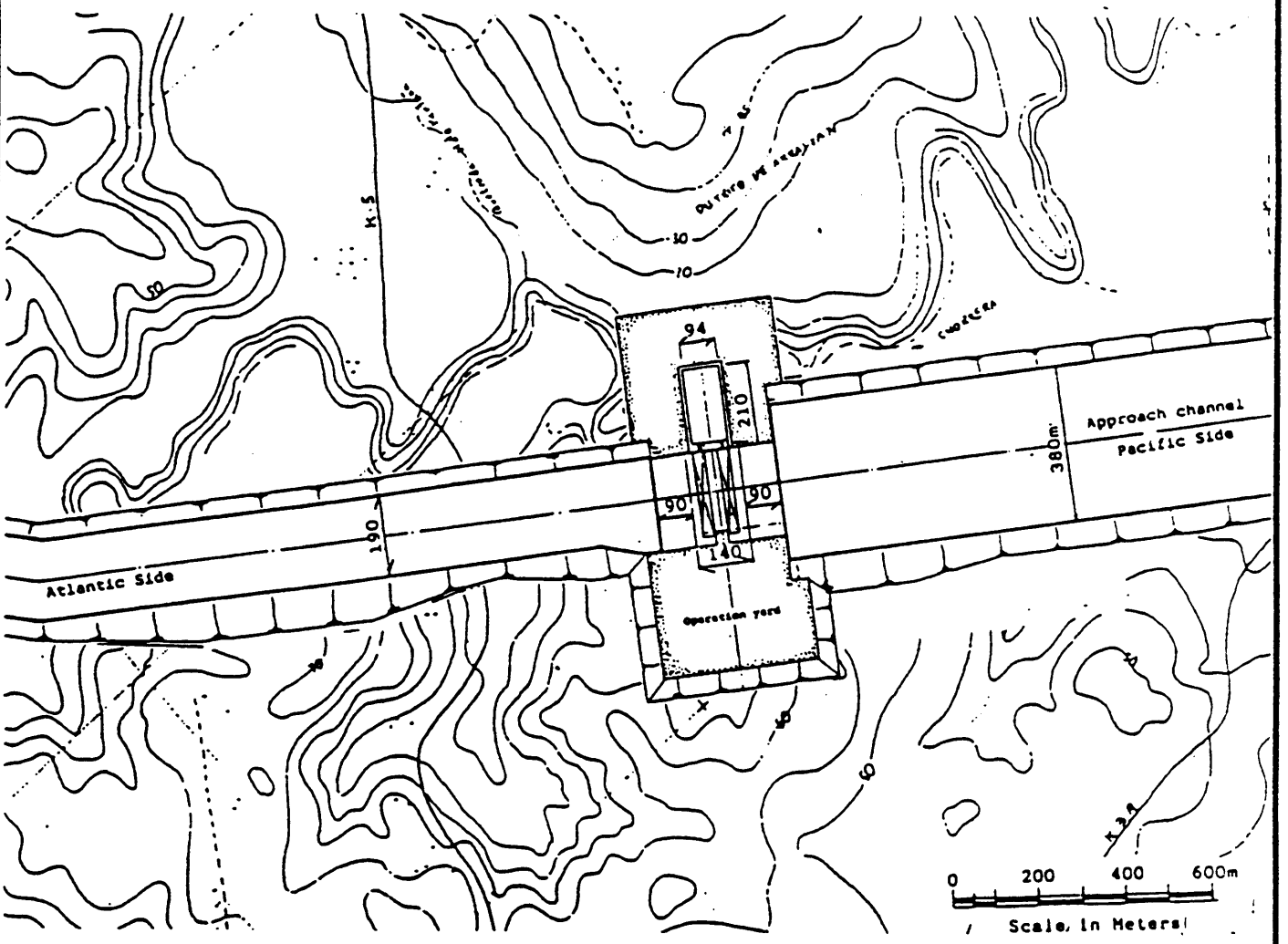
AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF TIDAL LOCK FACILITIES SEA LEVEL CANAL - PACIFIC SIDE	DAMES & MOORE FIGURE 3.23



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FINAL REPORT, 1993
THE STUDY OF ALTERNATIVES
TO THE PANAMAL CANAL
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AND COST ESTIMATES

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	LAYOUT OF TIDAL GATE FACILITIES SEA LEVEL CANAL - PACIFIC SIDE	DAMES & MOORE FIGURE 3.24

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4.0 OBJECTIVES, APPROACH & SCOPE OF WORK

The objectives, approach and scope of work of the Environmental Analysis Component of the Study of Alternatives to the Panama Canal were consistent with the Terms of Reference (TOR) provided by CAS, which were incorporated into Dames & Moore's proposal, dated February 15, 1993. The scope of work was modified on March 15, 1993 to accelerate the study schedule and incorporate additional items requested by CAS. This section presents a description of the objectives, approach, and scope of work of the studies required to complete the Environmental Analysis component.

4.1 OBJECTIVES

The overall objective of the Environmental Analysis Component was to consider the anticipated impacts that construction, operation and maintenance activities of each of the two alternatives selected by CAS will have on the natural environment of Panama. The analysis also included the identification of additional biological information, if deemed necessary, to adequately assess the environmental impacts. In addition, this study focused on assessing the changes to ecological conditions in specific areas affected by the alternatives and evaluating how these changes would affect regional biodiversity and ecological integrity of the project area.

4.2 APPROACH

The analysis of ecological conditions was based on consideration of the plans and designs available for the two alternatives, in relation with local marine, freshwater, and terrestrial ecosystems. The basis of the analysis was the information provided in the ECE, OCCE, and BI/BD reports, together with other available data sources. Complementing the environmental analysis, a rapid environmental characterization of the Indio River watershed was completed. This assessment was based on a visual inspection from a site overflight combined with an interpretation of black and white photos providing partial coverage of the Indio river area. In addition, an attempt was made to extrapolate biological data gathered in the BD/BI component along the existing canal route, effort that was supplemented by a review of information obtained from aerial photographs along the Route 10 alignment.

Environmental changes caused by construction, operation and maintenance of the two canal alternatives were evaluated by reviewing available information and preliminary plans; identifying ecological impacts of the different facilities and activities; listing potential effects of each alternative on biotic groups; and defining the possible extent of those effects. The Environmental Analysis, while considering important species (representative, sensitive, economically valuable and/or endangered), was directed towards a regionally based consideration of ecological integrity and biodiversity.

Key issues which were considered included:

- Physical, chemical and biological changes in lakes and rivers.
- Inter-oceanic transport and colonization of marine organisms.
- Clearing of forests and loss of agricultural land.
- Changes in water quality and effects on biota.
- Direct and indirect effects of dredging and other construction activities.
- Sedimentation or spoil placement effects on terrestrial and aquatic resources.
- Effects on protected and unique habitats or species.
- Changes in fisheries resources.
- Bio-contamination due to discharges, spills or other accidents.
- Impact from the loss of the biological corridor at the continental and local levels.

4.3 SCOPE OF WORK

In order to fulfill the project objectives, the Study was divided into six tasks, as follows:

1) Data Review and Analysis
2) Baseline Characterization
3) Project Description
4) Impact Analysis
5) Mitigation Planning
6) Recommendations for Future Studies

Based upon data review and analysis, the baseline characterization and project description were developed which provided the basis for impact analysis and mitigation planning. The following sections present a summary of the work scope which was completed for each of the above mentioned tasks.

4.3.1 Data Review

In order to establish a historical background for the project, data analysis included a literature review of the construction of the original canal, review of the initial activities associated with the proposed third set of locks during the 1930s, and review of the 1960-1970 study for the sea-level canal, the 1977 seawater pumping study, and the 1989 widening of the Gaillard Cut.

Upon completing review of the project background, existing biological baseline information was identified and collected. This included: 1) searching available wildlife and botanical literature, study reports and databases, 2) reviewing relevant aerial photography, historical

and other habitat information on file with CAS, 3) identifying information on the marine environment and continental water, and 4) consulting with local biological, environmental organizations, and taxonomic experts. The main source of information for the biological baseline information was the first three of four quarterly reports from the BD/BI component.

Upon completion of the data review, an analysis of ecological data was performed for the following key items:

- Initial identification of ecosystem (habitat) types by vegetation associations.
- Identification of important ecosystem processes and functional classification of ecosystem biota.
- Determination of the number and types of species within each community type.
- Examination of species interactions.
- Estimate of the relative importance of individual species and functional groups.

4.3.2 Baseline Characterization

Based upon the results of the data review and analysis, a baseline characterization of the project area was prepared to provide a reference point for the evaluation of potential environmental impacts. The baseline characterization was based on the existing conditions in the project areas including all its existing environmental stress, as well as the Gaillard Cut widening project, and included a description of the natural project environment, including the physical and biological environment, and biological diversity.

The baseline characterization was based primarily on the information available in the BD/BI reports. Additional sources of information included materials obtained from the Smithsonian Tropical Research Institute (STRI), the Panama Canal Commission (PCC), the Tommy Guardia Geographical Institute (TGGI), and the personal libraries of the Team members.

Wherever possible, keystone species, species which play a key role in ecosystem processes, were identified as well as functional groups within representative community types. In addition, sensitive, endemic species or those with economic or medical importance were identified.

Description of the physical environment included a general summary of climatic conditions, geography, geology, hydrology, hydrogeology and oceanography of the study area. Regarding hydrology, a description of the existing hydrologic regime in connection with surface and sub-surface waters was completed; for oceanography, a description of the existing conditions

at the sea bottom and currents in the Caribbean Sea and Pacific Ocean was performed within the study area.

Description of the biological environment included a general discussion of the major aquatic and terrestrial communities found within the study area. These communities included pelagic, subtidal and intertidal, coral reef, seagrass, mangrove, lakes and rivers, freshwater wetlands, forest (mature and successional), open areas (grassland and pastures) and agricultural assemblages. In addition, a review of biological diversity was completed, including an evaluation of the potential reduction or loss of biological diversity, fragmentation and associated implications.

Vegetation descriptions relied heavily on published descriptions, together with personal experience of the staff and data from the inventory. Ample data were available for forests and mangroves, but other terrestrial habitats (wetlands, grasslands, agricultural) have had little scientific study.

Terrestrial habitat classes were chosen based on recognizable biological processes and on land use patterns; for example, the separation of neotropical forests into early and late successional forest stages is widespread in the ecological literature. This allowed the use of data from published sources, when needed to supplement data from the Inventory.

Lists in the Biological Inventory formed the basis for lists of threatened and endangered species. When possible, criteria for inclusion were identified, giving emphasis on legal statutes which protect individual species.

Available scientific literature was searched for information to supplement the data of the Biological Inventory. Studies from Barro Colorado Island and adjacent areas were particularly useful. Whenever available, studies based in the study area were used. When those were not available, studies from Panama and/or adjacent countries were consulted. Studies from Costa Rica were particularly useful, due to the long-term studies of the Organization for Tropical Studies, Tropical Science Center, and other tropical research programs conducted in that country.

Implicit in the use of these other studies was the assumption that general processes and patterns of abundance would be comparable between geographically distinct but ecologically similar habitats (e.g. moist tropical forests of central Panama should resemble moist tropical forests of Costa Rica). These similarities are discussed in a recent volume comparing fauna and flora at four Neotropical forest sites, including Barro Colorado Island (Gentry 1990).

Supplemental sources of information are cited within the text for each section. The field experience of the Dames and Moore team members was also used to supplement the available data when appropriate.

In order to incorporate the special environmental considerations associated with this project, a review of ecology-related environmental regulations was completed. In addition, an evaluation of protected natural areas and protected species was presented, together with a review of the fauna of special medical or veterinary interest.

4.3.3 Project Description

A description of the planned project and related infrastructure associated with the construction, operation and maintenance of the proposed alternatives was prepared to identify sources of potential environmental impacts in the study area. Information regarding the engineering and construction characteristics of the proposed alternatives was obtained from the ECE final report supplemented by an Addendum to the report which corrected the locations of spoil placement areas.

The project description presents the engineering and construction methodology for the High-Rise Lock and Sea-Level Canal alternatives. This description addresses canal alignments, excavations, slopes and spoil areas; proposed canal structures, such as locks and tidal gates; construction sequencing, spoil areas, dams and reservoirs required for water balance, access roadways, bridges, work camps, jetties, and other infrastructure required in connection with the construction, operation and maintenance of the proposed alternatives.

A June, 1993 annex to the ECE Report, presents additional options for the High-Rise Lock and Sea-Level Canal alternatives. These alternatives reduce the amount of excavated material by more than half, in the case of the High-Rise Lock alternative, by making the bypass channel into a single lane. In the case of the Sea-Level alternative, excavation is decreased when the Atlantic portion is also reduced to a single lane.

4.3.4 Impact Analysis

From the baseline characterization and the project description, potential environmental impacts were evaluated and compared for both alternatives. These included:

- Short and long-term general environmental impacts that may occur to humans (epidemiological), flora, fauna, soils, water, and air as a result of the construction, operation and maintenance of each of the proposed alternatives.

- Activity-specific construction impacts that would depend on the action being performed, such as roads, reservoirs, dredging, locks and tidal gates, quarries, worker camps and villages.

- Alternative-specific impacts that would occur depending on whether the High-Rise Canal or Sea-Level Canal alternative is constructed.

The impact analysis included estimates of impact areas based on the design information presented in the ECE report. Areas of impact included excavation and dredging areas associated with construction of the canal, locks, gates, and breakwaters, as well as areas proposed for dam and reservoir construction and infrastructure related with the construction of each of the two alternatives. Subsequently, the impact areas were evaluated to differentiate areas impacted by excavation and dredging activities. Impact areas were further quantified by habitats, which included wetlands, mangroves, grasslands, pastures, agriculture, and forests, as well as open areas, urban areas, lakes and rivers, and oceans.

4.3.5 Mitigation Planning

On the basis of the impacts identified, a basic mitigation approach was developed to present general and specific mitigation measures. In addition, guidelines were provided for additional mitigation plans and monitoring programs. In those situations where inevitable impacts will occur, guidelines were presented for compensation.

4.3.6 Recommendations for Future Studies

Based upon the results of the impacts analysis and mitigation planning, recommendations were provided for additional studies which could further identify and define baseline conditions and potential environmental impacts at a local and regional level for each of the proposed alternatives.

5.0 NATURAL ENVIRONMENT

The natural environment of the project study area has been divided into two major groups: the physical environment and the biological environment.

5.1 PHYSICAL ENVIRONMENT

The physical environment consists of those abiotic characteristics within the study area fundamental to the presence of life, including climate, geography, geology, hydrology, and the oceanography within the study area. A description of these characteristics follows.

5.1.1 Climate

The climate of the study area is typical of tropical zones. Based on information available from 1978 to 1983, the average temperature in the vicinity of Lake Gatun is between 25 and 26 °C. The average temperature near the Pacific and Caribbean coasts increases to between 26 and 27 °C. The high and low temperatures measured at Tocumen (Pacific coast) have been 36 and 16 °C, respectively. Daily temperature variations range between 8 to 8.9 °C at Tocumen, and 9 to 9.9 °C at Buena Vista (inland, near Lake Gatun).

Rainfall is greatest from the end of April, or beginning of May, through November. This period is normally considered the rainy season. More rainfall occurs near the Caribbean coast, where yearly rainfall ranges between 3,000 to 3,500 mm. Rainfall diminishes inland, ranging between 2,000 and 3,000 mm in the Lake Gatun area. Rainfall on the Pacific shore ranges between 1,500 and 2,000 mm per year. The rainfall is usually deposited during intense events of short duration. Consequently, runoff is high. Relative humidity is high, with the yearly average ranging between 85 and 90% within the study area.

According to the Köppen climate classification, the western portion of the Caribbean shoreline of the study area is considered to have a very wet tropical climate, with substantial rains throughout the year and with <60 mm of rain during the driest month. The lowest temperature during the year is >18° C, and the average temperature difference through the year is <5° C.

The eastern portion of the Caribbean coast, and the Lake Gatun region is considered to have a wet tropical climate. Annual precipitation is greater than 2,500 mm, with one or more months having <60 mm of rainfall. The lowest temperature during the year is >18° C, and the average temperature difference through the year is <5° C.

The Pacific coastal portion of the study area has a tropical savannah climate. Yearly precipitation is less than 2,500 mm, with a prolonged dry season, corresponding with winter in the northern hemisphere. The lowest temperature during the year is also >18° C, and the average temperature difference through the year is <5° C.

5.1.2 Geography & Geology

The study area comprises the Isthmus of Panama. This thin strip of land measures between 58 to 65 kms from the Caribbean to the Pacific. The highest elevations within the study areas range between 100 to 199 m above sea level, and are located near the Gaillard Cut of the Panama Canal and northwest of Lake Gatun.

The proposed canal alternatives cross the four physiographic provinces of the study area: Littoral swamps of the Pacific Coastal area; the igneous complex areas of the Continental divide; the stratified rock of the Lake Gatun-Atlantic Ocean section of the route; and the littoral swamps and lowlands of the Atlantic coastal plain.

Pacific littoral swamp extends along the Pacific coastline reaching inland at the lower elevations of the major streams, where subsidence of the stream valleys has caused deposition of stream loads, forming thick deposits known as the Pacific Muck.

The igneous complex extend from the southern shores of Lake Gatun southward to the swamps of the Pacific shore. The topography is typically steep and rugged with elevations over 120 m above sea level. Maximum relief is approximately 200 m. In isolated areas along the Panama Canal, typical topography of stratified rock occurs within the igneous complex region. Igneous complex areas are characterized by steep gullies with irregular patterns. The upper portions of hills consist of hard basalts and agglomerates. These occur either capping the hills as eroded remnants, or as dikes and plugs that have intruded into the softer and less erosion-resistant rocks of the lower hill slopes and valleys.

The stratified rock province extends from the Atlantic littoral swamps and lowlands along the Atlantic coast to the southern shore of Lake Gatun. The primary formations in this area are the Chagres sandstone, Gatun sandstone and Caimito sedimentary formations. The stratified materials form a young coastal plain which gently dips toward the Atlantic Ocean. Inland, the Chagres sandstone forms a prominent ridge along its contact with the Gatun formation. A well-developed drainage pattern occurs throughout the stratified rock area, resulting in steep-sided hills separated by narrow valleys.

The Atlantic littoral swamps and lowlands comprise portions of the Chagres, Trinidad, Gatun and Caño Quebrado River Valleys with associated inland and coastal swamp areas. In Pliocene-Pleistocene time, the land surface was much higher than at present, and rivers cut deep valleys on the Atlantic slope. A period of subsidence followed, which reduced the velocities of the streams and allowed deposition of silt and organic material in the lower elevations of the valleys. Periodic encroachments of the sea allowed mingling of stream deposits and Pleistocene marine sediments. Thick sequences of this material, known as Atlantic Muck, have been deposited in sections of the old river valleys near the Atlantic

coast. The surfaces of the swamps have been raised a few feet above sea level by a recent uplift which may be continuing today.

Significant geological events in the study area are listed described below in chronological order:

a. Deposition of the basement complex of the area during Late Cretaceous or Early Eocene.

b. The Isthmus was structurally high and above sea level prior to the Late Eocene as evidenced by fossil remains of land mammals of both North and South America. The project area was below sea level during the Late Eocene. The earliest recognizable diastrophism of the basement complex took place at this time. Deposition and subsequent folding of the rocks upon which the Oligocene sediments were laid down occurred in Late Eocene.

c. No geologic record was found older than Oligocene along the proposed Sea-Level Canal alignment. Volcanic activity and deposition were continuous throughout the Oligocene epoch. At the close of the Oligocene there was a relatively strong upwarping, raising the Pacific portion of the Isthmus above sea level.

d. The capping basalt flows of the Pacific Divide Region occurred during the Early Miocene. The Oligocene volcanic rocks were cut by an intrusive basalt porphyry during Middle Miocene. Deposition was continuous on the Atlantic side of the divide during Middle and Late Miocene. Although there are thin beds of tuff within the Gatun formation, their origin is believed to be from remote volcanic activity. The shallow-water Gatun formation was deposited during Late Miocene. Subsidence near the end of the epoch is evidenced by a change to a deeper water environment of deposition. The Gatun formation was subsequently uplifted and eroded. This period of erosion was followed by deposition of the Toro limestone beach deposit, which is generally considered the basal member of the Chagres formation. The discontinuity between these formations necessarily required subsidence of the Gatun formation prior to deposition of the Toro limestone.

e. The deep-water Chagres formation was deposited in Late Miocene and Early Pliocene.

f. Uplift, faulting, and eroding of the area took place during Late Pliocene followed by subsidence and subsequent deposition of the Atlantic and Pacific Mucks during Pleistocene.

g. From Pleistocene to Recent there has been an intermittent slow uplift of the region and erosion of the mucks.

Most of the faulting and fracturing of the study area is controlled by tensional forces, subsurface exploration, and tectonic history. Correlation between subsurface and surface fracture orientations is good and the major North-South and East-West subsurface fracture orientations encountered on the Sea-Level Canal alternative are identical to the regional structural orientations observed in the High-Rise Lock Canal alternative. The extrusive basalts have the highest frequency of fractures and the soft altered volcanics the lowest.

Seismic data strongly indicate that the study area is part of a relatively rigid aseismic plate undergoing little deformation. Thus, it appears that the area will continue to remain stable and no regional tectonic activity is expected which would affect canal construction or operation.

The Gatun and Chagres sandstones of the Atlantic side of the Route have exhibited considerable slope strength. A 200-foot cut was made in the Gatun formation for the Third Locks excavation with an overall slope of 3 vertical on 2 horizontal with 25-foot benches at 50-foot intervals. This cut is still stable after 48 years of exposure. A wave-cut cliff of over 50 feet relief in the Chagres sandstone near Fort San Lorenzo attests to the stability of slopes in the Chagres formation.

Rocks in the Pacific Continental Divide area vary from slightly altered (retaining their original rock structure) to severely altered to clay (exhibiting the characteristics and the weaknesses of clay shale). Slickensides are common and water contents high at considerable depths, varying with changes in depth, lithology, and degree of alteration. Localized weak zones are found along some fractures in the basalts and their frequency indicates a necessary flattening of some slopes during construction. The soft altered volcanic rocks underlying the basalts in the Divide area are generally weak and may require relatively flat slopes for stability.

Recent exploration has shown that the area of the Sea-Level Canal alternative is intensely faulted and highly fractured with widespread distribution of soft altered volcanics, mantled in the Pacific Continental Divide area by extrusive basalt.

5.1.3 Hydrology, Continental Waters & Hydrogeology

The Panamanian rivers run in two main directions: towards the Caribbean Sea and to the Pacific Ocean. Generally they are short and the streambeds are, in most cases, directed to the coasts. The yearly flow of surface water totals approximately 4,570 m^3/sec, where 60% drains toward the Pacific Ocean. The monthly variation of flow volumes in the Caribbean region is less than in that of the Pacific.

The flow rate of the Pacific rivers during the dry season can be one-tenth of the flow observed during the rainy season. In general terms, the month of greatest flow is October and the greatest water resources in the country are found towards the Pacific shores.

For the study area of the alternatives to Panama Canal, the most important hydrographic areas are Lake Gatun, Lake Madden or Alajuela, and the Rio Indio watersheds, whose drainage areas are, 2,321 km^2, 1,018 km^2 and 380 km^2, respectively.

The principal tributary to Lake Gatun is the Chagres River. Other tributaries that contribute significantly are the Ciri and Trinidad rivers to the south, and the Gatun river on the north. Lesser tributaries include the López, Palenque, Sucia, Quebrada Palma, Màrina and Hacienda rivers to the east and northwest of the Lake; and the Pescado, Tinajones, Azules, Caño Quebrado, Cañito and Paja rivers in the area of La Laguna.

Other minor tributaries include Quebradas Caño Grande, Santa Rita, Leona, Los Centros, La Pantanosa, Pabloncito, El Congal and La Primitiva. On the other hand, the Pequeni (with its tributary, the San Miguel), Boqueron and Chagres rivers flow into Lake Alajuela. The Chagres is very important and smaller tributaries such as Las Palmas, Piedras and Esperanza empty into it. Another important basin is that of Rio Indio to the north, with its principal tributaries the rivers Uracillo and Terial. Another important river within the study area is the Caimito, which runs toward the Pacific.

Hydrogeologic resources in the study area are poorly understood. No information was available from the Panama Canal Commission Department of Hydrology or the water supply authority IDAAN (Instituto de Acueductos y Alcantarillados Nacionales). The only information available was from the Engineering Department of the Ministry of Health. Even this information was incomplete, as the only data available had been lost due to a recent fire and subsequent flooding of the records department.

Based on his personal recollection, Mr. Rolando E. González (Engineering Department of the Ministry of Health) indicated that there is little or no information regarding aquifers in the study area, as most communities use surface water. Existing wells in the vicinity of the Sea-Level Canal alternative route reach a maximum depth between 24 and 36 m below land surface. In the northern portion of the route, it is possible that these may be tapping into the coquina layers of the basal member of the Chagres sandstone. This material has a high probability of providing a good water source. In the southern portion of the route, they may be tapping into the undifferentiated, volcanic rocks, generally of early Miocene or older ages. Other areas have intrusive and extrusive basalt, of middle and late Miocene age. These formations may produce water in fracture zones.

5.1.4 Oceanography

World oceans have vertical and horizontal subdivisions. Figure 5.1 shows the typical oceanic divisions. The Isthmus of Panama emerged from the sea completely between 3.0 and 3.5 million years ago. This event marked the final cohabitation of Pacific and Caribbean biota in the Pliocene age (Glynn, 1982). Since then, marine species have evolved in two completely different environments.

5.1.4.1 Caribbean Sea

The continental shelf extends to a depth of 200 m approximately 20 km from the Caribbean coast, out from the north entrance of the Panama Canal. Maximum depth inside the study area is 40 m (Batelle, 1970). Figure 5.2 shows the depth gradients and bottom types of the Colon area; Figure 5.3 shows transverse-section profiles of the continental shelves of Panama.

Throughout the entire year, Caribbean currents move along the Panamanian coast counterclockwise, from west to east. Figure 5.4 shows the current circulation pattern on both coasts of Panama. There is no upwelling on the Caribbean coast of Panama (Batelle, 1970; Glynn, 1982). Average tidal amplitude is 30 cm with two daily tides (Cubit et al., 1989). Figure 5.5 compares tidal differences along both coasts.

Mean annual surface water temperature is 29.0° C, with a minimum of 21.5° C and a maximum of 27.0° C. Mean annual salinity is 33‰ (parts per thousand). Figure 5.6 shows precipitation, water temperature, air temperature, salinity, solar radiation, wind, water level, and reef emersion time fluctuations at the Galeta Island meteorologic station (Province of Colon).

The dry season extends from the end of December to April. It is characterized by high solar radiation, strong northerly winds, lower air and water temperatures, and higher salinity. The decreased solar radiation during the rainy season is due to greater cloud cover, gentle winds, higher air and water temperatures, and lower salinity (Cubit et al., 1989). The thermocline occurs at a shallower depth than in the Pacific (Glynn, 1982).

Table 5.1 summarizes the physical characteristics of the Caribbean and Pacific.

5.1.4.2 Pacific Ocean

The Gulf of Panama has a semi-circular shape and covers 28,850 km^2, reaching a depth of 200 m at about 170 km offshore the southern entrance to the Panama Canal. Its average depth is 60 m (Smayda, 1966). The maximum depth in the study area is 32 m. Figure 5.7

shows the depth gradients and bottom types of the Gulf of Panama; Figure 5.3 shows transverse sections of the continental shelf of Panama.

Table 5.1. Summary of the environmental parameters of the Pacific Ocean (Naos Station, University of Panama; D'Croz et al. 1989) and the Caribbean Sea (Galeta Island Station, STRI; Cubit et al. 1989) of Panama.

PARAMETER	PACIFIC	ATLANTIC
Extension of the Continental Shelf	170 Km	20 Km
Marine Currents	Equatorial Current (East- West) Colombian Current (West-East)	(West-East)
Upwelling	Yes (dry season) 75-150 m	No
Average annual ocean temperature	26.3°C	28.0°C
Maximum ocean temperature	29.5°C	37.0°C
Minimum ocean temperature	14.9°C	21.5°C
Average annual salinity	30.6 o/oo	33.2 o/oo
Maximum salinity	34.8 o/oo	36.0 o/oo
Minimum salinity	23.4 o/oo	24.0 o/oo
Turbidity	High	Low

The Gulf of Panama has a complicated current system (Figure 5.4). The dominant current is the Equatorial Countercurrent, also known as the Colombian current, which follows an east-west direction. This current is stronger in September and October, with a mean speed of 0.3 knots (0.15 cm/s) at 18 m deep, and 0.7 knots (0.35 cm/s) at 36 m deep. Its maximum speed is 1.5 knots (0.8 m/s) between Punta Chame and Taboga (Bennett 1965,

Wyrtki 1965). Tidal fluctuation is about 600 cm, with two daily and predictable tides (Figure 5.5; Glynn, 1982).

Mean annual surface water temperature is 26.3° C, with a minimum of 15.9° C and a maximum of 29.5° C. Mean annual salinity is 30.6 ‰, with a minimum of 23.2 ‰ and a maximum of 34.8 ‰ (D'Croz et al., 1991). Figure 5.8 shows the surface water temperatures, salinity, and phosphate levels at Naos station (Amador Causeway, Panama City).

Although dry and wet seasons in the Pacific are climatically similar to those in the Caribbean, there are marked seasonal changes in the Gulf of Panama. Salinity decreases at the end of the rainy season because of amount of rain emptying into the basin. Water temperatures decrease during the dry season because of upwelling. The thermocline occurs at shallower depths than the Caribbean during the entire year (Glynn, 1982).

Gulf of Panama waters exhibit higher turbidity than the Caribbean because of the upwelling, higher concentrations of organic solids, suspended inorganics, and a greater discharge of freshwater (Batelle, 1970). Figure 5.9 shows the hydrographic system of Panama. The maximum total evaporation in the Gulf is 980 mm/year. Freshwater drainage into the Gulf is 33 x 10^9 m^3/year (Forsbergh, 1963). The Gulf may be divided into seven zones that contribute different amounts to the total volume of freshwater drainage. Figure 5.10 shows the seven areas and general information about them with respect to the Gulf.

The Gulf of Panama has higher phosphorous, calcium, nitrogen, carbon, and oxygen concentrations than in the Caribbean Coast (Batelle, 1970). Rivers contribute 3.3% of the phosphate and 1% of the nitrate and silicate that make up the primary production of the Gulf. The remaining amounts of phosphorous and nitrate come from upwelling (Muschett, 1974). The strongest concentrations are observed in waters close to estuaries dominated by mangrove communities. Mineral concentrations decrease in November with depth, and increase in March, during upwelling (Smayda, 1966; Muschett, 1974).

Upwelling is not observed in the Gulf of Chiriqui, even when both gulfs have the same wind pattern (Smayda, 1966). The high mountains of Chiriqui reduce northern wind speeds, which are responsible for upwelling in the Gulf of Panama. Water temperature, salinity, and nutrient concentrations are different in both gulfs because of upwelling (Kwejcinski & Chial, 1982).

Similar oceanographic comparisons can be made between the Gulf of Panama and the Central and East Pacific, using information from Smayda (1966), Forsberg (1963), Wyrtki (1965), and Bennett (1965).

Upwelling is observed in the Gulf of Panama during the dry season, when strong northerly winds blow between December and April. These winds produce a southerly displacement

of surface water toward the open sea. This water is replaced by water coming from 75 to 150 m deep; colder , rich in oxygen and nutrients (Figure 5.11).

The movement of this water mass during upwelling is described by Smayda (1963) and Forsberg (1963). Upwelling is the major difference between both oceans. It produces a 6-9° C decrease in water temperature, increases salinity from 2 to 6‰, increases phosphate 1.5 μg mol/l, chlorophyll content 2.5 mg/m^3, and phytoplankton from 180 to 270 cell/ml (D'Croz et al., 1991). The greatest carbon concentration is observed between January and April (90 g); the rest of the year another 90 g are fixed, giving a total carbon fixation of 180 g. The photosynthesis-chlorophyll relation is 11 mgC/mg chlorophyll-a/ha. In other areas, the maximum value is 8 mgC/mg chlorophyll-a/ha (Forsberg, 1963). All these data confirm a productivity increase during upwelling.

The Pacific is periodically affected by El Niño. However, strong environmental changes have been observed on both coasts during all El Niño events. It produces an increase in the water temperature and salinity, and a decrease in the nutrients and oxygen concentrations in the Gulf of Panama. These environmental changes occur in the dry season and have repercussions in productivity and fisheries.

A comparison between El Niño of 1957-58 (Bjergens, 1961; 1966) with that of 1982-83 (Glynn, 1990) shows that all environmental parameters exhibited greater variation during the latter episode.

The increase in temperature in the Eastern Pacific produced a massive coral mortality, especially in Costa Rica, Panama, Colombia, and the Galapagos Islands. Even though environmental parameters vary less in the Caribbean, massive coral mortality was observed in Colombia, Panama, Costa Rica, Florida Keys, and the Bahamas. Several authors found a strong association between the high temperatures and the massive coral die-off (Glynn, 1983; Glynn & D'Croz, 1989).

The environmental disturbances from the 1982 El Niño extended through October 1983. At the end of 1983, Eastern Pacific reefs had lost between 70% and 95% of their live coral cover. Local extinction of several species was observed. Recovery of Eastern Pacific reefs might take decades because of four fundamental factors: 1) reef-building species produce few planulae (larvae), 2) populations were reduced or completely destroyed in several areas, 3) corallivores are abundant and are expected to concentrate on living coral, and 4) when bioerosion is high, large extensions of reefs fall (Glynn, 1983).

Environmental perturbations associated with the 1982-83 El Niño event also had negative effects on bird migration, tropical forest productivity and fisheries (Glynn ed., 1990).

In summary, there are marked differences between the physical parameters on both oceans. The most important differences are:

1) Thermocline and high nutrient levels occur at shallow depths in the Eastern Pacific than in the Caribbean Sea.

2) Upwelling areas and cool water currents are widespread in the Eastern Pacific, where there is no upwelling in the Caribbean.

3) Tidal amplitude is large (up to 6 m) and predictable in the Eastern Pacific, while it is small (<0.5 m) and unpredictable in the Caribbean.

4) High turbidity near the coast characterizes the Eastern Pacific, with water clarity increasing on offshore islands. Light penetration is moderate to high in the Caribbean.

5) El Niño produces greater environmental changes and more massive coral mortality in the Eastern Pacific than in the Caribbean.

5.1.5 Water Quality

5.1.5.1 High-Rise Lock Canal

The present analysis is based on water quality samples collected at sites indicated in the Biological Data Background Report and Biological Inventory prepared by UNIPAN-ANCON.

Caribbean Coast

The most outstanding characteristics in the region of the Caribbean coast are the cities of Colon and Arcoiris, which dispose of their wastewaters into the Caribbean. The coliform counts are 2,000/100 ml (Bahia de Manzanillo) and 5-200/100 ml (Bahia Limon). These bays are the Caribbean approach to the existing Canal. The environmental problems in these bays are basically due to pollution by wastewaters from the adjacent communities and the discharge of hydrocarbons. It has been found (CONAMA, Dec. Report, 1988) that, on an annual average, a thousand barrels of oil are discharged into Bahia Limon from the ships that travel through the canal and from runoff. Although Bahia Limon is ten times larger in surface area than the Bahia de Manzanillo, it receives between 20 to 50 times more pollutants.

There is a high level of bacterial pollution in the Puerto Escondido River, between 6,000 to 750,000 FCU/100 ml, increasing to its maximum near the discharge area of the water

treatment plant of Ft. Gulick (Gonzalez et al., 1975). The Bahia Limon forms a closed system with fresh water and wastewater. The water quality is characterized by a decrease in salinity (25-30‰), high turbidity (2-4 NTU), and low transparency. The dissolved oxygen presents an average of 6.0 ppm on the surface and descends to 2.0 ppm in Bahia de Manzanillo (Gonzalez et al., 1975). The average nutrient levels registered at six different locations in the Atlantic region were: Nitrogen = 0.04 ppm; Ammonia Nitrogen = 0.04 ppm and Phosphorus = 0.04 ppm. No pesticide pollution has been detected in this area. No thermal stratification exists between the surface and the bottom.

There is the presence of a thin (5 m) layer of decreased salinity beyond the breakwater at Puerto Cristobal, whose minimal values are 25 to 30‰. Additional impacts to these waters have come from the extensive deforestation that has occurred in the last years at the headwaters of many rivers. The elimination of this vegetation increases the salinity of the coastal habitat, with an unfavorable effect on the water quality. The concentration of nutrients in the surface water decreases, while increasing in deeper zones (due to greater rainfall and runoff, there are lower concentrations of nutrients, while at greater depth, there is a greater influence from oceanic water). The dissolved oxygen concentration in the surface oscillates between 5.7 and 7.0 ppm (87-107% of saturation) while in deeper waters, it is rarely under 5 ppm (76% of saturation).

In the months when there is an increase in the BOD (Biological Oxygen Demand), there is an increase in the total coliform (76-348 NMP/100 ml) and fecal matter (34-97 CFU/100 ml). The presence of volatile organic compounds was not detected, except at station MWQ-15 (near Galeta Island) with 2,000 μg/L of 1,1,1-tricloroethane. The analysis of metals in marine waters indicated normal values for copper, zinc and manganese, with higher values for iron. Clay and limestone prevail in sediments, although the waters near Fort Sherman and the Panama Refinery have a higher sand content. The sandy sediments predominate from the coast to 15.0 m of depth after which muddy sediments increase as depth increases.

The largest known oil spill in a tropical marine ecosystem occurred on April 27, 1986 in the Bahia Las Minas, about 10 km to the east of the North entry of the Panama Canal. This was the result of the failure of a storage tank at the Refinery of Panama. In this accident, 38.3 million liters (240,000 barrels) of crude oil were poured to the sea and spread over sandy beaches, swamps, seagrass beds and coral reefs. According to claims of the Refinery, 9.6 million of liters (60,000 barrels) were recovered, corresponding to 25% of the total spill, but the exact quantity recovered was never determined. It caused a great deal of destruction of Panamanian flora and fauna.

The surviving flora has was forced to change its growth and reproductive habits. Natural habitat was lost, and it is estimated that this deteriorated area will not fully recover for 50 to 70 years. Other smaller spills have occurred around Punta Toro in May 1988, December

1988, and January 1990. Crude oil continues to seep out from the mangrove zone and the land located under the Refinery. This occurs mostly after torrential rains or when there are large storm surges. The Panama Canal Commission maintains a record of the spills that occur within the operational limits of the Canal. These records date from 1971 through 1979 and since then, have been maintained in cooperation with the National Port Authority (CONAMA, 1988).

Lake Gatun

Lake Gatun (431 km^2) is one of the largest artificial lakes in the world. The waters of the deepest part of the lake, north of Barro Colorado Island, have excellent physical quality and chemistry. The temperature varies between 27.5° C and 29.5° C. The water has a low alkalinity (<40 mg/L).

Northerly winds prevail in the northern portion of Lake Gatun, causing turbulence and large waves, while in the northeastern portions of the lake, the winds come generally from the north, and do not cause much turbulence. Prevailing winds in the western portions of the Lake (near Escobal) are from the southeast and there are frequent rains during the rainy season. The waters near Escobal have an average depth of 24 m, which drops to 5 m near the shoreline of Lagarterita. Northerly winds prevail in the southwestern portions of Lake Gatun (area of the rivers Cirito and Ciri), but there is no turbulence in the waters, as this area is surrounded by hills. During the dry season, strong winds prevail that produce turbulence and surges, affecting water quality.

The analysis of sediments indicate that decomposed organic material still exists on the lake bottom. Organic brush and undergrowth also accumulates on the shores and in shallow zones. These decomposing dead plants have a high dissolved oxygen consumption, which increases the acidity of the water. Aquatic undergrowth also occurs in the tributary rivers. In the areas of Barro Colorado, Barbacoa, the Bohio Peninsula, and Aojeta, Frijoles and Gigante Bays, there are aquatic plants and remaining tree trunks that lessen water quality as they decompose. Around Barbacoa Island, the waters have more suspended solids and are higher in turbidity, due to current dredging operations and ship movements. Sediments from dredging operations in the Gaillard Cut are deposited east of Barro Colorado Island.

The area of La Laguna varies in depth between 3.5 m and 12 m in the access channel and between 12 and 15 m in the remaining areas. The waters are clear. The waters of the lake are affected by the presence of aquatic plants, such as *Hydrilla sp.*, which maintains a dense foliage to depths up to 6 m, and has been treated with copper-based herbicides, which alters the water quality. Copper levels in the area of the Rio Chagres and in Gamboa Reach are higher than those in Lake Gatun, probably due to the copper sulfate used in weed control (Analysis of Bottom Sediments, Canal Deepening Project, 1974). The highest copper

concentrations were recorded from stations FWQ-7, FWQ-8 and FWQ-10, located in the town of Darien, near La Laguna, and at the intersection of Gatun and Piedra Blanca.

Alajuela Lake is one of the few areas associated with the Panama Canal aquatic system that is thermally stratified. Here, the Indio (Viejo), Pequeni and Chagres Rivers introduce cold (under 25° C), well-oxygenated, water into the Lake, to an approximate depth of 6-7 m, affecting the hipolimnion. During the rainy season, thermal stratification is even more pronounced, with differences up to 4° C between the surface and the bottom.

Deforestation of impoundment areas, uncontrolled agriculture, cattle grazing, road construction, and frequent burning of vegetation have all affected the water quality of the headwaters of Lake Gatun. All this has caused a chain reaction, which has ultimately led to the disappearance of the natural habitat with the consequent reduction of water storage and increase in the content of nutrients in the lake (Gonzalez et al., 1975). The Lake has begun the process of eutrophication, during which the bulk of the water has "aged" due to the increase in the growth of vegetation (Bush et al., 1990).

Gaillard Cut

The soils in the region of the Gaillard Cut, between Gamboa and Contractor's Hill, including Culebra Reach, Empire Reach, La Cascada Reach and Bas Bishop Reach, are muddy and acidic with a high mineral content. The waters that flow through the Gaillard Cut flow southward from the mountainous area within the limits of the study area. Due low elevation differences in this region, the waters move slowly, increasing somewhat during the rainy season. The Gaillard Cut area is periodically dredged, which increases the waters' turbidity and the concentration of suspended solids. Water quality here is also influenced by wave action, runoff, wastewater, ship propellers, and the shallowness of the waters.

The flows of the Chagres River can be diverted to the west, into Lake Gatun, or to the southeast (Pedro Miguel Locks), depending on the needs of ship traffic and other activities. This causes that great variability in water quality in the Gaillard Cut. The waters of the Canal in this area remain turbid all year round, with low levels of dissolved oxygen and sufficient nutrients to promote proliferation of the aquatic plants. It also receives chemical and biological wastewater from the Chilibre River, which contains high levels of coliform bacteria (Gonzalez et al., 1975).

The area of the Gaillard Cut near the drainage of Summit shows BOD levels under 4.0 ppm. The waters of Gaillard Cut generally have low levels of alkalinity, are soft in nature and do not contain heavy metals or pesticides; the chloride level is maintained between 5-7 ppm and the temperature averages 28.3 ° C during the dry or rainy season. The area of Gaillard Cut has other tributaries, in addition to the River Chagres, including the Mandinga, Bishop, Masambi, Sardinilla, Camacho and Quebrada del Puente Rivers, among others

Miraflores

The region of Miraflores extends 8 km, from Contractor's Hill to the Miraflores Locks. The water quality of Lake Miraflores depends on the Paraiso and Pedro Miguel drainage which flows into the lake near the Pedro Miguel Locks, and also into the waters of Gaillard Cut. In addition, Miraflores Lake receives leachate from the Red Tank landfill. and contains fecal coliform levels of 1000 CFU/100 ml. The coliform levels in the center of the Lake decrease to 200 CFU/100 ml, except for the waters in Caimitillo - Camaron branches, where levels are under 200 CFU/100 ml (Gonzalez et al., 1975). The temperature averages between 27.5° C and 28.9° C. The dissolved oxygen varies between 6.5 ppm and 5.2 ppm through the year.

The results of nutrient analyses indicate that the lake is in a state of meso-eutrophication, the pH oscillates between 6.6 and 7.0. The Pedro Miguel Locks, which supply water low in chlorides (<8 ppm) to Gaillard Cut, tend to dilute the chloride concentrations in the Lake. The brackish water from the Miraflores Locks lies on the bottom of the Lake as a dense layer and eventually mixes with surficial waters. The analyses of the sediments indicate that a high organic matter content. The levels of zinc, lead and manganese in the sediments were 97, 34 and 1100 ppm, respectively.

Pacific Coast

The region toward the Pacific from Miraflores is 19.2 km in length. About 34 million tons of untreated sewage (D'Croz, 1988), products of domestic, industrial and commercial activities of the city of Panama, are discarded into the sea annually. These wastes arrive directly or indirectly through some 20 existing drainages and through the highly contaminated Matasnillo, Juan Diaz and Matias Hernandez Rivers. Marine water quality in this area is also affected by Canal traffic and activities related to the ports. This pollution reduces the dissolved oxygen levels in some parts of the Bay.

The Gulf of Panama is crossed east to west by the Equatorial or Colombian Countercurrent that is stronger in September and October, when it averages 0.3 knots (0.15 cm/s) to 18 m of depth and 0.7 knots (0.35 cm/s) to 36 m of depth, reaching a maximum speed of 1.5 knots (0.8 m/s) between Punta Chame and Taboga. The average fluctuation of the tides is of 600 cm with a cycle of 2 daily tides. The annual temperature of the water varies between 18.9 and 29.5° C, with an average of 26.3° C. There is no thermal stratification. The annual average salinity is of 30.6‰, with the lowest being 23.2‰ (D'Croz et al., 1991).

Few differences exist between the salinity on the surface and that of the bottom (< 1.5‰). Salinity decreases around the end of the rainy season, due to upwelling and rainfall and temperature decreases during the dry season. This contributes to greater turbidity in the

Pacific waters than in the Atlantic, as well as the greater concentration of organic and inorganic solids.

All stations sampled for the Biological Inventory indicated high levels of coliform (between 20 and 437 NMP/100 ml) and fecal coliform (between 4 and 231 NMP/100 ml), above the international criteria for seawater (1,000 total coliform and 500 fecal coliform per 100 ml in waters used for recreation and of 10,000 total coliform and 5,000 fecal coliform for waters supporting aquatic life; Cabrera, 1993). Fecal coliform in the Bay of Panama reach levels of 160,000 NMP/100 ml, which drop off to the west of the Bay from dilution by tides and coastal rivers (D'Croz, 1988). The concentrations of coliform generally drop as one moves away from the coast.

The water is relatively clear of bacteria near the Panamanian coast, in the area of Old Panama, where it receives the first significant load of wastewater from Panama City. From here, the currents and tidal action transport the bacteria to the west, toward Punta Paitilla (the concentration drops off due to tidal action the natural death of the bacteria). Contaminated waters originating in the Rio Matasnillo and Dock N° 1 arrive in the Bay are dragged by the currents, proceeding west to where the flow turns toward the southeast. The concentrations of coliform increase as the current moves through the interior of the Bay of Panama and again are dispersed by Pacific tides and reduced by natural mortality. The residual pollution continues in the Colombian Current westward to Flamenco Island, where they are diluted as the distance from the coast increases (IDAAN MPPE Consortium TECNIPAN-HAZANSAW).

Wastewater pollution reduces dissolved oxygen levels in some sections of the Bay and increases concentrations of nutrients and oils and lubricants in certain areas. High nitrogen and phosphorus concentrations have been reported in the Bay near Panama City, and drops off approximately 5 km offshore. Values oscillate between more than 0.30 mg/L (inshore) to 0.21 mg/L (offshore) for nitrogen, and from less than 2.0 mg/L (inshore) to more than 4.0 mg/L (offshore) for dissolved oxygen (D'Croz, 1988). The greatest concentration of dissolved hydrocarbons was registered at the Port of Balboa (23-87 μg/L). Hydrocarbon concentrations in the Pacific are generally >10 μg/L and occasionally exceed 20 μg/L.

In summary, the Pacific marine waters at stations MWQ-1, MWQ-2, MWQ-6, MWQ-8 and MWQ-10, show a decrease in salinity (25-30‰), high turbidity (4-9 NTU), low transparency, relatively high BOD (3 to 5 ppm) and levels of total coliform (100-437 NMP/100 ml). The stations MWQ-6, MWQ-8 and MWQ-10 probably reflect greater water quality impacts from the ports of Vacamonte and Caimito.

5.1.5.2 Sea-Level Canal

The waters of the Atlantic coast follow well-defined current patterns, determined by the two seasons within a great cyclonic gyre in the southern Caribbean. In spite of the fact that this gyre contains lower salinities due to a large influx of freshwater from rivers and high rainfall, the average temperature and salinity in the Atlantic off Panama (28° C, 32.5‰) is higher than the temperature and salinity in the Pacific (27° C and 31‰). The Atlantic region extends 4.4 km from the Caribbean to the mouth of Rio Lagarto.

The Queblado region extends 16.5 Km, from the outlet of the Lagarto River to Caño Las Cruces on the shores of Lake Gatun. Although there are no reports on water quality in this area, rivers such as the Caño Quebrado and Rio Arrieros, and creeks such as the Lagarterito and La Chunga, among others, are adjacent to the alignment of the proposed Sea-Level Canal alternative.

The region of the Lake Gatun from Caño Las Cruces to the shore of Lake up to the mouth the Rio Pescado is an extension of 21 Km. Its description is similar to the previously described area for the High-Lock Canal alternative. Residents of the three towns in this region (La Laguna, Tinajones and Pueblo Nuevo) pursue agricultural activities, deforestation, and frequent burning of vegetation that aggravate erosion and runoff problems. This results in the disappearance of the natural habitat (plants and animals that depend on the soil), a consequent reduction in water storage, increased nutrients and organic materials in the lake waters from erosion (Gonzalez et al., 1975).

The area of the Continental Divide extends 22.5 km, from the mouth of the Rio Pescado up to the mouth of the Rio Caimito. There were no water quality sampling stations in this zone.

The Pacific zone (Zone V) extends 25.1 km, from the mouth of the Rio Caimito to the Pacific Ocean, and includes marine sampling stations at MWQ-1 through MWQ-10. Zone V has similar characteristics to the Pacific region of the High-Lock Canal alternative. The results obtained in the sampling stations from the Bay and the Gulf of Panama can be considered valid for this region.

5.2 BIOLOGICAL ENVIRONMENT

In order to evaluate the potential environmental impacts the proposed alternatives may cause to the biological environment, it was necessary to identify the various types of communities that may occur here. Using the data presented in the three available quarterly reports from UNIPAN-ANCON, together with the information accessible from additional existing literature, the review of the available aerial photographs and the personal experience of the Team members, the biological communities were characterized.

These characterizations are presented in detail in Appendix A due to their magnitude. Additional special considerations were also evaluated. These includes a review of existing Panamanian environmental regulation, protected natural areas (such as National Parks and Barro Colorado Island), protected species (by Panamanian laws or international treaties) and fauna of medical and veterinary interest (disease carrying insects and hosts).

Summarized descriptions of the biological communities are presented in this section. The biological communities described in this section are assemblages of flora and fauna with specific associations and characterized on the basis of a combination of biotic and abiotic factors. Abiotic factors can include depth, substrate type, temperature, and flow rate, in the case of aquatic communities; and soils, humidity, and climatic conditions, in the case of terrestrial communities.

Biological communities can cover extensive areas, or can be limited to small, discrete locations. For the purposes of this report, the team identified and described the principal biological communities within the study area. Using the materials described above, a number of general community types were identified. These include: Pelagic, Subtidal, Intertidal (which include Rocky Shores, Sandy Beaches and Mud Flats), Coral Reefs, Seagrasses, Mangroves, Lakes and Rivers, Freshwater Wetlands, Forests (mature & successional), Open Areas (grassland & pastures) and Agricultural communities.

5.2.1 Pelagic

The tropical pelagic includes the oceanic marine environment that overlies the continental shelf and abyssal regions. The relationship between coastal upwelling and the productivity of this area has been proven. This community is characterized by free ranging fauna and a floating, planktonic flora. Important commercial fisheries are found in this community.

5.2.2 Subtidal

The continental subtidal zone is located from the low tide line down to approximately 200 m depth (the edge of the continental shelf). The largest part of this zone is composed of soft bottoms (sand and mud) and in some occasions, by hard substrates (Fig. Nº 5.2.2-1). On the Caribbean side north of the entry to the Canal, the continental shelf reaches 200 meters at a distance of 20 km from the coast. In the Pacific Ocean, the platform reaches 200 meters at a distance of 170 km from the south entry of the Canal (Battelle, 1970). Thus, there is a more extensive subtidal zone in the Pacific than in the Caribbean. In these shallow waters, the interaction of waves and upwelling creates turbulence. The type of bottom is important in the establishment of biological communities.

The hard-bottom communities in the Caribbean have very little in common with those in the Pacific. The former are essentially coral in origin and are associated with coral reefs

(e.g., the echinoderm communities). A similar community is not found in the Pacific, but may exist in the area of Las Perlas Islands. Throughout the Gulf of Panama in the area between Punta Mala (Los Santos province) and the Gulf of San Miguel (Darien province), there are extensive zones of sandy sediments where the predominant organisms are burrowing fauna. The productive soft-bottom communities in the Pacific have no comparable counterparts in the Caribbean.

5.2.3 Intertidal

The intertidal zone is characterized by being partially exposed during the normal tidal cycle. For the purposes of this report, three major subdivisions have been identified. These depend primarily on the energy provided by wave action. Due to the energy input, there is a segregation of sedimentary materials. In high energy environments, all fine particles are suspended and are washed away. In low energy environments, these may be deposited and form part of the substrate. High energy environments have been identified as rocky shores. Low energy environments are identified as mudflats. Intermediate energy conditions are classified as sandy beaches.

5.2.3.1 Rocky Shores

Intertidal rocky shores are very different on opposite sides of the Isthmus of Panama. Pacific rocky shores present a typical vertical zonation for this substrate type, while Caribbean habitats are represented by fossil coralline boulders and exposed shores. Pacific rocky shores support a higher species diversity and density of sessile biota that reflect a larger number of microhabitats for a diverse microbiota (Glynn 1972). Caribbean rocky shores are composed of boulders and exposed shores of fossil coral.

5.2.3.2 Sandy Beaches

Sandy beaches are dynamic environments where physical habitat structure is determined by the basic elements of sand and water. Sandy beaches are exposed to two types of waves, tidal and surface gravity. Tidal waves produce an intertidal zone that dries for several hours a day. Surface gravity waves induce secondary currents, shoaling and breaking, that transport sand along the beach (Brown & McLachlan, 1990). Less complex than other intertidal tropical habitats, sandy beaches exhibit less biological diversity than intertidal rocky shores, mudflats, mangrove roots or coral reefs.

5.2.3.3 Mudflats

Whereas sharp boundaries exist between rocky shores and sandy shores, differentiating between muddy and sandy beaches is not as straightforward. Often, it is not possible to distinguish the two beach types. In lower energy sites, beaches become finer grained and

accumulate larger amounts of organic matter, thus becoming more muddy. Mudflats and sandy beaches are the extremes of a continuum.

5.2.4 Coral reefs

Coral reefs are the most complex tropical coastal ecosystems and exhibit the highest species diversity and the strongest differences between both oceans. They also present a very high productivity. The are characterized by the presence of coral reef constructing organisms, such as coralline algae and stony corals.

5.2.5 Seagrasses

Seagrasses are characteristic of shallow coastal waters in temperate and tropical zones. In tropical zones, they are distributed along the Gulf of Mexico and the Caribbean Sea, where there are vast seagrass beds associated with various species of algae. These communities are characterized by the presence of specific plant species, which develop in shallow waters. Certain marine species spend much of their developmental stages in these areas.

5.2.6 Mangroves

Mangrove forest, mangrove swamp, and mangal are general terms used to describe a variety of tropical inshore communities dominated by several species of trees or shrubs that have the ability to grow in saltwater. Mangroves make up the most conspicuous vegetation on Central American tropical coasts and are possibly of greatest ecological importance in coastal communities. Approximately 1,750 hectares of mangroves occur in the study area.

Mangroves have a net import of nutrients, freshwater, and sediments from terrestrial environments and a net outflow of organic matter and water to marine or estuarine waters. Numerous marine organisms pass through their juvenile stages either in coastal fringe mangroves, estuaries or lagoons. Mangroves offer abundant food, guaranteeing rapid growth, and vital protection from predators.

5.2.7 Lakes and Rivers

In Central America the dominant lacustrine environments are not in discrete lake basins, but are rather those poorly defined lakes which are part of rivers. The Lake Gatun/River Chagres basin illustrates a dominant form of lacustrine water body which typifies the lowlands of tropical America.

5.2.8 Freshwater Wetlands

Freshwater wetlands represent the transition from terrestrial to aquatic habitats, and occur most extensively in the study area where streams enter Lake Gatun, and around its shores. They are normally characterized by hydromorphic soils, but a variety of water regimes are encountered. Most of the wetland areas experience periodic inundation, but free-draining levees and permanently wet marshes also occur. Soil fertility is variable, depending on local sediment characteristics. Although complex vegetation patterns may exist within wetlands, individual wetland formations frequently display similar physiognomy and composition over large areas. Periodically flooded, herbaceous wetlands are scattered along freshwater streams and lakes in the study area.

5.2.9 Tropical Forest Ecosystems

The majority of the forests in the study area fall within the tropical Moist Forest life zone (Holdridge, 1967), with small areas of Premontane Wet Forest and Premontane Moist Forest in the northwest corner of the study area, as well as Tropical Dry Forest on the islands of Taboga and Uraba, and in limited areas near the Pacific coast mainland.

5.2.9.1 Mature and Old Successional Forests

Mature and old successional forests are tall and dense, with a large phytomass and heterogenous composition. Most trees are evergreen, although some deciduous species occur. The canopy of mature and old successional forests is continuous and commonly reaches 25-35 m in height, with emergent trees rising to 45 m or more. These forests are dense, frequently containing 160-170 trees/ha with a circumference of 60 cm or more (Foster and Brokaw, 1982). Although the forest margin, like the canopy above, has a luxuriant and impenetrable aspect, the interior of a mature or old successional forest is relatively devoid of understory. Straight trunks ascend, often covered with lianas, but there is limited growth in the shaded conditions at ground level. The ground surface is covered by a layer of leaf litter and other debris, and root systems are mainly superficial.

5.2.9.2 Young Successional Forest

Following the disturbance of the vegetation, a successional process begins which typically results, after many decades, in a complex, mature forest. While the vegetation that replaces the original forest depends to some extent on the nature of the perturbation, in most cases a successional sequence occurs which is typical throughout Neotropical moist forests

5.2.10 Open Areas (Grasslands & Pastures)

These habitats are characterized as open, grassy areas. These areas are found most extensively on the Pacific slope, but in recent years, large grassy areas are being created by forest clearing on the Caribbean slope as well. While some areas may have a long history as grasslands, this association usually occurs after an area is disturbed, either by forest clearing, tilling or cultivating the soil (Sarmiento and Monasterio, 1975). Under natural conditions, this type of vegetation (if present at all) is usually transitory, being replaced by early successional forest. With the addition of cattle grazing and non-native grasses, succession is slowed, and in some cases, e.g. if the soil has been seriously degraded, grasslands may persist for a longer period of time.

5.2.11 Agricultural Ecosystems

Most agricultural holdings in the study area consist of small farms (5-10 hectares). The food items produced on these farms are diverse, as the farmers frequently produce a significant percentage of the food they consume. The plantation agro-ecosystem occurs in the study area primarily in the coastal area between the Rio Indio and Rio Lagarto, where African oil palms (*Elaeis guineensis*) are grown. The plantation ecosystem frequently require a great deal of pesticide to keep them producing, presumably in accord with the well-known speculations about monoculture susceptibility in the tropics. Since most plantations are monocultures, they usually have a relatively uniform physical environment in their understory, which may favor certain pest species.

5.3 BIOLOGICAL DIVERSITY

The concept of biological diversity has become recognized as an important guide to the existing status of a habitat, community or region.

5.3.1 Introduction to Biological Diversity

Biological diversity has been defined as the variety and variability of life and its processes in an area (U.S. Congress, 1987). The biological diversity of an ecosystem can easily encompass thousands of species, their genetic composition, the assemblages of plants and animals that are recognized as distinct communities, and countless evolutionary and ecological processes and pathways through which species interact. Plant and animal species do not exist independently, but are instead a part of a multi-scaled web of associations encompassing several levels - from molecular structures to entire landscapes. It is important to comprehend each level, and its relationship to others, in order to understand biodiversity and its implications in light of development.

Species Diversity: Species Diversity refers to the number or variety of plant and animal species and their abundance. The term includes both the number of species and the evenness of abundances among species. The number of species in a region (i.e. its species "richness") is on measurement used. However a more precise measurement, "taxonomic diversity", also considers the relationship of species to each other. For example, an island with two species of birds and one species of lizard has a greater taxonomic diversity than an island with three species of birds, but no lizards (World Resource Institute, 1992). A community with a fairly even distribution of individuals among species is considered more diverse than another community with an equal number of species, some of which are very common and others rare. Some species are particularly important to biodiversity because many other species depend on them directly or indirectly (= keystone species). Loss of these keystone species that play pivotal ecological roles in a community may change the nature of a natural system considerably and result in many secondary extinctions.

Ecosystem Diversity: Ecosystem Diversity is hard to define because of the difficulty in delineating the limits of an ecosystem, but must relate to geographically mappable units composed of commonly associated flora and fauna. In the context of this project, we have distinguished ecosystems by assemblages of vegetation types, also referred to as communities or habitats. These ecosystems or habitats are defined according to the species that use them and include both physical substrates and successional stages of plant communities. Because an ecosystem encompasses many species and their inherent genetic variability, loss of ecosystem diversity may result in loss of diversity at other levels as well. Therefore protecting ecosystems low in species richness may be as important as protecting species-rich systems.

Ecological and evolutionary processes: affecting biological diversity include interactions within and between species (e.g. predation, competition, pollination, parasitism), natural disturbances (fire, drought, storms), and nutrient cycles (weathering, decay, nutrient uptake by plants). Evolutionary processes such as mutation, gene flow, geographic isolation, and hybridization must be maintained at rates characteristic of the natural ecological system to preserve existing and future biological diversity.

5.3.2 Reduction or Loss of Biological Diversity

Tropical forests, by nature of their composition and dynamics, are particularly vulnerable to the loss of, damage to, or fragmentation of habitat resulting from human disturbance. Not only are forests exceptionally diverse and thus prone to multiple extinctions, but also many forest species are specialized and inter-related and are intolerant of general disturbance. With the loss or alteration of a habitat, its capacity to sustain animal or plant populations is modified. Species dependent on intact forest are the first affected, either

from a direct loss of individuals or of essential resources required for the maintenance of local populations.

Even if some members of affected populations survive by moving to adjacent intact forest, they face increased competition with other conspecifics. Consequently, they may suffer a loss of fitness or early mortality from an inability to garner sufficient resources to sustain reproduction. As the sizes of local populations decline, demographic factors that affect small populations also become more important. Population size will tend to fluctuate more widely due to random processes (e.g. climatic variation, disease, floods, storms, drought, fire) that influence natural birth and death rates.

5.3.2.1 Forest Fragmentation

A conceptual problem is how to distinguish between habitat loss and habitat fragmentation, as the latter also gives rise to the former. Habitat loss can in some cases, reduce the amount of habitat without causing fragmentation, but this is rarely the case. The primary impact of habitat fragmentation is through loss of habitat continuity (i.e. insularization). This is because it is possible to reduce habitat size without disturbing its continuity; that is, habitat loss *per se*. Nevertheless, habitat loss is an important by-product of fragmentation and vice-versa.

Deforestation inevitably results in fragmentation of forests that are already disappearing in the face of regional development and colonization. Consequently, islands of forest are left amidst a "sea" of nonforest habitat. A fragment is defined as a detached, isolated, or incomplete part broken away from a whole. Habitat fragmentation is, therefore, the sub-division of a certain habitat into several isolated patches. Scale is crucial to the issue of fragmentation. A fragment of a given size may provide perfectly well for one species and be wholly insufficient for another. Current evidence suggests that species with the largest spatial requirements play indispensable roles in the long-term maintenance of diversity.

There are macroscopic animals whose spatial requirements vary by orders of magnitude. Some invertebrates are capable of carrying out their entire life cycles within the space occupied by one tree, while others involved in complex dependencies and mutualisms might need as much as 10 ha to meet all their requirements on a long-term basis. On the other end of the spectrum are highly mobile bird and mammals, that function as top predators or seed dispersers, that need thousands of hectares to maintain breeding populations, but whose loss from smaller patches may have serious consequences for the persistence of many other species with far more modest spatial requirements.

Habitat fragmentation leads, over a range of time scales, to a variety of effects, both physical and biotic. Migration and dispersal patterns are disrupted, population sizes and gene pools are reduced, nutrient and energy inputs and outputs can be altered by the

modification of adjacent areas, exotic species gain access to a previously insulated habitat, the creation of edges modifies the physical microenvironment, and this in turn can lead to accelerated tree mortality and the penetration of nonforest species into forest habitat (Lovejoy et al., 1986).

Habitat fragmentation is a complex process involving many interrelated components, including fragment size, habitat heterogeneity (e.g. microclimate, vegetation structure, etc.) within fragments, surrounding habitat (mosaic) and edge effects. For the following discussion, habitat fragmentation will be used as a collective term to describe a wide range of habitat alterations, all of which are consequences of the initial sub-division of a continuous habitat (Figure 5.3-1; Rolstad, 1991).

The biological and physical effects of forest fragmentation are still poorly understood. Certain changes are easy to predict, at least qualitatively. Population sizes will be reduced, which may have deleterious genetic consequences. Because most species' distributions are not homogenous, some species will be absent from certain fragments simply because they were not in the patches of forest before the fragments were isolated. Species requiring large home ranges (e.g. spider monkeys, large predators) will not survive in small fragments. Microclimate may change within fragments, especially along the edges. Local macroclimatic patterns may also be altered.

We are only beginning to learn how such changes affect ecosystem function and structure. For example, as Terborgh (1992) has pointed out, the loss of large predators may have a destabilizing effect on populations of seed eaters, which in turn may affect the composition of tree species in the forest.

5.3.2.2 Implications of Habitat Fragmentation

Understanding the implications of forest fragmentation is essential to land use planning if development is to proceed with minimal disturbance to the natural ecosystem. Questions that need to be addressed include the following:

> **How great a distance of separation from continuous forest effectively isolates a forest fragment?** Studies have indicated that a break of as little as 80 m is a strong barrier to movement to an isolated forest fragment by some insects and mammals and the vast majority of understory birds. When interpreting the consequences of forest fragmentation, it becomes crucial to take into account the scale. On a local scale, individuals and the minimum area requirement for territories is the key issue. On a regional scale, a continuous population may retreat to less fragmented parts of a region and become patchily distributed. At a certain point, movement between populations in fragments is prevented by one or more hostile intervening habitats,

which in turn results in complete loss and isolation of local populations. If the isolating process continues, the population could become extinct.

What is the effect of fragment size on the degree to which the forest community is preserved? The MacArthur and Wilson model of Island Biogeography (1963) predicts that small forest remnants will support smaller populations and fewer species than larger ones. Studies of insects, birds, and mammals in forest reserves of varying sizes indicate that the number of species, and in some cases population sizes, in these groups varies with the size of the forest fragment. As forest is felled around a remnant patch, individual animal numbers and activity within the newly isolated forest fragments may increase for a period of time before population sizes drop to below pre-isolation values. The rate and extent of this faunal collapse seems to be greater in smaller forest remnants than in larger ones and the extent of alteration of faunal community structure appears to be more drastic the smaller the forest fragment.

What is the role of edge effects? By definition, the periphery of a forest fragment is an edge between forest and nonforest habitat. Changes that occur along these edges may affect both form and function of the isolated ecosystem. Increased insolation and wind penetration along a newly formed forest edge can be expected to change temperature and relative humidity in the remnant forest patch and structural damage is likely to occur when storms buffet trees along a forest edge. Changes in vegetation structure caused by edge-related tree mortality are likely the major cause of increasing complexity of microenvironmental climatic gradients in remnant forest patches.

How important is the vegetation surrounding a forest fragment? Vegetation surrounding a forest fragment is dynamic, changing with natural succession and maintenance of agricultural lands, and is not completely hospitable to many of the organisms in the remnant forest patch. Whereas community structure of primates, understory birds, and some insects seems strongly affected by patch size, small mobile mammals and some butterflies are apparently more sensitive to the vegetation structure around the forest fragments than to fragment size. Where population sizes and species numbers of understory birds tends to decline as fragment size decreases, species richness, biomass, and abundance of most small mammal species tend to be greater in smaller patches. In addition, the communities in fragments show a shift in the vertical distribution of mammalian biomass. In continuous forest, arboreal biomass tends to be slightly greater than terrestrial, whereas the reverse is true in fragments, mainly due to the development of a denser understory component at or near the edges of the fragment. Insect abundance also tends to be greater in the understory of forest fragments, where foliage density is higher than in continuous forest.

What indirect effects of fragmentation can affect forest populations? Indirect effects refer to the propagation of perturbations through one or more trophic levels in an ecosystem, so that effects are felt in organisms that may seem far removed, both ecologically and taxonomically, from the subjects of the perturbation. The role of predators in regulating relative and absolute abundances of their prey species is an elementary type of indirect effect. More recently, ecologists have discovered a process called "apparent competition", in which an inverse density relationship between two prey species is mediated, not by the exploitation of a common pool of resources, but by the intervention of a selective predator (Levine, 1976; Holt, 1977). Brown et al. (1986) found that, while species may compete on a year-to-year basis through their sharing of a common pool of resources, they engage over the longer term in a type of "indirect mutualism", where a balance in the species' respective resource requirements is maintained to mutually assure each other's food supply.

In summary then, it becomes clear that distortions of any link in the chain of interaction in ecosystems such as tropical forests will induce changes in the remaining links. So long as perturbations are mild and of short duration, the system can probably recover, although the time needed for recovery may have to be measured in tree generations. However, when there is a complete loss of any one of the links, the whole system could fall out of balance with consequent repercussions for both plant and animal communities. By far the most vulnerable link is that represented by top carnivores. Where these have been extirpated, it may be impractical to reintroduce them, and once they are gone, it may be impossible to reverse the chain reaction leading to loss of diversity.

5.4 SPECIAL ENVIRONMENTAL ISSUES

Several environmental issues require special consideration in the final selection of the alternatives to the Panama Canal. These include existing environmental regulations, protected natural areas, protected species, and fauna of special medical or veterinary concern.

5.4.1 Environmental Regulations

This section discusses the specific environmental regulations that have been implemented to promote the conservation and protection of renewable natural resources and the environment in Panama.

The Republic of Panama lacks an organized framework for its environmental legislation, since it has been dispersed throughout various governmental agencies which has reduced their effectiveness in enforcing the legislation. The existing Political Constitution of 1972, revised in 1983, is the primary basis for Panamanian environmental regulations.

The Political Constitution defines the Ecological Jurisdictions in Panama and establishes the bases for environmental policy in articles 114 to 117. These articles indicate that environmental protection and the maintenance of an ecological balance in the country is the obligation of the State. It grants the State powers for regulation, inspection, and timely application of environmental protection measures and the rational use of the terrestrial, riverine, and marine fauna, as well as defining the use of forests, lands, and waters. Additionally, it indicates that the Law will regulate the utilization of renewable natural resources.

Chapter 8 of the Panamanian Constitution refers specifically to agriculture, and Article 118 indicates that "The State will pay special attention to the integral development of the agricultural sector, encourage the optimum utilization of the soil, will watch over its rational distribution and its adequate utilization and conservation."

The primary environmental measures that regulate damage caused to the environment on private property are found in the Civil Code. Volume III of the Administrative Code indicates that rural and urban policemen are empowered to enforce environmental policies. The Sanitation Code establishes important procedures related to public health and hygiene, sanitation oversight, and preventive and therapeutic medicine. The Fiscal Code provides procedures for regulating national assets, especially with respect to natural resources of the State.

The Mining Code regulates the conservation and utilization of mining resources. The Agrarian Code regulates the conservation and rational use of renewable natural resources. The Work Code contains environmental procedures for specific public health and safety matters. In addition, there are special laws that regulate the use of renewable natural resources, and other decrees, resolutions, regulatory texts and procedures, which originate from contracts with the State, that specify other significant environmental procedures.

The legal provisions relating to the use, protection, and conservation of renewable natural resources (soil, water, flora, and fauna) are listed below:

Soils

Soils are least protected under Panamanian regulations. For example, there is no mention of the impact of industrial development on soils. In general, existing panamanian regulations concerning soils are primarily based on their use, conservation, protection and administration.

- Law № 78 (1941) vests a Municipality with the authority to regulate the use of soils, according to the character of the surrounding urbanization. In the

same fashion, it is the responsibility of the Municipality to provide authorization for the extraction of sand and stone from river beds.

- Law № 71 (1973) regulates the use of areas contiguous with highways and roads. No mention is made in this Law in reference to the potential ecological hazards may result from various uses of soils, nor are measures presented to prevent any such effects.

- The Agrarian Code, created by Law № 37 (September 21, 1962) provides most of the relevant regulations for the development and protection of soils.

Waters

Constitutional procedures established in articles 148, 226, 227 and 228 relate to the protection of water resources. Additional existing regulations occur in:

- Articles 535, 536 and 544 of the Civil Code.

- Law № 45 (January 30, 1963) declares the hydrologic basins of the Indio, Chagres, Pequeni, Aguas Claras, Gatun, and Agua Sucia Rivers as national resource areas and gives the Institute of Hydraulic Resources and Electrification authorization to perform studies for the installation of hydro-electrical power plants and irrigation systems in these areas (Official Gazette of February 5, 1963, № 14, 810, p7.)

- Decree-Law № 35 (September 22, 1966) regulates the use of waters and created the National Water Commission (Official Gazette of October 14, 1966, № 15, 725, p. 1).

- Law № 31 (February 2, 1967), extends the Republic of Panama's Territorial Sea to a distance of 200 miles off the coast (Official Gazette of February 14, 1967, № 15, 802, p. 1).

- Cabinet decree № 235 (May 8, 1969) replaced old Law № 31 (January 31, 1961), which concerns the organization of the Institute of Hydraulic Resources and Electrification.
- Decree № 84 (May 8, 1972) declares the area of High Darien as an erosion control sector to preserve the hydrographic basins of large rivers in that region.

- Decree № 55 (June 13, 1973) includes additional regulations for the use of waters (Official Gazette of June 7, 1974, № 17, 610, pp. 1-6).

- Executive Decree № 70 (July, 1973) establishes permits and grants for the use of water and creates an Advisory Council on Hydraulic Resources (Official Gazette September 11, 1973, № 17, 429, p. 1-5).

- Law № 18 (November 10, 1977) addresses the Treaty between Republics of Colombia and Panama, delimiting marine areas and related matters (Official Gazette of June 30, 1978, № 18, 610, p1 and 2).

Flora

The principal factors and criteria used to classify production forests, protected forests, or other special forest lands, are defined in Decree-Law № 39 (1966). This Decree provides a legal framework for all forests and existing forested lands in the country (Article 3). It declares the forest lands of the state to be inalienable resources (Art. 14). The legislation also designates INRENARE as responsible for the administration of this natural resource. Article 64 establishes 20 functions of the Panamanian Forest Service, including:

- the formulation of forestry policy,
- the conduct of forest inventories,
- the investigation of forest resource exploitation,
- the performance of technical studies,
- the creation of forestry stations and forest nurseries,
- the recovery of eroded lands,
- public education,
- the creation of forest colonies, and
- the encouragement of the creation of communal forests.

Other laws and regulations pertaining to forests and their resources include:

- The Agrarian Code, approved as Law № 37 (September 21, 1962) states that it is responsibility of the State to preserve, improve and to revegetate all the forests, control erosion, and increase forestry resources.

- The Fiscal Code of 1956 establishes grants for the initial development of forests and describes the procedures to be followed for obtaining such grants.

- Decree - Law № 39 (September 29, 1966) which formally issues Forestry Legislation of the Republic.

- Decree № 299 (August 11, 1966) establishes an official tariff to compensate for the destruction of timber, fruit trees, and other agricultural products.

- Decree № 44 (February 16, 1967) addresses slash and burn conditions in rural areas.

- Law №6 (January 3, 1989) ratifies approval of Panama's signing of the Ramsar Convention and its associated protocol. Ramsar protects wetlands of international importance, especially waterfowl habitat.

Since the 1960s, legislation has emerged to create forest reserves and national parks in Panama. Those created to date include the forest reserves of: "La Yeguada" (1960s) in the Province of Veraguas; the Chagres, Pequeni, Aguas Claras, Gatun, Indio and Agua Sucia rivers (1967) in the provinces of Panama and Colon; "La Fortuna" (1976) in the Province of Chiriqui; "El Montuoso" (1977) in the Province of Herrera and the "Bosque Protector del Alto Darien".

Since 1966, various National Parks have been created, including: the National Park for Climatic Welfare of "Altos de Campana" in the Province of Panama. Recently, a National Parks System has been established throughout the country. Within the Canal area, several national parks have been established that are referred in Section 5.4.2.

Fauna

There are subsequent decrees that complement existing constitutional regulations protecting terrestrial and aquatic fauna. National parks and other areas have been established for the protection of wildlife. These areas are discussed in more detail in Section 5.4.2.

The protection and conservation of fauna are also addressed in the following decrees:

- Decree-Law № 23 (January 30, 1967) specifies measures for the protection and conservation of wildlife (Official Gazette of March 10, 1967). This was modified in Decree № 104 (September 4, 1974; Official Gazette № 15, 821, pp. 2-6). This law prohibits the killing of sixteen (16) species in danger of extinction, including: White Tail deer (*Odocoileus virginianus*), Brocket deer (*Mazama americana*), Tapir (*Tapirus bairdii*), Agouti (*Agouti paca*), Ruddy Ground-Dove (*Columbina talpacoti*), Great Tinamou (*Tinamus major*), Great Curassow (*Crax rubra*), Crested Guan (*Penelope purpurascens*), Black Guan (*Chamaepetes unicolor*), Black-Bellied Tree-Duck (*Dedrocygna autumnalis*), Muscovy Duck (*Cairina moschata*), Quetzal (*Pharomachrus moccino*), Harpy Eagle (*Harpia harpyja*), Manatee (*Trichechus manatus*), Green Sea Turtle (*Chelonia mydas*), Gilded Frog (*Atelopus zeteki*). A limit was also placed the number of iguanas (*Iguana iguana*) that could be hunted. This legislation also forbids the use of explosives or full stream-width nets.

- Executive Decree № 104 (September 4, 1974) added several species to the above list of species, including: the Hawksbill turtle (*Careta caretta*) and Mulatto turtle (*Lapidochelva olivaces*).

- Resolution № -002-80 (1980), of the (then) Department of Renewable Natural Resources of the Ministry for Agricultural Development added more animals to this list.

- Decree № 15 (July 23, 1969) regulates the hunt of the pale-vented pigeon (*Columba cayennensis*) in Panama (Official Gazette of August 7, 1969, № 16, 420, p. 4-5).

- Executive Decree № 10 (June 24, 1975) regulates hunting in the region of Bayano, District of Chepo, Province of Panama (Official Gazette of the 26 of June of 1975, № 17, 870, p. 1).

Panama has also signed the Protocol for the Protection of the Flora, Fauna and of the Natural Scenic Beauties of the Americas in 1972. This agreement refers specifically to the protection and conservation of "all species and genera of flora and indigenous fauna, including migrant waterfowl, in sufficient number and in sufficient areas to avoid their extinction". Panama also subscribed, in 1977, to the Convention on International Trade of Endangered Species (CITES) of Flora & Fauna, which was ratified through Law № 14 of October 28, 1977.

The fauna of continental waters are subject to few regulations. Decree № 23 (January 30, 1967) and Decree № 79 (November 29, 1972) prohibit the sale of trout captured in the country, (Official Gazette of December 14, 1972, № 17, 243, p. 1).

In recent years, commercial marine fishing has increased. Among species currently exploited are, shrimp (seven species) lobster, fish (anchovies and herrings for oil and fish flour) and shark, for use of its meat, skin and fins. The National Government, has recently established protective measures to control fishing in Panamanian waters. Existing regulations for protection and conservation of marine resources include:

- Law № 25 (December 6, 1910) dictates some measures for fishing in territorial waters, as well as fiscal matters (Official Gazette of December 21, 1910, № 1305, p. 1561).

- Decree № 30 (December 22, 1952) regulates bait fishing by oceanic ships in jurisdictional Pacific coastal waters, and superseded Decrees № 215 and 216 of 1951, № 324 of 1952 and № 330 of 1952, which previously regulated these

activities (Official Gazette of December 30, 1952, № 11, 964, p5). This was later modified by Decree № 202 of October 14, 1965.

- Decree-Law № 17 (July 9, 1959) regulates fishing and the export of fishing products.

- Law № 33 (January 30, 1961) provides economic measures to regulate and protect shrimp and sardine fishing in Panamanian waters (Official Gazette of March 9, 1961, № 14 p. 345).

- Decree № 202 (October 14, 1965) prohibits the capture of all marine species within 12 miles of the Panamanian coast (Official Gazette of October 22, 1965, № 15, 884, p. 2).

- Decree № 162 (June 6, 1966) regulates the size of fishing nets used for shrimp (Official Gazette of August 1, 1966, № 15, 673, p. 1-2).

- Decree-Law № 11 (April 27, 1967) modifies article 297 of the Fiscal Code, to more efficiently protect marine fauna (Official Gazette of May 16, 1967).

- Decree № 3 (July 23, 1969) regulates the issuing of certificates of origin for the export of fish captured on the high seas by Panamanian registry ships.

- Decree № 368 (November 26, 1969) reform articles 20, 21, 22 and 23 of Decree № 17 of July 9, 1959 (Official Gazette of the 17 of December of 1969, № 16, 507, p. 1-2).

- Decree № 50 (July 19, 1972) modifies and supplements Decree № 49 of March 2, 1965 (Official Gazette of August 1, 1972, № 17. 154, p2 and 3).

- Law № 14 (March 20, 1975) regulates the activities and location of companies that are devoted to the fishing and processing of tuna, shrimps, and other marine goods (Official Gazette of May 2, 1975, № 17, 831, p1).

- Decree № 58 (November 23, 1976) regulates the issuance of fishing licenses for shrimps (Official Gazette of December 2, 1976, № 18, 223, p. 1-30).

- Decree № 41 (October 7, 1977) regulates the issuance of fishing licenses for anchovies and herrings (Official Gazette of November 24, 1977, № 18, 465, p. 1-3).

- Executive Decree № 9 (February 3, 1980) temporarily modified Decree № 1 of January 19, 1977, on shrimp fishing (Official Gazette of February 11, 1980, № 18, 007, p. 1; 1972 National Constitution - Article 225).

The Government of Panama has created organizations with the responsibility for natural resources and the environment in Panama. The Agricultural Development Ministry and National Department of Renewable Natural Resources were created under Law № 12 of January 25, 1973. Law № 21 of December 16, 1986, formally established the National Institute of Renewable Natural Resources (INRENARE). In accordance with Article 2, the objectives of INRENARE were stated as "the definition, planning, organization, coordination, regulation and promotion of the policies and actions, conservation and development of the natural resources of the country. In particular those that relate to the conservation, management, utilization, enrichment and development of water, soils, flora and fauna, forests, national parks, equivalent reserves and the hydrologic basins in the national territory, consistent with the national development plans". Article 5, Part 4, assigns INRENARE the functions of "directing or collaborating with the plans and studies for the development of the activities and projects that could be accomplished in the Area of the Canal, related to conservation, development and usage of the natural renewable resources".

The National Commission of the Environment was created by Decree № 29 (August 3, 1983) as a permanent organization to advise the Executive Branch in all matters concerning the protection, improvement and defense of the natural heritage of Panama and its ecology.

5.4.2 Protected Wilderness Areas

The recognition of the role that wilderness areas play in the social, economic, cultural, and spiritual progress of Panama, has increased in recent years. In this general context, it is recognized that the wilderness areas constitute an all-important element in the conservation and rational use of natural resources, including the protection of hydrologic basins to assure an adequate water supply.

Wilderness areas respond to the need to conserve biodiversity, develop basic research and environmental education activities, and promote recreation and tourism as part of a sustainable development plan for the country. Current planning for and management of wilderness areas is insufficient to insure their conservation and achieve the objectives that they represent. Consequently, the destruction of forests, with the environmental, social and economic costs that this represents, continues.

In order to improve and protect the wilderness areas, the Government of Panama has recently proposed legislation that would create the National System of Protected Wilderness Areas. Section 1 of this Bill establishes and defines Wilderness areas, Management Units, and Management and Repopulation Units. Articles 2 and 3 of Section 1 of this Bill

establishes and describes the management categories that integrate the National System of Protected Wilderness areas. These include:

a) Wilderness areas,
b) Management Category,
c) Management Unit,
d) Repopulation,
e) National Park
f) Scientific Reserve,
f) Natural Monument,
g) Wildlife Refuge,
h) Regional Park,
i) Recreational Natural Area,
j) Protected Landscape,
k) Biosphere Reservation and
l) Natural Patrimony Area.

Various Protected Wilderness Areas have been established in Panama during recent years that fulfill the definitions of the categories listed above. In the region of the current Canal, there are ten Protected Wilderness Areas corresponding to four of the above Management Categories (Table 5.2).

The Management Classes and protected Wilderness Areas that have been established in the area of the current Canal include:

National Park: A relatively large area of land or water (more than thousand hectares), administered by the National Government, that contains outstanding representative samples of the principal regions, features or scenery of international and national importance, where the floral and faunal species, geomorphology and habitats are of special scientific, educational, tourist, aesthetic and recreational interest.

A. SOBERANIA: Created by Decree 13 on May 27, 1980. It is located in the provinces of Panama and Colon and covers 22,104 hectares. Article Four established that the Park be administered and managed by the National Administration of Renewable Natural Resources (today INRENARE) of the Ministry of Agricultural Development (today the Ministry of Planning and Economic Policy), according to the procedures of outstanding renewable natural resources and its bylaws.

B. CHAGRES: The Chagres National Park was created by Executive Decree № 73, on October 2, 1984. It is located in the provinces of Panama and Colon and has an approximate surface area of 129.000 hectares. This Park

covers the mountainous region formed by the watersheds of the rivers Gatun, Boqueron, San Juan of Pequeni, Indio, Chagres, Mandinga, Zaino, Cuango, Piedras and Nombre de Dios.

C. CRUCES: Created on December 30, 1992, located in the province of Panama, district of Panama, county of Ancon, with an approximate area of 4,000 hectares of natural forest. One of the specific objectives of this Park is to protect and maintain the natural forests that occur between the Metropolitan Natural Park and the Soberania National Park, in order to guarantee maintenance of an ecological corridor for animal movement that permits the conservation of the biodiversity and the survival of flora and fauna.

D. INTEROCEANIC PARK OF THE AMERICAS: This park was created by INRENARE through the Resolution № 028-93 of may 25, 1993. It includes the forested areas on the west bank of the Panama Canal, and extends through the provinces of Panama and Colon. It has an approximates surface area of 62,159 ha. Areas excluded from the park include those associated with the operation of the Panama Canal the island and peninsulas comprising to Barro Colorado Natural Monument. The objectives of the Park are to:

1. Capture, storage, and supply the required volume and quality of water for the function of the Canal, and for industrial, commercial and domestic supply of the Metropolitan Region.

2. Protect and conserve the primary resources and extraordinary biological diversity.

The area between the barrier dams for the proposed Sea-Level Canal alternative, as well as the area of La Laguna and Lagarterita are currently within park boundaries. Several placing areas for spoils from the planned widening of Gaillard Cut (D-4, D-6, D-8 and D-9) as part of the High-Lock Canal alternative may also be partially inside park boundaries.

E. ALTOS DE CAMPANA: This park was created on June 28, 1996, and covers 2,630 ha. It is located in the Province of Panama, and is the oldest national park in the system.

Wildlife Refuges are defined as areas that provide specific habitats necessary to support populations of flora or fauna, migrant or resident, of international or national importance.

The size of the area and seasonal management considerations depend on the requirements of the habitat or specific characteristics of the species be protected.

A. TABOGA AND URABA ISLANDS. Part of the Island of Taboga and all the Island of Uraba, in the District of Taboga, Province of Panama was declared a Wildlife Refuge by Executive Decree № 76 on October 2, 1984. A part of the Island of Taboga and the Island of Uraba serves as important rookeries for the brown pelican (*Pelecanus occidentalis*). The Wildlife Refuge Taboga and its resources are administered by INRENARE.

Natural Monument is defined as an area that contains one or more natural qualities, such as geological or natural features, habitats or biota, that, due to its singularity, can be threatened and therefore requires protection. The size is determined by the specific features and the area needed to protect them. The features must be distinctive and in a natural or almost natural state.

A. BARRO COLORADO. The Smithsonian Tropical Research Institute (STRI) was named as caretaker of Barro Colorado Natural Monument through an exchange of diplomatic letters between the Government of the Republic of Panama and the Government of the United States of America, as part of the Panama Canal Treaty of September 7, 1977. STRI was empowered to act on behalf of both Governments, to authorize the use of the Natural Monument for educational studies and scientific research, and was given responsibility for its protection.

Natural Recreational Areas are relatively vast areas that rely on man-made or natural attractiveness in order to provide public recreation and environmental education.

A. METROPOLITAN NATURAL PARK. It was established through Law № 8 of July 5, 1985. This park is located in the Province of Panama, District of Panama, county of Ancon, and has a surface area of 265 hectares.

B. LAKE GATUN. Lake Gatun was declared a Natural Recreational Area through Decree № 88 of July 30, 1985. It is located in the Province of Colon and has an approximate surface area of 348 hectares.

C. SUMMIT MUNICIPAL PARK. The Summit Municipal Park was created through Decree № 1 of January 8, 1985. It is located within Soberania National Park, in an area within a polygon of 46 hectares, located along the Gaillard Highway, county of Ancon, District of Panama. The Summit Municipal Park is administered by the government council of the District of Panama.

TABLE 5.2 PROTECTED WILDERNESS AREAS IN THE PANAMA CANAL REGION

MANAGEMENT CATEGORY	APPROXIMATE SURFACE (HECTARES)	DATE CREATED	DECREE LAW	LEGAL BASE OFFICIAL GAZETTE	DATE OF THE GAZETTE	PROVINCE
National Park						
1. Soberaní a	22	07-May-80	Dec.13	20.333	24-Jun-85	Panama/Colon
2. Chagres	129,000	02-Oct-84	Dec.Ejec.73	20	04-Feb-85	Panama/Colon
3. Cruces	4,000	30-Dec-92	Ley.30		06-Jan-93	Panama
4. Interoceanic of the Americas	62,159	25-May-93	Res. J.D. 028-93			Panama/Colon
5. Altos de Campana	2,630	28-Jun-66	Dec. 153	15,655	06-Jul-66	Panama
Wild Life Refuge						
6. Taboga and Uraba Islands	258	01-Oct-84	Dec.76	20	06-Mar-85	Panama
Natural Monument						
7. Barro Colorado	5,400	05-Jul-85		20	19-Jul-85	Panama
Natural Recreational Area						
8. Metropolitan Natural Park	265	05-Jul-54	Ley 8	20	06-Mar-85	Panama
9. Lake Gatun	348	30-Jul-85	Dec.88	20	19-Sep-85	Colon
10. Summit Municipal Park	45	08-Jan-85	Dec.1	20	22-Jan-85	Panama

5.4.3 Protected Species

Table 5.3 lists the vertebrate fauna given special status according to international agreements and Panamanian environmental legislation. The internationally recognized categories are Threatened (T), Endangered (E), and Protected (P). The (T) and (E) classification categories correspond to the Convention on International Trade of Endangered Species (CITES), which the Republic of Panama has signed, and the Red List of Threatened Species of the International Union for the Conservation of the Nature (IUCN). The classification P is exclusively used for the species covered by Panamanian environmental regulations. Table 5.3 also specifies the habitats within the Canal basin in which the listed species are found. These communities include: Wetlands (W), Mangroves (M), Grasslands (G), Agricultural Areas (A), Tropical Mature Forest (TMF) and Tropical Young Successional Forest (TYF).

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
MAMMALIA									
EDENTATA									
Bradypus variegatus	+							+	+
Dasypus novemcintus			+			+		+	+
Cabassous centralis			+					+	
Cyclopes didactylus			+					+	
Myrmecophaga tridactyla	+		+					+	
Tamandua mexicana			+			+		+	+
PRIMATES									
Saguinus geoffroyi		+	+					+	+
Alouatta palliata		+	+					+	
Aotus trivirgatus	+		+						
Ateles geoffroyi		+	+					+	
Cebus capucinus	+		+					+	

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
RODENTIA									
Agouti paca			+					+	
Dasyprocta punctata			+					+	
Hydrochaeris hydrochaeris			+	+		+		+	
CARNIVORA									
Speothos venaticus		+						+	
Urocyon cinereoargenteus			+			+		+	+
Bassaricyon gabbii		+							
Bassariscus sumichrasti		+						+	
Nasua nasua			+					+	+
Eira barbara	+								
Procyon cancrivorous			+	+	+				
Procyon lotor			+					+	+
Galictis vittata	+							+	
Lutra longicaudis		+	+	+				+	
Felis concolor		+	+					+	
Felis jaguaroundi	+		+					+	+
Felis pardalis		+	+					+	+
Felis wiedii		+	+					+	
Panthera onca		+	+					+	
PERISSODACTYLA									
Tapirus bairdii	+		+					+	
ARTIODACTYLA									
Tayassu tajacu	+		+					+	
Tayassu pecari	+		+					+	
Mazama americana			+					+	

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
Odocoileus virginianus			+					+	+
SIRENIA									
Trichechus manatus		+	+	+					
TOTAL MAMMALIA	**10**	**12**	**29**	**4**	**1**	**4**	**0**	**30**	**10**
AVES									
TINAMIDAE									
Crypturellus soui		+	+					+	+
Tinnamus major		+	+						+
ANATIDAE									
Cairina moshata	+			+					
Dendrocygna autumnalis		+	+	+					
Dendrocygna viduata	+			+					
ACCIPITRIDAE									
Accipiter bicolor	+								+
Busarellus nigricollis	+							+	
Buteo swansoni		+				+			
Buteogallus urubitinga	+								+
Elanoides forficatus		+							+
Leucopternis plumbea	+								+
Harpia harpyja									
Morphus guianensis	+								+
Spizaetus tyrannus	+								+
Spizartur melanoleucus	+								+

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
FALCONIDAE									
Daptrius americanus	+								+
Falco columbarius	+								
Falco femoralis	+								
Falco rufigularis	+							+	
Micrartur mirandollei	+								+
CRACIDAE									
Crax rubra		+	+						
Ortalis cinereiceps		+	+					+	+
Penelope purpurascens		+	+						
PHASIANIDAE									
Odontophorus gujanensis		+	+						+
RALLIDAE									
Amaurolimnas concolor	+								
Aramides axiliaris	+								
Neocrex erythrops	+						+		
SCOLOPACIDAE									
Actitus macularia	+								
Arenaria interpres	+					+			
COLUMBIDAE									
Columba cayennensis		+	+		+				+
Columba nigrirostris		+	+						+
CUCULIDAE									
Coccyzus minor	+				+				
Neomorphus geoffroyi	+								+

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
TROCHILIDAE									
Amazilia amabilis	+								+
Amazilia edward	+							+	
Amazilia tzacatl	+					+		+	
Anthracothorax nigricollis	+								
Chalybura buffoni	+							+	
Chlorostiibon assimilis	+								
Damophila julie	+							+	
Florisuga mellivora	+								+
Glaucis aenea	+								+
Glaucis hirsuta	+							+	+
Heliotryx barroti	+							+	
Klais guimeti	+							+	
Lepidopyga coeruleogularis	+				+			+	
Lophornis delattrei	+							+	
Phaeochroa cuvierii	+							+	+
Phaethornis longuemareus	+							+	+
Phaethornis superciliosus	+								+
Thalurania colombica	+							+	
Threnetes ruckeri	+								+
MOMOTIDAE									
Hylomanes momotula	+								+
PICIDAE									
Piculus chrysochloros	+					+			
TOTAL AVES	**42**	**11**	**9**	**3**	**3**	**4**	**1**	**16**	**25**

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
REPTILIA									
ALLIGATORIDAE									
Caiman crocodilus		+	+			+		+	
CROCODILIDAE									
Crocodylus acutus		+	+	+			+		
CHELYDRIDAE									
Chelydra serpentina		+		+					
GEKKONIDAE									
Lepidoblepharis sanctaemartae	+					+		+	
Lepidoblepharis xanthostigma	+							+	+
IGUANIDAE									
Anolis frenatus	+							+	
Anolis humilis	+							+	+
Anolis poecilopus	+							+	+
Corytophanes cristatus	+							+	
Iguana iguana		+	+	+		+		+	
TEIIDAE									
Ptychoglossus festae	+							+	+
BOIDAE									
Boa constrictor		+	+	+				+	+
COLUBRIDAE									
Chironius carinatus	+							+	+
Drymarchon corais	+							+	+
Enulius sclateri	+								+
Leptophis ahaetulla	+							+	
Pliocercus euryzonus	+								+

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
Pseustes poecilonotus	+							+	+
VIPERIDAE									
Bothrops lansbergii	+			+		+	+	+	+
Bothrops nasuta	+					+		+	+
ELAPIDAE									
Micrurus multifasciatus	+							+	+
TOTAL REPTILIA	**16**	**5**	**4**	**5**	**0**	**5**	**2**	**17**	**13**
AMPHIBIA									
CAECILIDAE: Cecilias									
Oscaecilia ochrocephala	+							+	+
PLETODONTIDAE									
Bolitoglossa biseriata	+							+	
BUFONIDAE									
Bufo thyphonius	+					+		+	+
CENTROLENIDAE									
Centrolenella granulosa	+							+	
Centrolenella pulverata	+							+	+
Centrolenella spinosa	+							+	
DENTROBATIDAE									
Colostethus talamancae	+							+	+
HYLIDAE									
Agalychnis callidryas	+			+		+		+	+
Hyla palmeri	+							+	+
Hyla rufitela	+							+	

TABLE 5.3 ANIMAL SPECIES IN SPECIAL CONDITION.

TAXON	CONDITION			COMMUNITY					
	T	E	P	Wet	M	G	A	TMF	TYF
LEPTODACTYLIDAE									
Eleutherodactylus biporcatus	+							+	+
Eleutherodactylus cerasinus	+							+	+
TOTAL AMPHIBIA	12	0	0	1	0	2	0	12	8
GRAND TOTAL	80	28	42	13	4	15	3	75	56

Condition Code
T = Threatened
E = Extinction
P = Protected

Community Code
Wet = Wetlands
M = Mangroves
G = Grasslands
A = Agriculture
TMF = Tropical Mature Forest
TYF = Tropical Young Forest

5.4.4 Fauna of Medical or Veterinary Interest

The construction of the existing Panama Canal was plagued by outbreaks of malaria, yellow fever, dysentery and other fatal diseases. It was not until breakthroughs in medical science permitted the control and treatment of these diseases, that the construction of the Panama Canal was completed. General William C. Gorgas used oil and other products to eradicate larval stages of malaria and Yellow Fever vectors. After the construction of the Canal, and the formation of Lake Gatun, malaria persisted in the towns surrounding the Lake, and was a serious problem in the labor force used to build Madden Dam.

In 1992, 727 cases of malaria were detected in Panama, of which 614 (84.4%) were caused by *Plasmodium vivax*, 111 (15.3%) by *Plasmodium falciparum* and 2 (0.3%) from mixed infections or associated cases (Ministry of Health, 1992).

Below is a short summary of the primary pathogens, insect vector species, and vertebrate hosts of medical and/or veterinary interest. Existing information is evaluated to identify potential impacts on public health from construction, operation, and maintenance of the proposed Canal alternatives.

The insect vectors of interest consists mosquitoes (Family Culicidae), phlebotomine sand flies of the genera Lutzomyia (Family Psycodidae), Ceratopogonid flies *Culicoides* (Family Ceratopogonidae), Tabanids (*Tabanus* spp.), and triatomine bugs (Order Hemiptera, Family Reduvidae).

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Malaria is produced by the infection of one of the more than four blood protozoans (Apicomplexa, Sporozoae) belonging to the genus *Plasmodium*. These parasites share a common transmission patterns, but they show distinguishable morphological characteristics in macroscopic preparations of blood cells. The *Plasmodium* develop within red blood cells, which are destroyed during asexual reproduction or sporulation, which occurs at typical intervals for each *Plasmodium* species.

The symptoms of the disease include febrile paroxysms at more or less regular intervals, commonly accompanied by chills, fever, and profuse perspiration. However, these symptoms do not occur in well differentiated stages and the paroxysms do not always occur at the same intervals. When they occur in 48-hour intervals, it is called malaria vivax (previously known as tertiary malaria). If it occurs every 72 hours, it is known as quaternary malaria. The most severe form of this disease is caused by *Plasmodium falciparum*, known as malaria falciparum (previously known as malignant tertiary malaria).

Malaria parasites are almost exclusively transmitted by mosquitoes of the genus *Anopheles*. There are exceptions, including transmission through transfusion of infected blood, intravenous drug usage, and rare infections through the placenta.

There are 3 malaria vectors in the Canal area: *Anopheles albimanus, A. punctimacula* and *A. pseudopunctipennis*. *Anopheles albimanus* is the principal vector of malaria in Panama and it is common in Lake Gatun and in other water bodies in the Canal Watershed. The presence of these malarial vectors and the potential problems caused by this disease during any proposed canal construction should be carefully considered, especially as environmental modifications from proposed activities could create the appropriate conditions for breeding of any of these species.

Yellow Fever (YF) has been widely known since the middle of the 17th century, when large epidemics swept through the Americas and the Mediterranean. For unknown reasons, this disease has never been reported in Asia. The disease is caused by a group B arbovirus. The disease is characterized by a sharp onset of chills, fever, slow pulse, headaches, body aches, and abdominal pain. After the second day the patient suffers vomiting, and by the fourth day, a pronounced jaundice. Death can occur suddenly during the first six days, either by acute hepatic deficiency or by "shock". There is no specific treatment against the disease (Asesores Ecológicos, 1974).

Urban Yellow Fever is the epidemiological form of the disease that was responsible for large epidemics on the American continent from the mid-16th century to the early 20th century. In Panama, Yellow Fever has had a long history and has affected the socioeconomic development of the country. During the construction of the Canal by the French, it was one of the principal causes of death among the project personnel and in the city of Panama. It was first eradicated in Panama in 1906. Subsequently, yellow fever has occurred in waves in the jungles of eastern Panama. Arboreal mosquitoes are transmitting vectors in the forest.

The virus is highly pathogenic for Howler Monkeys (*Allouata palliata*), Night monkeys, (*Aotus trivirgatus*) and mildly pathogenic for black spider monkeys (*Ateles fuscicepes*), and white-faced capuchin monkeys (*Cebus capucinus*). The mosquitoes in Panama that are natural vectors for the disease include *Haemagogus luficer, H. jantinomysm, H. equinus, Sabethes chloropterus* and *Anopheles neivai*. The vector of the Urban Yellow Fever is the *Aedes aegypti*.

The results of the Biological Inventory indicate that the three primary susceptible monkey species (Howlers, Night monkeys, and White-faced capuchin monkeys) are present in mature secondary forest habitats within the area of the High-Rise Lock alternative. The Biological Inventory does not present results on captures of mosquitoes, However, previous studies and existing knowledge of the area indicate that the mosquito vector species mentioned above can be found in several habitats described and characterized in the study area, including Gallery Forest, Secondary Old Forest or Tropical Mature Forest, Secondary Young Forest. Other breeding habitat for mosquito vectors may be created by construction activities associated with the Canal alternatives. Larvae can develop in a variety of microhabitats, such as tanks, puddles, 55-gallon drums, discarded tires, pails, cups, lids of barrels, boots, and shoes, and in natural areas such as lakes, lagoons, tree hollows, leaf axils, rocks, coconut husks, and snail shells.

The eggs of *Aedes aegypti* are quite tolerant to desiccation. This allows them to be accidentally transported in dry containers. Because of this, elimination of adult and the larval mosquitos in a given location will not necessarily prevent reinfestation. *Aedes aegypti* was re-introduced into Panama in 1985. From that date, a National Campaign of Control for *Aedes Aegypti* was initiated. In spite of these efforts, 7 of 9 provinces in the country and the region of San Blas were found to be infested in 1992.

Venezuelan Equine Encephalitis is a serious disease produced by a virus that affects horses as well as humans in most of the areas in which it occurs. Two sub-types that are not pathogenic to horses have been isolated in Panama. There is evidence that rodents are hosts to these subtypes. It is suspected that the natural hosts for both the pathogenic and non-pathogenic viruses are waterfowl, which are also responsible for its dispersion. The virus is transmitted primarily by *Culex occosa* mosquitos, and secondarily by *Culex erraticus*

and *Mansonia dyari*. The immature stage of these mosquitoes are associated with water lettuce (*Pistia stratiotes*). The females and larvae may travel on plants that are transported downstream along the Rio Chagres. This form of dispersion may be important in local outbreaks of this disease (Galindo and Adames, 1972).

In studies conducted at the Gorgas Memorial Laboratory during development of the Bayano River Hydroelectric Project, east of the city of Panama, construction of the dam and filling of the related reservoir (1973-1976) was associated with an outbreak of Venezuelan Equine Encephalitis in 1977 (Adames, *et al.*, 1977).

Saint Louis Encephalitis (SLE) occurs throughout the western hemisphere and, in the last 40 years, has increased in senior citizens and children in the southeastern U.S. Only sporadic cases have occurred in South America. The virus is normally found in low, wet, tropical areas. Waterfowl are suspected to be the natural hosts. The SLE virus is transmitted by the mosquito *Mansonia dyari* though other mosquitos harbor the virus, including *Haemagogus equinus, Sabethes chloropterus, Deinocerites pseudes, Culex nigripalpus* and *Culex pipiens quinquefasciatus*.

In Panama the SLE virus has been isolated from the olive cormorant (*Phalacrocorax olivaceus*), and antibodies have been detected in other species, such as the striated heron (*Butorides striatus*). Antibodies have also been found in mammals, such as the three-toed sloth (*Bradypus infuscatus*) and two-toed sloth (*Choloepus hoffmani*). Results of other studies indicate that the cattle egret, (*Bubulcus ibis*), american egret (*Casmerodius albus*), water turkey (*Anhinga anhinga*) and boat-billed heron (*Cochlearius cochlearius*) could all serve as intermediary hosts in the transmission of SLE (Adames, *et al.*, 1993). All of these species are known to be present in the area of the two proposed canal alternatives.

Dengue fever is a viral disease that also affects man. It is transmitted exclusively by *Aedes aegyptii*. The incubation period is 5 to 8 days, with symptoms that include headaches and backaches, fatigue, insomnia, chills, general discomfort and occasionally a skin rash. This is followed by an abrupt increase in body temperature, acute pains in the head, back, muscles, and joints. The fever persists for 5 or 6 days in the typical cases. Classic dengue fever is not a deadly disease, but disables patients with its slow recovery.

Leishmaniasis is a disease of the skin and mucous membranes characterized by ulcerous lesions that they can be simple or multiple. With some strains, even if the primary lesion has healed, or with an unrecognized initial lesion, it can develop into mucocutaneous lesions that block the nasopharynx. This form can be deadly. (Benenson, 1980). Leishmaniasis is produced by a protozoan of the genus *Leishmania* that can be acquired from wild animals through phlebotomine sandflies of the genus *Lutzomyia* (Psycodidae family). Fourteen (14) wild animals infected with *L. brasilensis* have been found in Panama. These include two- and three-toed sloths, night monkeys, titi monkeys (*Saguinus geoffrogyi*), rice rats (*Oryzomys*

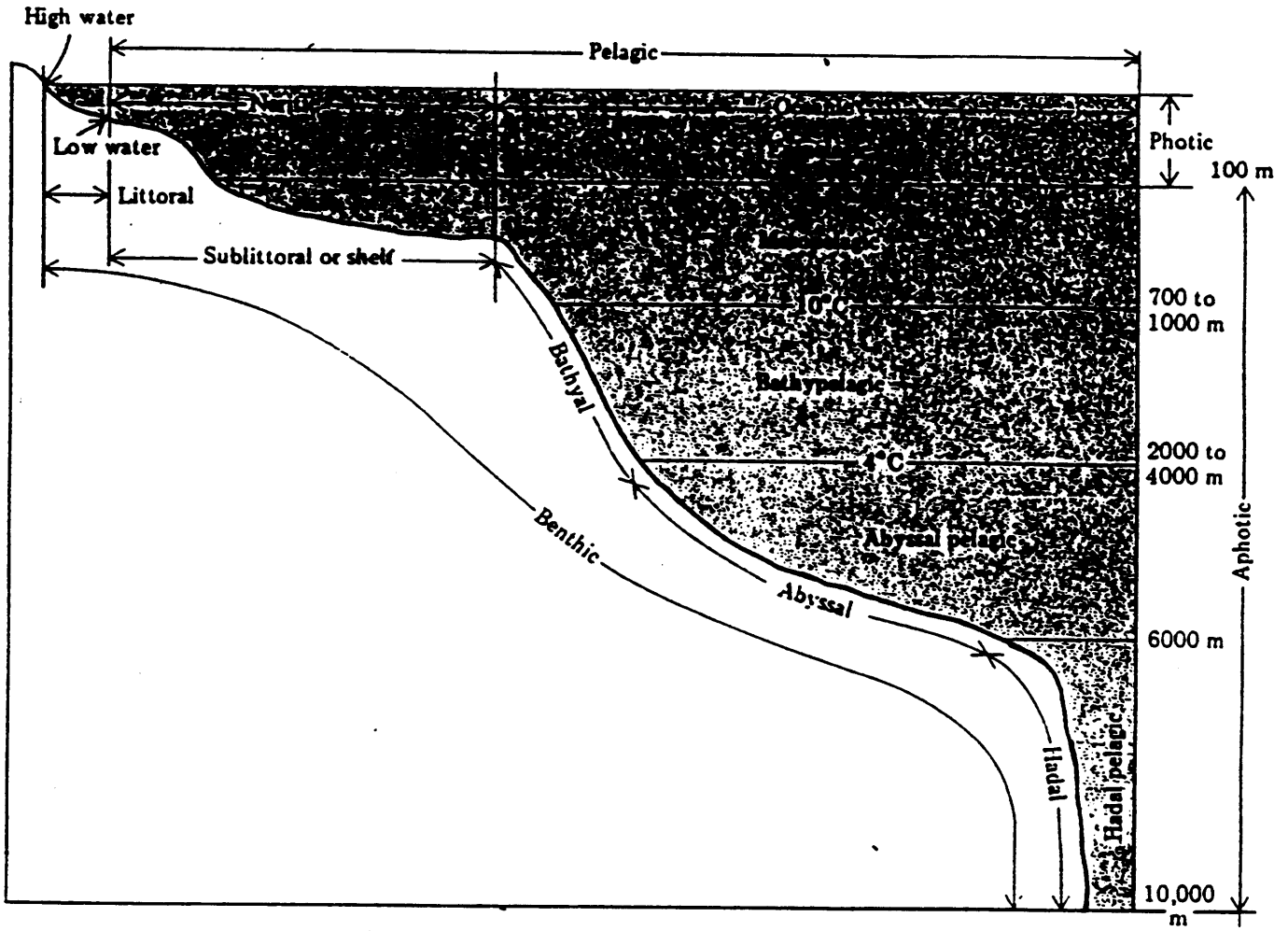
capito), arboreal rats (*Tylomys panamensis*), porcupines (*Coendu rosthschildi*), spiny rats (*Proechimys semispinosus*), rat (*Hoplomys gymnurus*), and coati (*Nasua nasua*). The domestic dog is commonly infected in areas where its transmission cycle is maintained.

Punta Toro Virus was isolated for the first time in 1966 from a patient traveled to Pittsburgh from Fort Sherman. The virus was determined to belong to the Phlebotomus Fever Group and is transmitted by phlebotomine sandflies.

Chagres Virus was isolated for the first time from the blood of a feverish patient in Panama. It was determined to be a new virus of the Phlebotomus Fever Group and Sandfly Fever Group, and up to 1988, four human cases have been reported with this virus. Subsequent studies (Galindo, *et al.*, 1983) during the construction of the Bayano Dam found 18 instances of the virus. During these studies, the virus was isolated from phlebotomine sand flies (*Lutzomyia* spp.). The presence of this virus in the area of the alternatives must be taken in consideration during project construction and operation.

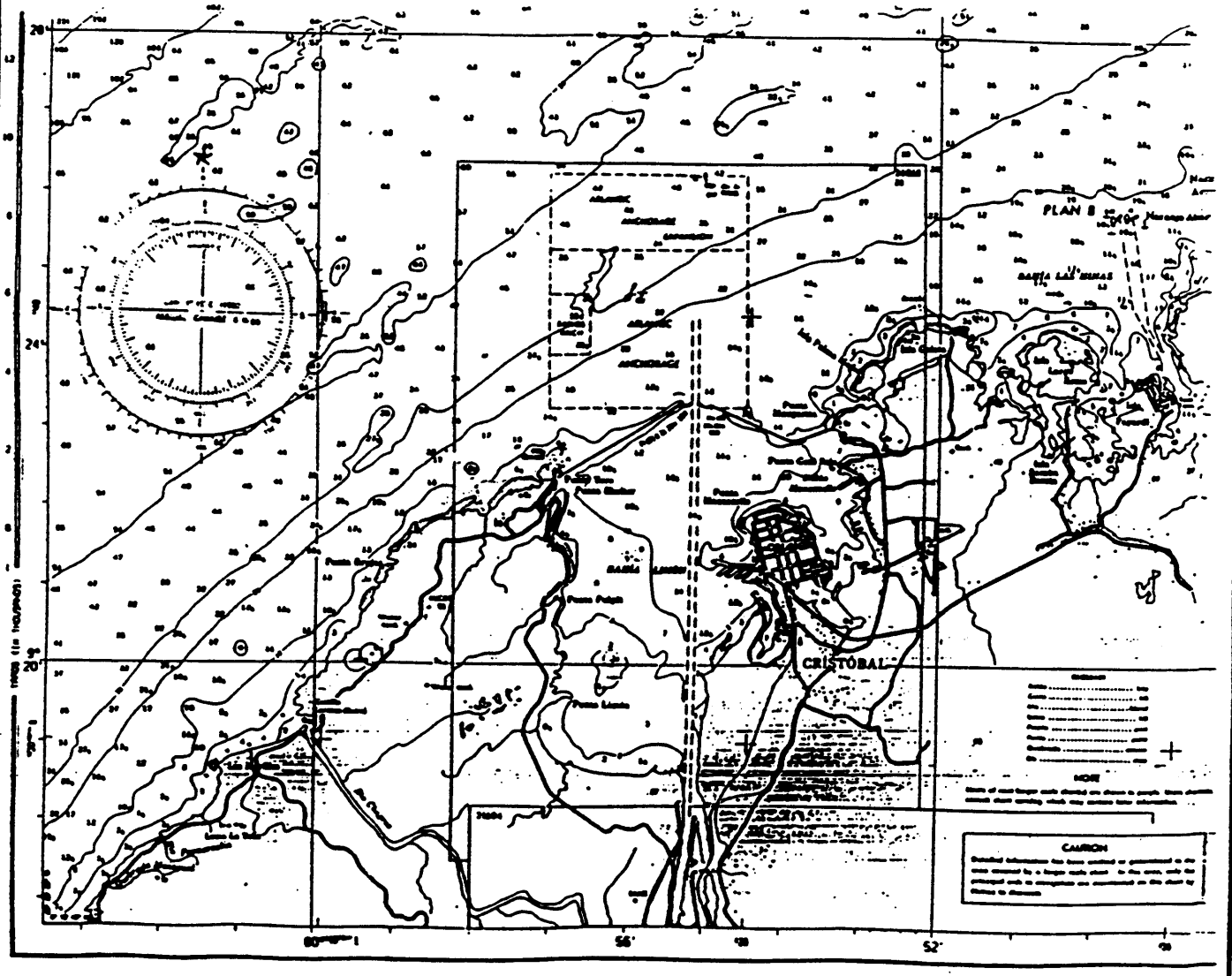
Chagas' Disease or **American Trypanosomiasis**, it is one of the most important diseases transmitted by arthropods in the Tropical Americas. The etiological agent is *Trypanosoma (Schizotrypanum) cruzi*, whose life cycle includes mammals as vertebrate hosts and the triatomine bugs as vectors. The parasite develops in the triatomine intestine and passes to the vertebrate host when the insect defecates on the skin of its victims during feeding. From the skin, the trypanosomas are transferred to the eye or to the mucous membranes of the nose or mouth, subsequently penetrating into the body. The incubation period in man is 1 to 2 weeks. Four weeks after the initial infection, the patient recovers, but the disease then enters a chronic phase.

In Panama, there are ten triatomic bugs known to carry the trypanosome. The principal vectors for this disease are *Triatoma dimidiata*, and *Rhodnius pallescens*. Other species like *Eratyrus cuspidatus* has also been found to be infected with *T. cruzi*, as well as *Panstrongylus geniculatus*, which appears to be associated with armadillos, but has occasionally been found near human facilities. It is a species that apparently occurs only in central Panama. There are records of this species at Barro Colorado Island, and in other parts of the Canal Basin.



Reference: Nybaken, 1985

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	ZONATION OF THE OCEAN	DAMES & MOORE FIGURE 5.1



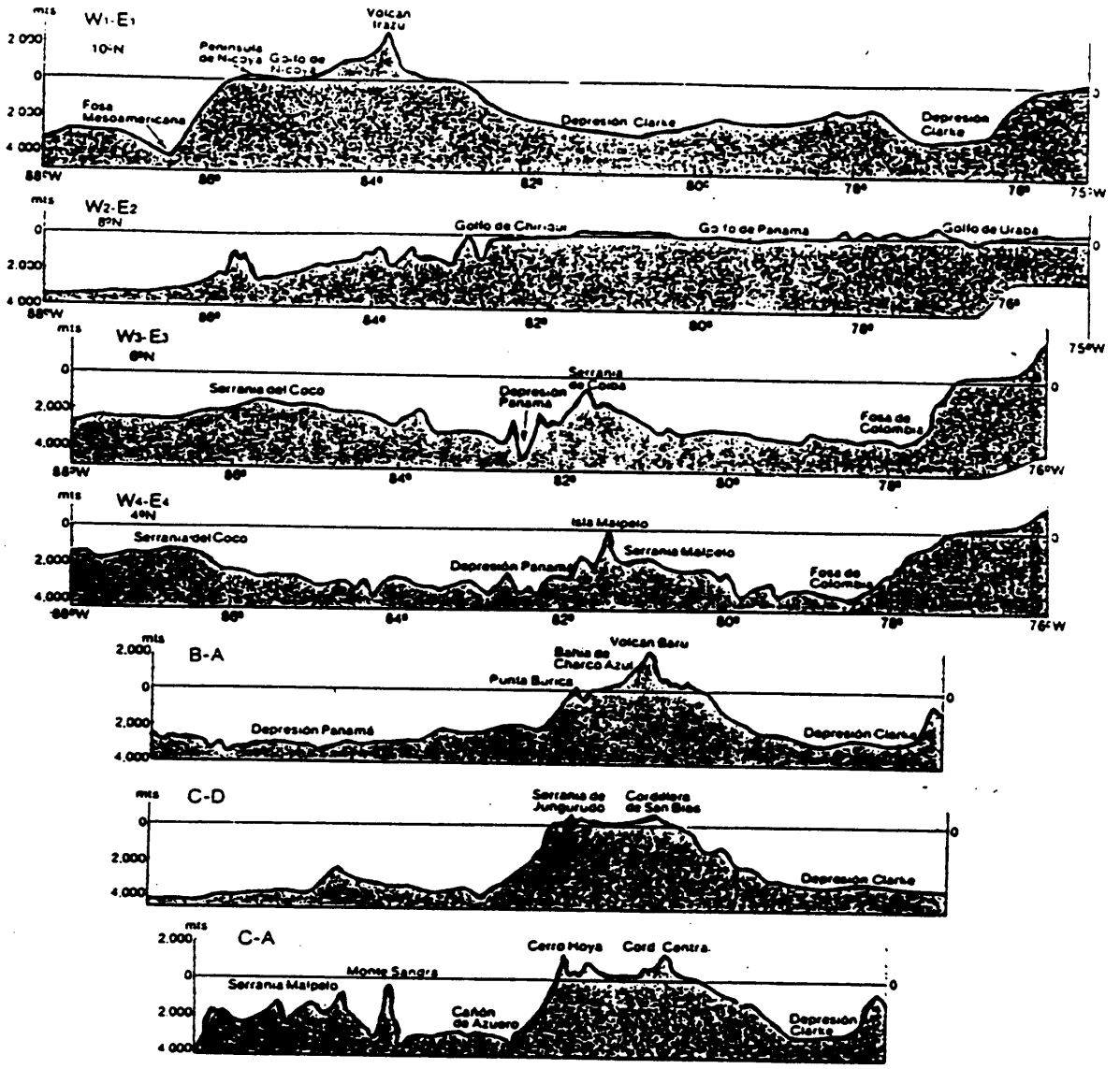
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

NAUTICAL MAP
CARIBBEAN COASTLINE
COLON REGION, PANAMA

DAMES & MOORE

FIGURE 5.2

BY Ralph DATE 06-21-93 CHECKED BY D & M JOB NO. 89437-001-0668 REVISIONS BY DATE



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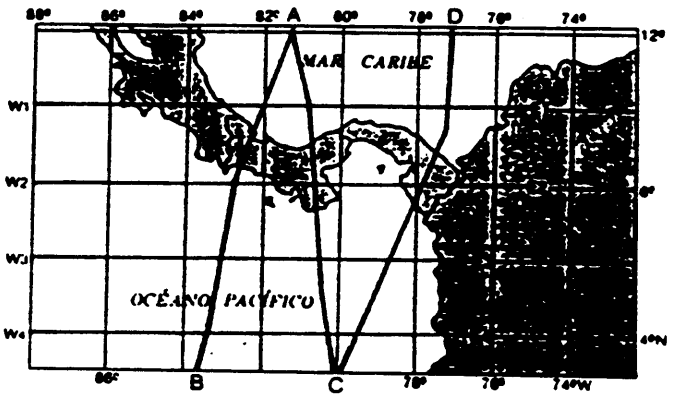
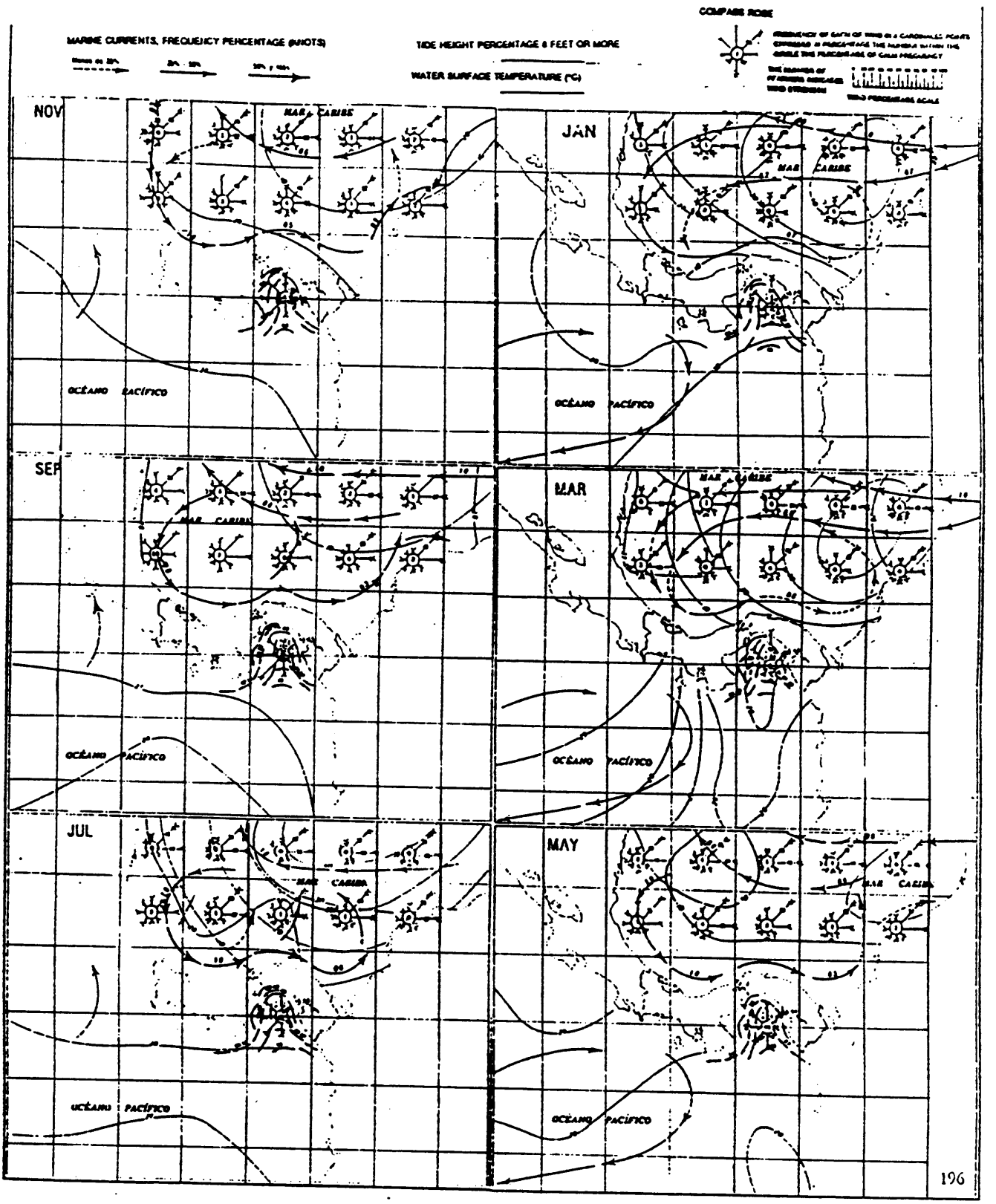


Reference: Tommy Guardia, 1988

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	PROFILES OF THE CARIBBEAN AND PACIFIC COASTS OF PANAMA	DAMES & MOORE FIGURE 5.3

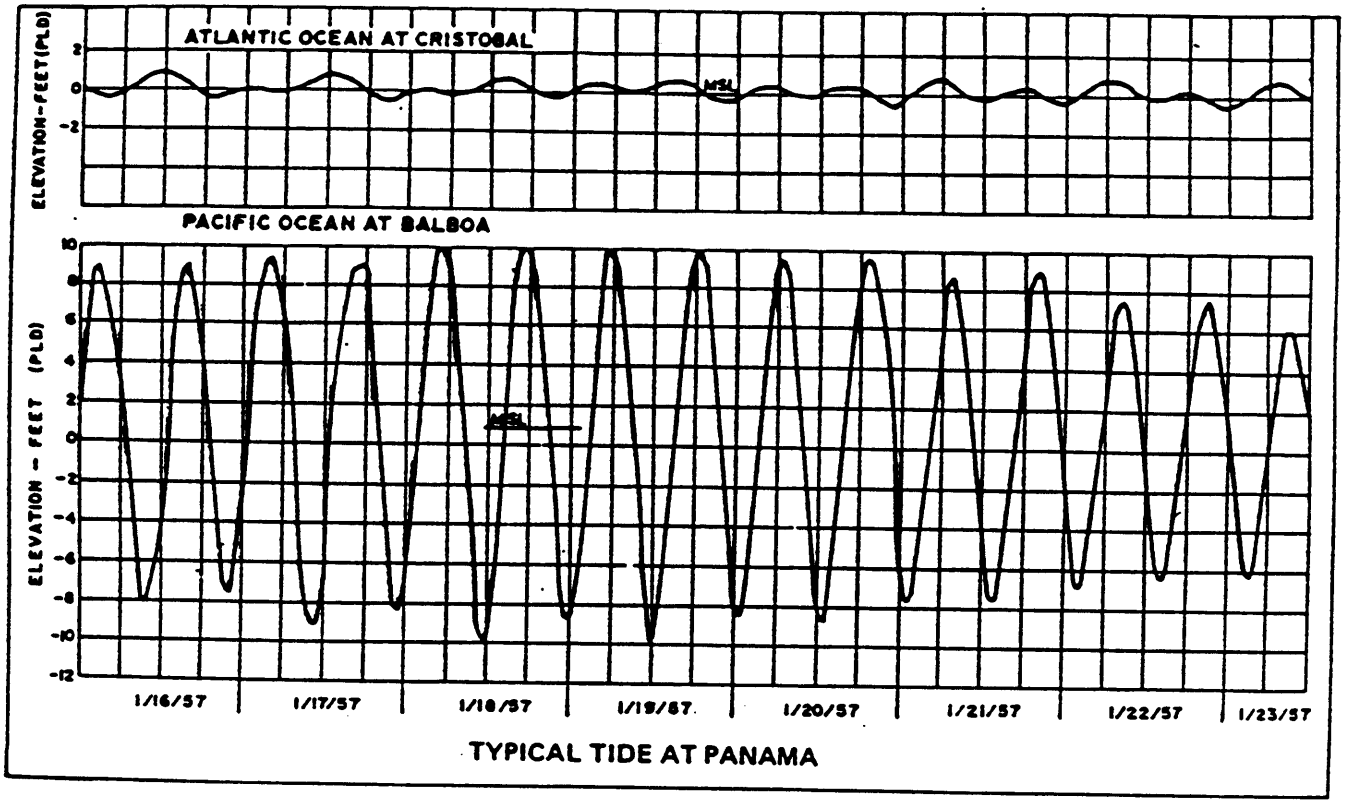
BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-6552 REVISIONS BY DATE



Reference: Tommy LaGuardia, 1988

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	MARINE CURRENTS ALONG BOTH PANAMANIAN COASTS	DAMES & MOORE FIGURE 5.4

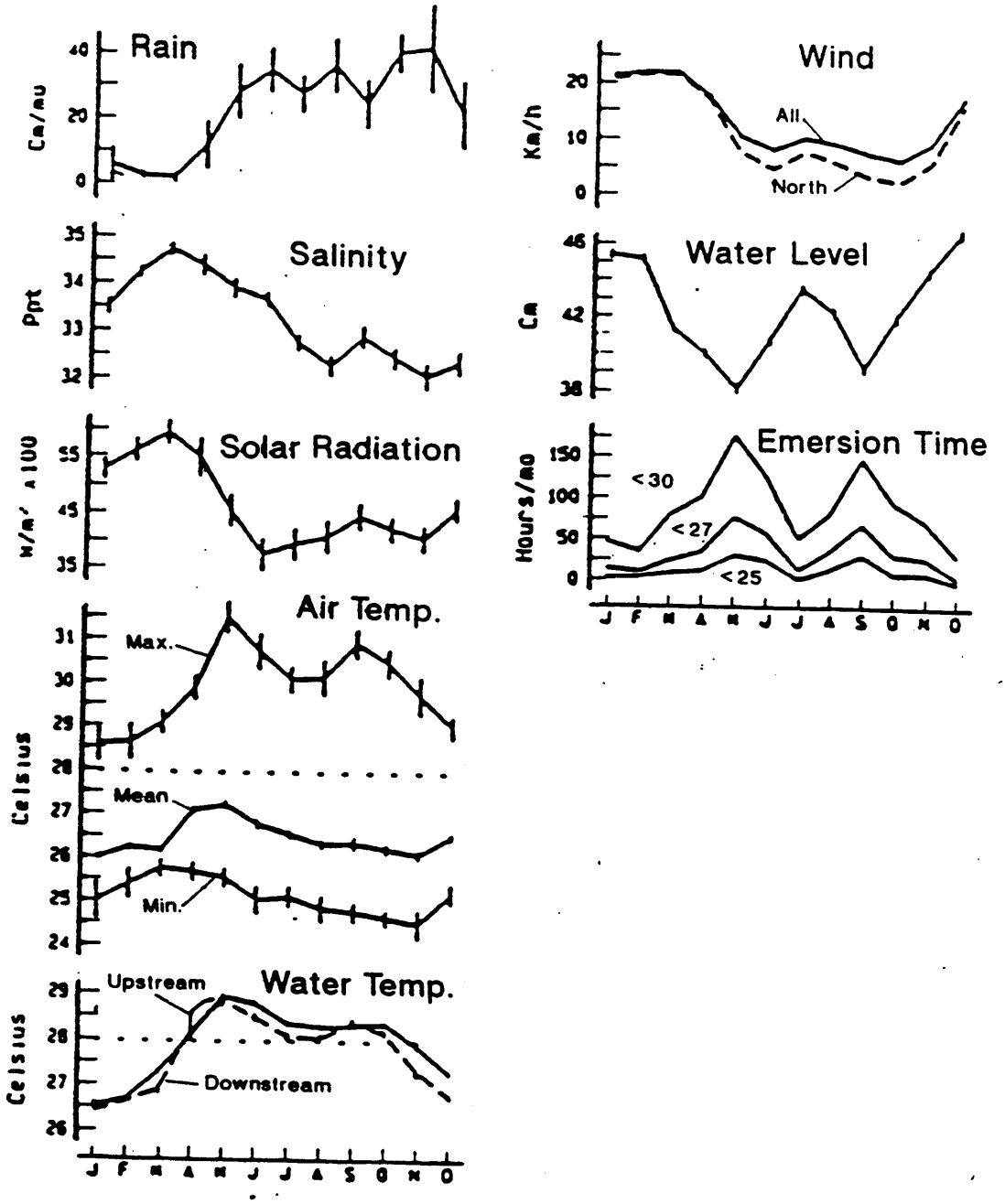
BY Ralph DATE 06-21-83 CHECKED BY D & M JOB NO. 00457-001-0068 REVISIONS BY DATE



Reference: PCC 1970

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	TIDAL FLUCTUATIONS IN THE CARIBBEAN SEA AND PACIFIC OCEAN	DAMES & MOORE FIGURE 5.5

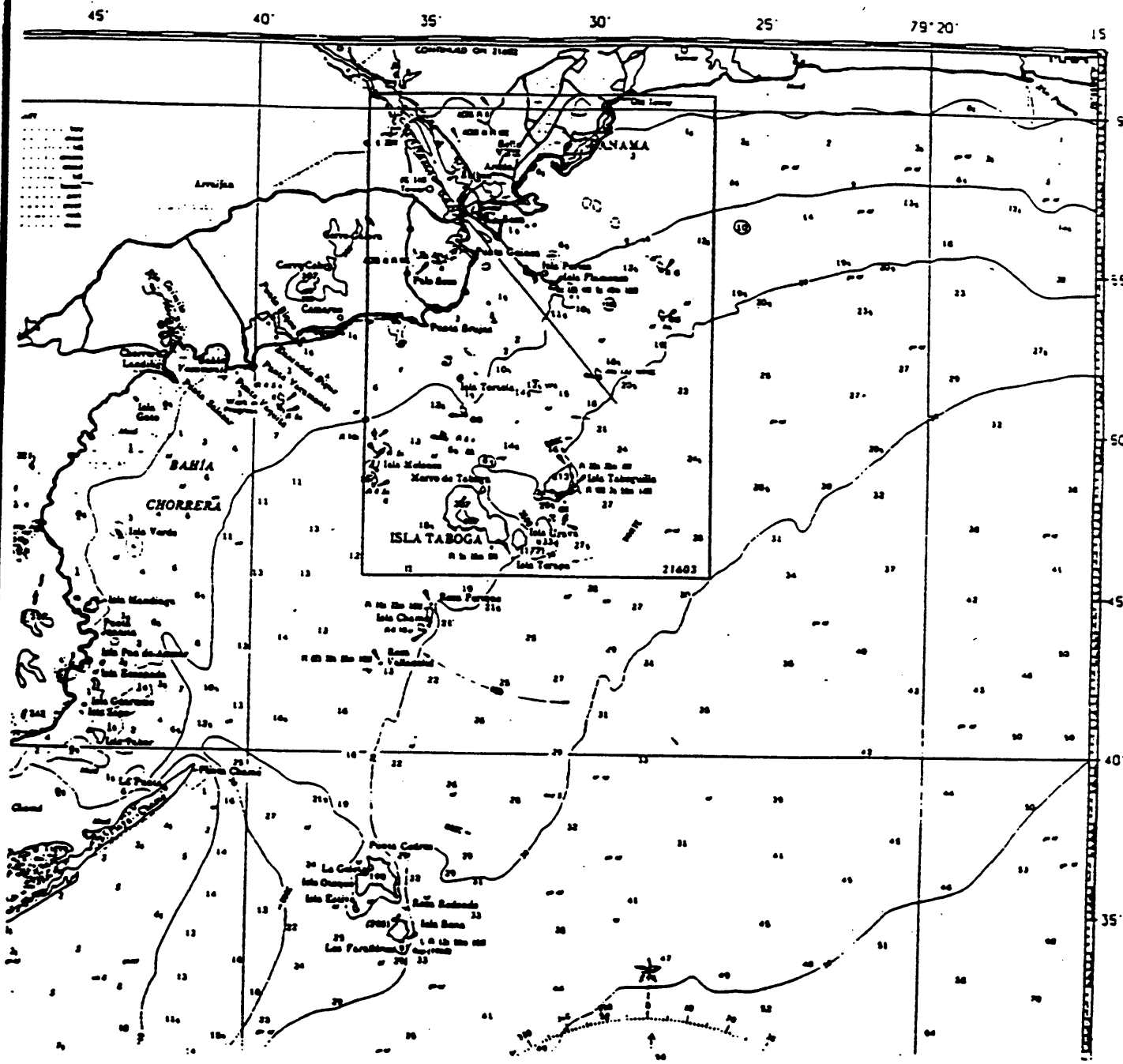
BY Ralph DATE 06-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE



Reference: Cubit et al, 1989

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	CLIMATE FLUCTUATIONS AT GALETA ISLAND, COLON, PANAMA	DAMES & MOORE FIGURE 5.6

BY Ralph DATE 06-21-93 CHECKED BY D & M JOB NO. 24437-001-6663 REVISIONS BY DATE



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

NAUTICAL MAP
PACIFIC COASTLINE
PANAMA BAY REGION

DAMES & MOORE

FIGURE 5.7

DATE
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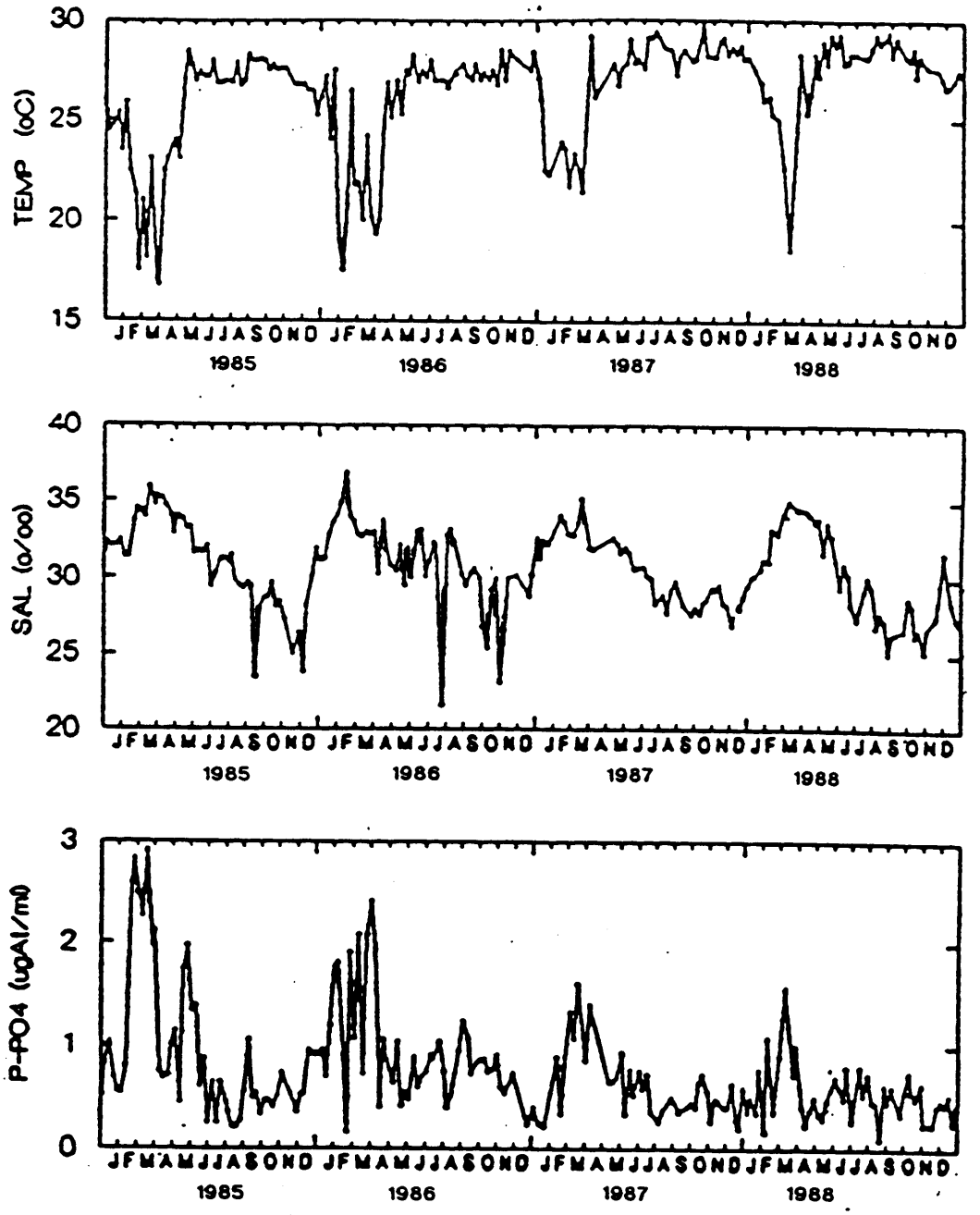
REVISIONS
D & M JOB NO. 00457-001-0000
CHECKED BY
DATE 06-21-83
BY Ralph



Reference: D'croz et al, 1989

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	WATER QUALITY - NAOS ISLAND AMADOR CAUSEWAY, PANAMA CITY	DAMES & MOORE FIGURE 5.8

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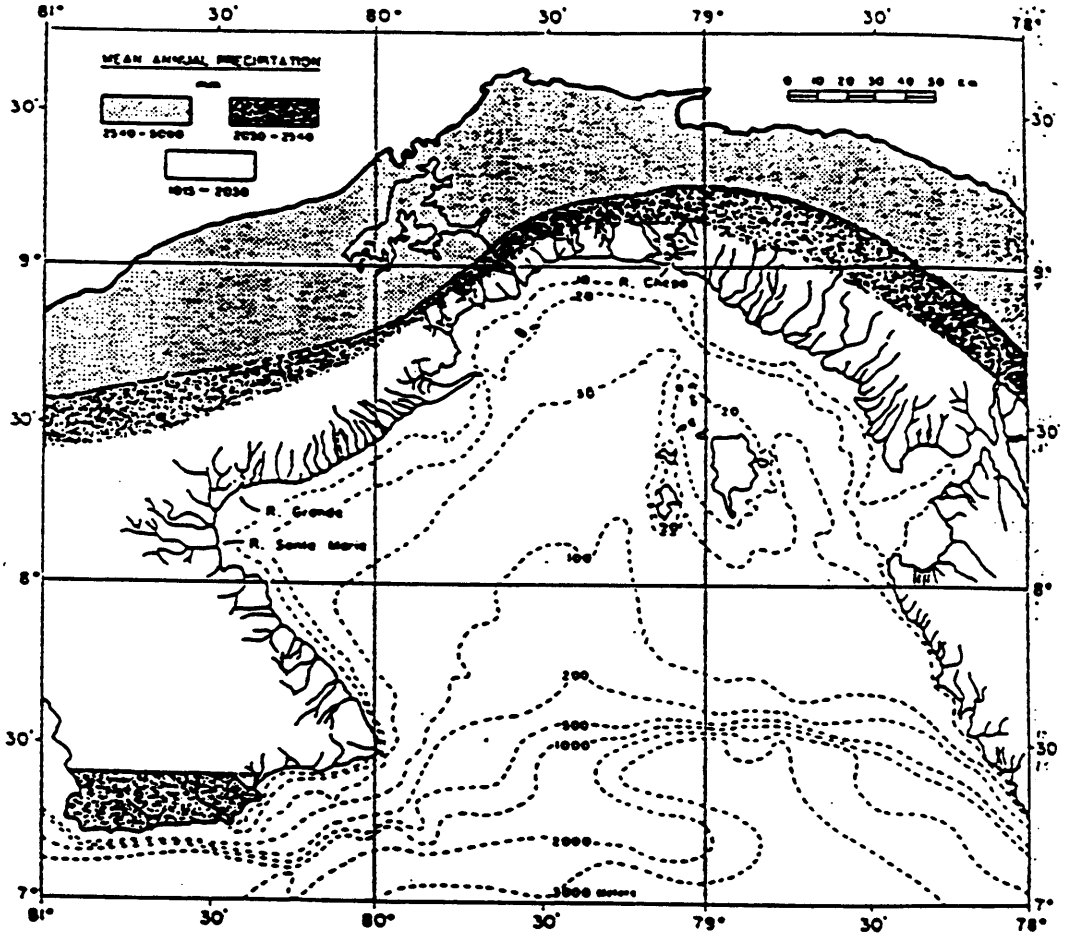
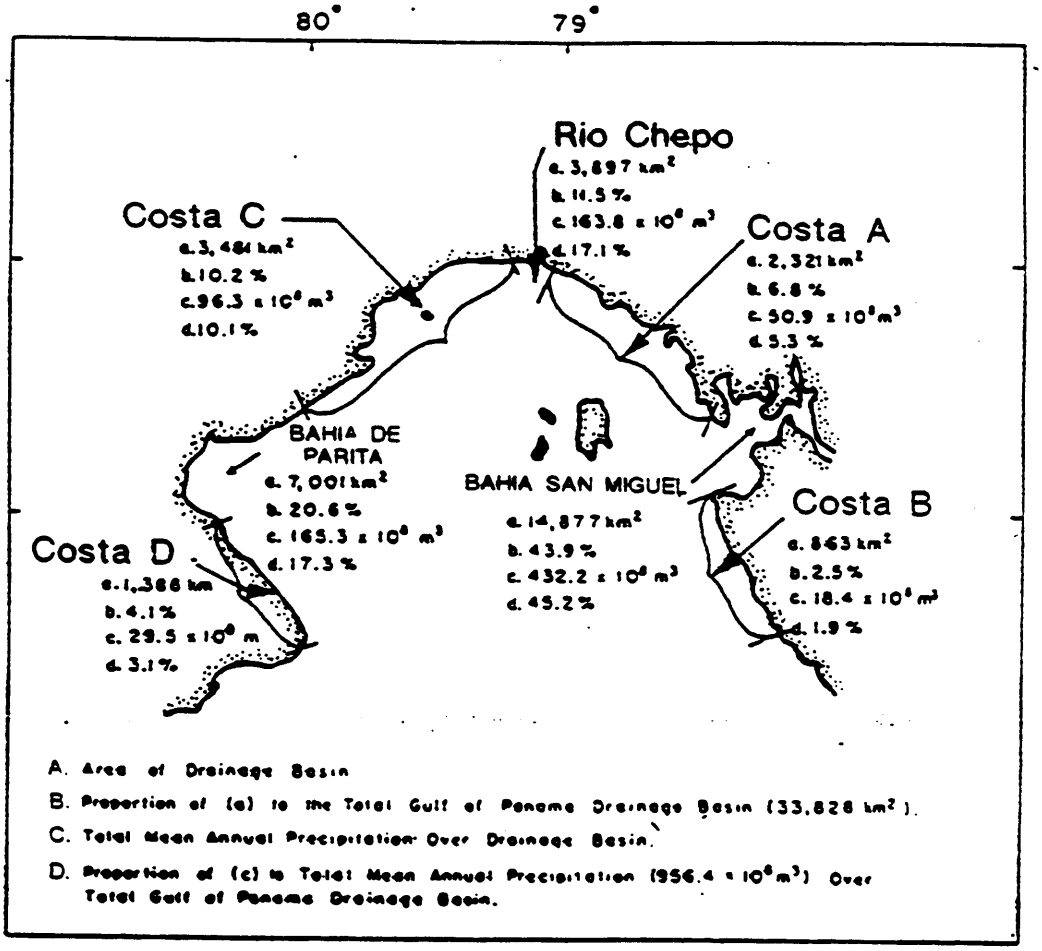
D & M JOB NO. 20437-001-0002
CHECKED BY
DATE 06-21-93
BY Ralph



Reference: Smayda, 1966

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	HYDROGRAPHIC SYSTEM OF THE GULF OF PANAMA	DAMES & MOORE FIGURE 5.9

BY Ralph DATE 06-21-93 CHECKED BY D & M JOB NO. 20437-001-5552 REVISIONS BY DATE



A. Area of Drainage Basin

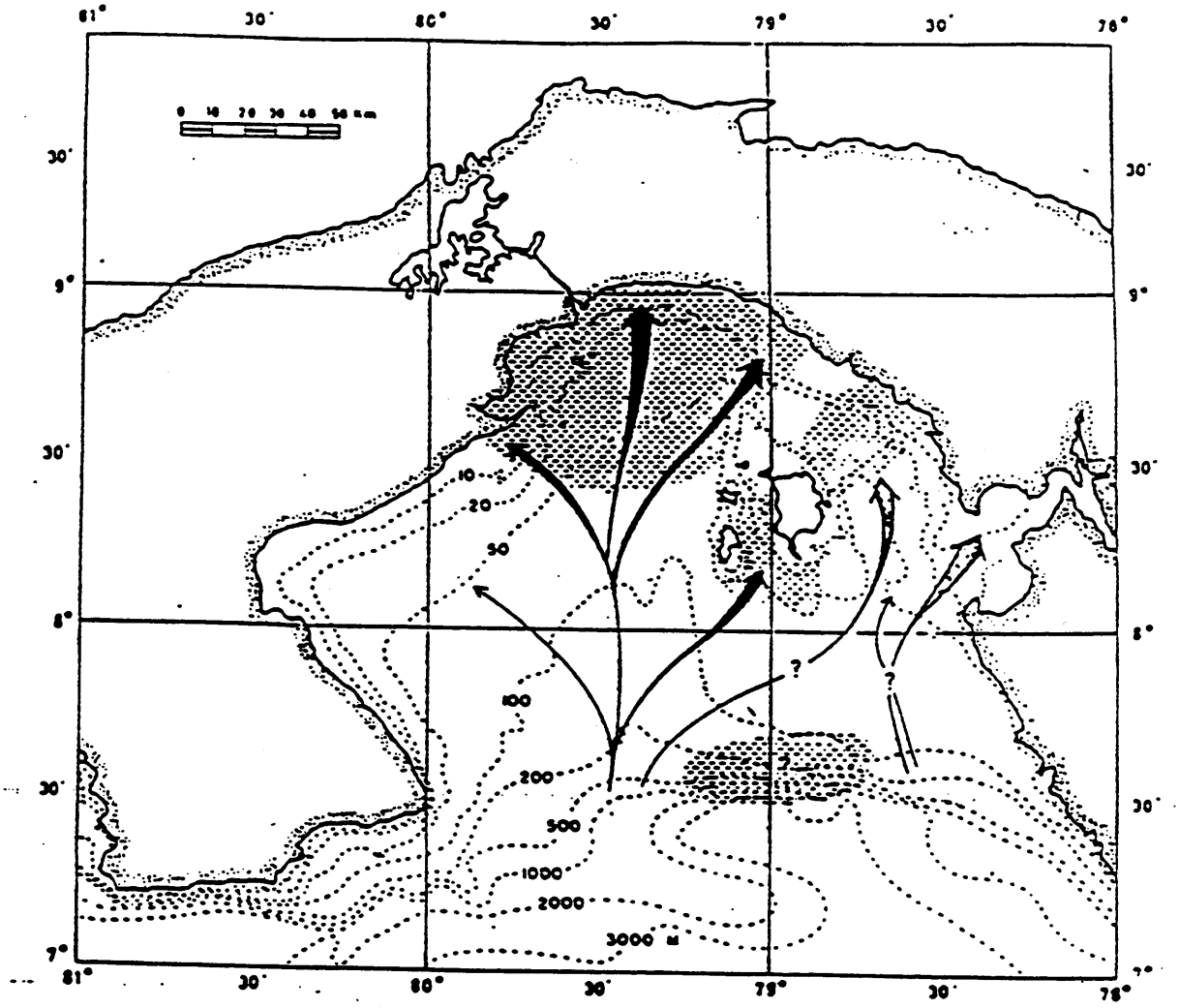
B. Proportion of (a) to the Total Gulf of Panama Drainage Basin (33,828 km²).

C. Total Mean Annual Precipitation Over Drainage Basin.

D. Proportion of (c) to Total Mean Annual Precipitation (956.4 x 10⁶ m³) Over Total Gulf of Panama Drainage Basin.

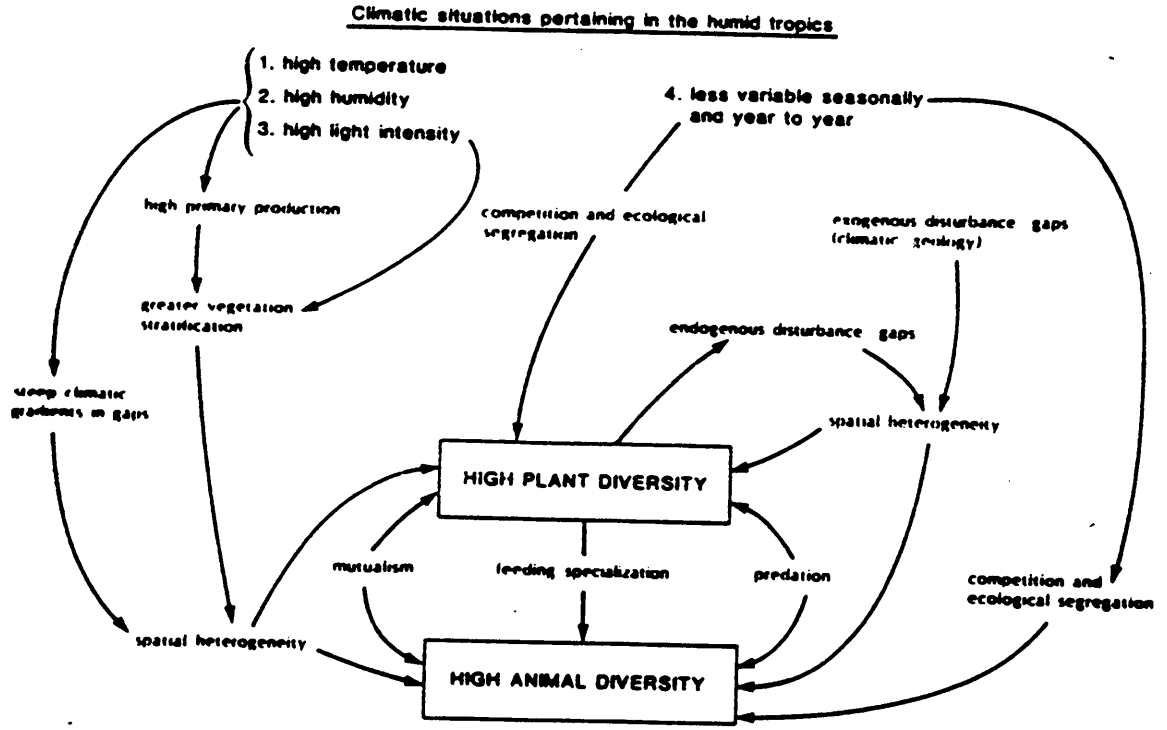
Reference: Smayda, 1956

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	RAINFALL DRAINAGE AREAS GULF OF PANAMA	DAMES & MOORE FIGURE 5.10



Reference: Smayda, 1966

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	CIRCULATION PATTERN OF WATER MASSES DURING UPWELLING GULF OF PANAMA	DAMES & MOORE FIGURE 5.11



Reference: Deshmunkh, 1986

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	HIGH SPECIES DIVERSITY IMPORTANT FACTORS	DAMES & MOORE FIGURE 5.12

6.0 ENVIRONMENTAL IMPACTS

Human activities in the tropics have converted "natural" ecosystems to agricultural, urban, and industrial uses; have exploited species, fragmented habitats, changed the demographic structure of forests; altered habitat, degraded the environment with atmospheric, aquatic, or soil pollutants; introduced exotic pests and predators; and domesticated favored species. All of these changes have had significant impacts on local and regional biological diversity. One can say with certainty that there are chains of cause and effect that lead to species loss. The chain begins with destruction (= loss) and fragmentation of habitat into smaller and smaller subdivisions, which is quickly accompanied by species loss. The loss of species, in turn, affects the integrity of ecosystems in which they have evolved, and the processes that maintain them.

6.1 GENERAL BIOLOGICAL IMPACTS

The development of either canal project may have both permanent and temporary effects on the biological environment. Permanent losses would occur in the immediate vicinity of excavation and construction. Adjacent habitat could be temporarily or permanently disturbed by equipment staging areas, materials and stock pile locations; work space requirements; and infrastructure such as worker camps, villages, electrical transmission lines, quarries, and roads. The impacts described in this section are common to both alternatives and virtually any disturbance-causing activity, such as those proposed.

The future persistence of biological diversity in remaining habitat (especially tropical forest) in the project area is a central concern in evaluating biological impacts of the proposed project alternatives. For a rough estimate of what to expect from such activities, one can refer to a rule of thumb for "islands" at equilibrium: the species number is halved for each reduction in area of 90 percent (Wilson, pers. comm. in Terborgh, 1992). Since most remaining fragments of tropical moist forest already comprise less than 0.1 percent of the original forested area in the tropics, at best, their ability to retain diversity is roughly one-eighth that of the intact forest. Further perturbation of these already stressed communities may continue to reduce their capacity to sustain biologically diverse communities.

Fragmentation inevitably implies a reduction of the total area of one habitat and a simultaneous increase in the areas of others. Plants and animals confined to fragmented areas have to cope with two basic problems: (1) whether the remaining fragments are large enough and close enough to each other to provide living space and opportunities for dispersal, and (2) the impact of the surroundings (the external threat). Man-made habitats support predators (e.g. dogs and cats), competitors (e.g. cattle, goats, pigs), parasites, and diseases which can spread into the fragments and interact with their residents.

Habitat loss reduces biological diversity by direct elimination of locally-adapted populations of plants and animals. Fragmentation can also affect the genetic diversity of, and within species by its influence on the evolutionary processes of extinction, selection, genetic drift,

gene flow, and mutation. Even if the level of diversity does not change, mating systems can be altered, which can affect the genetic structure of populations. Demographic changes influence survival by increasing the incidence of disease and introducing exotic pathogens, insects, mammalian herbivores, domestic predators, and competing vegetation, all of which have documented effects on genetic diversity, reducing the diversity of, and within species (Ledig, 1992).

Habitat fragmentation affects populations in several different ways. Subdivision of a continuous habitat increases insularization and reduces total area. This influences dispersal and population size directly by reducing immigration rate and increasing the extinction rate. A reduced fragment area and its changed configuration affect habitat composition within fragments; between the fragment interior and its edges; and in relation to surrounding habitats. These effects influence mortality and production through increased pressures from the surroundings, both biotic (e.g. predators, competitors, parasites) and abiotic (e.g. temperature, wind, light).

A local population may eventually become extinct if the size of a habitat fragment decreases below a threshold value, set by the minimum territory size requirements of a species. The effective population size of such species may then fall below the threshold of genetic viability or below some minimum size needed for recovery. This "effective population number" considers the relation between the effective number of reproducing individuals and the loss of genetic variation over time, in populations of various sizes and demographics. The smaller the population and faster the turnover of generations, the quicker inbreeding may occur and genetic variation be lost. Genetic variation provides for continual adaptation of a species to changing environmental conditions and the production of offspring that can persist in the face of new environments, new competitors, and new predators.

Forest fragmentation also creates non-forest habitat, which may increase the carrying capacity for generalist predators, open-field competitors, or parasites that may interact with species from the interior of the forest. A significant threshold probably appears when the amount of forest habitat decreases below 50%, i.e. when forest habitat shifts from a habitat mosaic to fragments. Forests become fragmented and may become transient habitat for specialist species from the interior of the forest, while non-forest habitat becomes continuous and becomes a more permanent habitat for generalist species.

Fragmentation also results in a biased sampling of the landscape mosaic, such that fragments may primarily represent only one, or at most, a few of the regionally available habitat elements. Such fragments may initially contain species that require missing habitats on a seasonal basis, or that are able to reproduce at levels above the replacement rate, only in habitats that no longer exist.

Consequently, a general loss or fragmentation of sensitive natural habitats in the project area may directly affect species abundance and diversity, population size, structure, and distribution, reproduction and survival, and ecosystem structure and function.

The following sections address potential impacts on various resources from construction, operation, and maintenance activities associated with the proposed project alternatives. Anticipated impacts are first described for the resources affected by all project activities. Impacts resulting from specific activities are then discussed, followed by an alternative- and site-specific description of impacts, where possible.

6.1.1 Soils

Soils are moved and compacted by heavy equipment, which can alter particle size and porosity, and destroy important soil components such as mycorrhiza and seeds and cause a loss of soil nutrients by leaching. Mycorrhiza associated with the root systems of many tropical plants influence nutrient cycling and germination processes. Excavation and construction activity may cause a mixing of soil layers and movement of organic materials. Once mixing occurs, essential nutrients may be leached from topsoil by underlying substrates. Harvesting and clearing of secondary forest for site preparation may adversely affect soils over the short-term by removing vegetative cover and exposing soil to more direct and intense rainfall, resulting in more extreme soil temperature variation and some soil movement; and to direct sunlight, causing a more rapid decomposition of humus layers.

The closed canopy, continuous litter cover, and root systems of natural forests reduce raindrop erosive forces and promote high infiltration rates. Removal of shade canopy may result in increased temperatures at the ground surface and decreased moisture content of the soil. This may result in the death of numerous soil organisms. Vegetation clearing activities would expose soil to more direct and intense rainfall, resulting in more extreme soil temperature variations and soil movement (erosion). Landslides and increased flooding are more likely where soils have been disturbed.

6.1.2 Botanical Resources

Effects on botanical resources could include direct disturbance to, or loss of sensitive species and establishment of undesirable ruderal species in areas of disturbance. Petroleum compounds could leak from construction equipment or spill on occasion, and toxic levels of these substances could be absorbed by plants, resulting in a local vegetation die-off.

Because plants are long-lived and cannot flee microclimatic conditions, the first changes in the plant community are expected to be manifested through differential mortality and growth of established individuals as well as through differential recruitment of seedlings. Demographic trends indicate a greater flux in the community structure of forest canopy trees

on the edges of forest remnants in comparison with continuous forest. Tree damage and mortality tend to be concentrated on the windward edge of forest fragments.

The understory plant community is also subject to edge-related changes, with seedling recruitment (growth) increasing significantly toward the edge of a forest fragment, especially with pioneers such as *Cecropia* spp. Litterfall rates also increase dramatically along the periphery of a fragment, soon after edge creation. This pattern tends to reverse after a period of time. The sudden loss of large numbers of leaves with high phosphorus content suggests that adult trees do not have time to mobilize and retract nutrients before dropping their leaves. Apparently, this occurs in response to the proximity of forest disturbance. This loss of nutrients may also play a significant role in the increased mortality of adult trees.

When soil structure and fertility are degraded by repeated disturbance, forest re-establishment may be greatly retarded. An alternate, and less desirable, successional sequence could occur, resulting in the rapid establishment of introduced grasses that support few species of plants or animals. When this occurs, the normal successional sequence halts or is dramatically slowed.

When disturbance occurs on a large scale, with thousands of hectares cleared in single blocks, the regenerative capacity of mature forests is impaired. Weedy shrubs and woody pioneer species readily re-establish themselves, but restoration of mature forests is less assured. This results from lack of seed input from tree species, whose seeds tend to be large, relatively short-lived, and dependent of animal dispersal. A secondary forest could become established, given sufficient time, but the process may take longer and it is likely to remain impoverished in comparison to the original climax forest.

Forest re-vegetation also varies according to local conditions. Regeneration on more infertile soils tends to be very slow. In areas of low and seasonal rainfall, forest regeneration is also slower, and there is always the possibility of deflecting succession to grassland or savanna ecosystems.

6.1.3 Wildlife

Excavation and construction activity is expected to have direct and indirect impacts to wildlife resources. These impacts may consist of temporary and permanent disturbance to wildlife habitats and temporary or permanent disturbance of regional fauna. Types of impacts (direct and indirect, beneficial and adverse) to wildlife resources would generally include:

- Direct loss or displacement of individual animals.
- Direct disturbance to or loss of wildlife habitat.

- Direct loss of important habitat elements such as breeding areas and cover sites.
- Creation of undesirable weedy habitat in disturbance zones.
- Fragmentation of habitats associated with construction.

Changes in physical parameters and their biological consequences are not the only effects of interrupting continuous habitat. Nonforest species for example, are given the opportunity to exploit forest habitat. Different species have different tendencies to disperse (e.g., migratory versus nonmigratory species) and require different home ranges or territories. Such differences should affect the likelihood that certain species may arrive and persist in a forest fragment.

Detailed knowledge of the ecology and specific habitat requirements of target species is required to fully understand the effects of habitat fragmentation in any given region. Is a mosaic of forest remnants of varying sizes enough to preserve forest-dwelling flora and fauna? Data confirm that forest remnants in such a mosaic would suffer significant alteration by edge effects and lose certain species of birds, primates, and perhaps important insect pollinators and coprophagous insects.

The amount, configuration, and duration of habitat disturbance at a given site, along with the home range and territory size of affected species may determine the impact on terrestrial biota. Individual animals, especially fossorial or sedentary species, such as some reptiles, small mammals, and carnivores, may be lost during construction. Temporarily disturbed areas could be recolonized and repopulated by the same species, but probably not by the same individuals, depending on the degree and extent of disturbance.

6.1.4 Aquatic Impacts

Dredging and aquatic deposition of spoils may have significant impacts, associated with the actual, physical removal of the resources, as well as through blanketing undisturbed areas of the lake and sea bottom.

Through clearing and erosion, soil and organic materials disturbed by construction can reach streams, lakes, estuaries, and oceans. The increased burden of soils and silts can cause physical changes through sedimentation and alteration of water flows. Sediments and suspended materials introduced into waters can affect water transparency, reducing visibility and affecting food gathering by fishes, invertebrates, and other organisms by settling on the gills and affecting physiologic activity and feeding processes.

Soil particles may also impede sunlight penetration, affecting the growth of aquatic plants. The heaviest particles may settle on the bottom, destroying existing plant and animal life and indirectly affecting all animals that rely on them. Suspended substances may be transported by prevailing currents. These can accumulate on the eggs of fishes, breaking some and impeding the normal growth of others; or on existing aquatic vegetation, where they may affect normal growth.

Changes in water quality may alter the trophic balance between producers and consumers. An increase in nutrients may cause an algal bloom, reducing the dissolved oxygen in the water and producing a die-off of aquatic fauna.

Excavation and dredging destroy benthic habitat. The suspension of sediments in the water column may lead to an increase in dissolved solids, some of which may be toxic to the biota, either directly or indirectly from bioconcentration in edible species.

Impacts associated with spoils deposition are similar, in that there may be an increase in suspended and dissolved solids. Benthic fauna and habitats may be destroyed as they are covered by the dredged materials. Other impacts to aquatic habitats may be produced by the erosion and rainfall runoff from the terrestrial operations. These also may cause changes in water quality, and can also affect the habitats by reducing the depths of streams due to increased sediment deposition.

Insoluble materials carried in the water or those created by the reaction of water with surface materials could be deposited in areas where dredge materials are removed. As corrosion of these materials proceeds, available oxygen in the water could be depleted.

The deposition of dredge spoils with high clay content could redden the receiving waters, altering their natural coloration. This could affect the transmission of light in these waters, which could inhibit vegetative growth and indirectly affect animal abundance.

Large quantities of dust generated at quarries and batching plants can pass, by means of rains and floods, into rivers and lakes. The dissolved and suspended solids could increase turbidity in surface waters. The same effect could occur from cement, concrete and cinder block residues, transported by rainwater to existing water bodies. Limestone in these residues can also alter the pH of these waters, upsetting the osmotic balance of sensitive, exposed animal tissues and damaging osmoregulatory abilities of aquatic species.

Water quality impacts associated with a reduction in riparian vegetative cover can also destabilize stream banks. Vegetation cleared in the construction zone may be carried by rains into nearby waterways, producing a layer of silt and organic material that could impede the normal development of some organisms, due to a reduction in dissolved oxygen.

Organic material in the water could die or continue to develop, affecting the existing nutrient balance.

Increased nutrient levels from decomposing organic materials, can stimulate the growth of plankton, algae and other aquatic plants. If the water receiving these nutrients are oligotrophic and contain dissolved oxygen in the bottom sediments, this may not produce significant environmental impacts, except where increased insolation contributes to temperature increases in the waters along stream margins, altering the equilibrium of the waterway. Thermal changes in fluvial systems can affect the local hydrologic cycle, microclimate, and water chemistry, which would subsequently impact fisheries and aquatic resources.

A small amount of organic material introduced into aquatic systems can be utilized by bacteria, other microorganisms and lower life forms, but if the quantity of these materials is very great, it may produce a disequilibrium between existing food resources, consumer animal populations, and available oxygen, affecting populations of secondary consumers.

If vegetation is not cleared from reservoir basins prior to filling, oxidation of these organic materials may result in the production of carbon dioxide (CO_2), which combines with water to produce carbonic acid, causing waters that contain considerable quantities of organic material to be more acidic (pH <7).

Spills of diesel, gasoline, hydraulic, brake, transmission, and other equipment fluids, as well as other chemicals including pesticides and herbicides may have a severe impact on aquatic resources, if they enter the system. Depending on the circumstances, the decrease in water quality, following such an event, may adversely affect botanical, wildlife, and aquatic resources. Fuels and lubricants are generally lighter than water and float on its surface, causing damage to animals and plants that come into contact with it.

Oils and other combustible fluids can emulsify in water, harming many forms of aquatic life. These pollutants are dispersed by currents, producing both short- and long-term effects. Organisms covered with such materials can die directly of asphyxiation or indirectly, as a surface layer of such material can disrupt the transmission of solar radiation, reducing the available oxygen. Direct contact with concentrated or diluted hydrocarbons can kill plants or animals that occur near the surface of the water. Some aromatic poisons can evaporate and disappear with time, but before this occurs, they contaminate the waters, causing the death of living organisms. Pesticides and herbicides used in agricultural activities can also contaminate surface and ground waters.

When pollutants are dispersed by currents, they can cause long-term effects, which affect the behavior of animals. When oils and similar substances coat the plumage of birds, for

example, they impede normal aeration, prevent the birds from floating or flying, or cause death upon ingestion during preening.

There is a greater likelihood of hydrocarbon contamination on the Caribbean side of the Canal, as a result of the loading of ships in Bahia Las Minas with petroleum from the Refinery of Panamá, S.A. Damage to marine ecosystems from a large oil spill has previously been observed on the reefs, mangroves, and seagrass beds of the Caribbean coast. Mangroves are particularly vulnerable because of their location and because they are low-energy habitats with little flushing. Their associated juvenile fish and shrimp fauna are sensitive and commercially valuable.

The Refinery of Panamá is actually situated on mounds of coral within the mangroves in the Bahia Las Minas, near the city of Colon (CONAMA 1988). Hydrocarbons that are ingested or absorbed by animals or plants do not decompose rapidly and can have cumulative effects on marine organisms. These substances inhibit the growth of corals and subsequently affect fishes, crustaceans, mollusks, and other reef-dwelling invertebrates and algae (CONAMA,1988).

Water used in the worker camps and villages can be contaminated with synthetic detergents, which are toxic to fish and other organisms, and from sewage discharges that could increase the level of pollution or nutrients. This is usually indicated by an increase in *E. coli* in the water. The controlled disposal of solid wastes in landfills could prevent the contamination of surface and ground waters.

Solid waste management, as such, does not exist in much of the project area. Traditionally, garbage, litter, and trash are dumped near housing facilities or into streams, rivers, and mangroves. Human wastes are treated similarly. At low population densities this practice may only be aesthetically undesirable, and may not present a significant threat to water quality. Adverse impacts typically associated with improper disposal of larger volumes of waste materials associated with worker camps and villages could be controlled by incorporating a waste management and disposal plan into the project.

Specific impacts associated with the aquatic habitat are indicated as follows: Associated with zone 1 (Caribbean) of the High-Rise Lock Canal, there may be effects from the construction of the temporary jetty, and the sediment deposition sites. Here, potential hydrocarbon spills from the operating equipment and ships may affect water quality. Increases in turbidity during the deposition of wastes are also expected here. Additional impacts are anticipated in Limon Bay, as well as in the Agua Clara and Chagres Rivers, due to increases in sewage waters, erosion from the construction of bridges, roads, batching plants and the proposed recirculating lock water basin.

In Gatun Lake (Zone II), impacts to surface water through a reduction in the water quality are expected from the use of the sediment deposition sites. This includes the areas near Barbacoa and Barro Colorado islands, as well as the rivers of Mandinga, Mariposa, Bailamos, Cueva and Corotu. Other effects may be observed in the bays of Aguas Claras, Frijoles, and Aojeta. Construction of roadways may affect the Carabi and Culo Seco rivers. Dredging and lock construction activities may have effects on the adjacent areas of Lake Gatun.

In Gaillard Cut (Zone III), impacts to surface water are expected at the Mandinga and Grande rivers as well as to the Mandinga and Del Puente creeks, due to the sediment deposition sites.

Dredging activities may affect the water quality within Gaillard Cut, and there may be effects to the Cocoli, Camacho and Mandinga rivers from the construction of the surge basin, construction camp and roads.

In the Miraflores area (Zone IV) the crushing and batching plants may affect the Grande and Sterpe rivers. The construction of bridges at Bas Obisbo and Miraflores lakes may have the potential to affect the water quality in these areas. Impacts to the water quality from the sediment depositions sites may affect the Grande, Sterpe and Conga rivers. The construction of the surge basin may affect the Victoria stream. One of the major excavation areas of this alternative is associated with the construction of the new Miraflores Locks, which may affect the water quality of the adjacent canal structures.

Within the Pacific (Zone V), impacts to the water quality may occur from the construction of the temporary and permanent jetties, bridge and the proposed recirculating lock water basin. More significant impacts may occur from the use of the sediment deposition sites that may also affect the Velasquez River and Victoria Creek.

Additional impacts may occur from the construction of the Indio River dam, and the Ciri or Trinidad River dam. Batching plants associated with the construction these dams may also have the potential to affect the water quality.

For the sea-level canal, water quality impacts may occur in the Caribbean (Zone I), that may be related to the excavation, dredging, sediment deposition, construction of the jetty, bridges and diversion channel. These may also affect the adjacent Lagarto and Quebrado rivers.

Within the Quebrado area (Zone II), impacts from the sediment deposition sites may be expected to affect the water quality from the Arrieros river, as well as the Candelejas, Escobas and Arrieros creek. Minor impacts may occur at the La Chunga creek. The construction of roadways may affect the Arrieros stream, Caño Quebrado river, an the

Escoba, La Chunga and La Guencha creeks. The batching plant and construction camps may also affect the water quality of the Arrieros River.

Within the Lake Gatun area (Zone III), there may be significant effects to water quality of Lake Gatun, caused by the construction of the barrier dams, and subsequent dewatering of the isolated portion and the area of La Laguna. Within La Laguna, there are extensive wetlands that may be lost by the planned dewatering. This may have additional effects to the water quality. The sediment deposition areas may affect portions of Lake Gatun, associated with Trinidad Bay, Caño Grande and Caño Gigante. Other areas affected by the sediment depositions areas include the Chica and Los Hules rivers. The plans for the diversion scheme may also affect the Cano and Quebrada Chica rivers.

Within the Continental Divide area (Zone IV), the sediment deposition sites may have the potential reduce the water quality, or eliminate various rivers and creeks. It is possible that the Caimito, Bernardino, Aguacate, Pescado, El Arado, Viejo, Lirio, and La Guabita rivers, along with La Jicotea, Naranjal, Mojica and San Jose creeks may be severely affected. Minor effects may occur in the Pasar, Buique and Limones creeks.

Roadway construction may affect the water quality of the Caimito, Congo, El Arado and Pescado rivers, along with Naranjal Creek. The construction of the Tidal gates may affect the Caimito River.

The ECE Report also indicates the Caimito and Pescado rivers may be used to provide water for the freshwater barrier within this zone, and that the Caimito and Martin Sanchez rivers may contribute in the Pacific area.

Within the Pacific area (Zone V), it is probable that strong water quality effects may result from the construction of the jetties, the dredging, and sediment deposition sites along the Caimito River and the Bay of Panama.

Additional impacts to water quality may occur from the creation of the small impoundments north of the actual canal at the Upper Gatun Dam. There may be impacts to water quality associated with the quarry, crushing plant and batching plant. The spillway from Impoundment E (west portion of Lake Gatun) into the Lagarto River may also cause changes in water quality.

Table 6.1 presents additional information regarding these potential water quality impacts.

Table 6.1a Environmental Impact - Water Quality

High-Rise Lock Canal - Zone I. Caribbean														
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Temporary Jety	Caribbean Sea (f)		+			+		+			+		+
Sediment Deposition Sites	Caribbean Sea		+		+	+							+
Town (g)	Clear Water R.		+			+			+		+		
Bridges	Limon Bay		+			+					+		+
Roads	Chagres R.		+			+	+				+		+
Batching Plants	Clear Water R.		+		+					+			
Recycling Areas	Clear Water R.		+			+							+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes:

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1b Environmental Impact - Water Quality (Cont.)

High-Rise Lock Canal - Zone II. Gatun Lake.													
Construction	Highly Impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Sediment deposition sites	Gatun Lake: Zones closed to: -Barbacoa Is., -Barro Colorado Is. Mandinga R. Mariposa R. Aguas Claras Bay Frijoles Bay Aojeta Bay Bailamos R.	R. Mariposa R. Cueva R. Corotu	+		+	+							+
Roads	Carabi R. Culo Seco R.		+			+	+				+		+
Dredging	Gatun Lake		+			+					+		+
New Locks	Gatun Lake		+			+	+				+		+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1c Environmental Impact - Water Quality (Cont.)

High-Rise Lock Canal - Zone III. Guillard Cut.														
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Sediment deposition sites	Mandinga R. Grande R.	Mandinga Creek Del Puente Creek	+	+									+
Roads	Caraba R. Culo Seco R.		+	+			+				+		+
Dreadging	Guillard Cut		+	+							+		+
Surge Basin	Cocoli R.		+	+									+
Costruction Camp	Camacho R.		+		+				+		+		
Roads	Mandinga R.	Del Puente Creek	+			+	+				+		+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1d Environmental Impact - Water Quality (Cont.)

High-Rise Lock Canal - Zone IV. Miraflores.														
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Crushing Plant		Grande R. Sterpe R.	+		+					+	+		
Batching Plant		Grande R. Sterpe R.	+		+					+	+		
Bridge (Close to Bas Obispo)	Canal		+			+							
Bridge (over Miraflores Lake)	Miraflores Lake		+			+	+				+		+
Reciclable zone			+			+					+		+
Sediment deposition sites	Grande R. Sterpe R. Conga S.		+		+								+
Surge Basin		Victoria S.	+			+							+
Lock Excavation	Miraflores Lake		+			+	+				+		+

Codes of impact classification:
D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes
DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water
PA = Particles in the Air N = Noise Pe = Pesticide
WC = Water coloration

Table 6.1e Environmental Impact - Water Quality (Cont.)

High-Rise Lock Canal - Zone V. Pacific														
Construction	Highly Impacted Seas, Rivers & Streams	Less Impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Sediment deposition sites	Pacific Ocean		+		+	+							+
	Velasquez R.	Victoria Creek	+		+								+
Temporary Jetty	Pacific Ocean		+		+			+			+		+
Permanent Jetty	Pacific Ocean		+			+		+			+		+
Recycling areas	Canal		+			+					+		+
Bridge	Canal		+			+					+		+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water

PA = Particles in the Air N = Noise Pe = Pistacide

WC = Water coloration

Table 6.1f Environmental Impact - Water Quality (Cont.)

High-Rise Lock Canal - Additional													
Construction	Highly Impacted Seas, Rivers & Streams	Less Impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	.T	P	DRE	H	SW	AP	N	Pe	W
Impoundments (Southeast of actual canal)	Ciri R. Indio R. Trinidad R.		+			+	+				+		+
Quarry	Gatun R.		+		+					+	+		+
Batching plants	Ciri R. (c) Indio R. Trinidad R. (c)		+		+					+	+		+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1g Environmental Impact - Water Quality (Cont.)

Sea Level Canal - Zone I. Caribbean.														
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Clasification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Excavation	Caribbean Sea		+		+						+		+
Dredging	Caribbean Sea		+		+						+		+
Sediment deposition sites	Caribbean Sea		+			+					+		+
	Quebrado R. (a) Lagarto R. (a)		+		+						+		+
Jetty	Caribbean Sea		+			+		+			+		+
Bridges	Canal		+			+	+				+		+
Diversion Channel	Lagarto R.		+			+							+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1h Environmental Impact - Water Quality (Cont.)

Sea Level Canal - Zone II. Queblado.													
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Sediment deposition sites	Arrieros R. Candelejas Creek Escoba Creek Arrieros Creek	La Chunga Creek	+		+								+
Construction campment		Arrieros R.	+		+				+		+		
Batching plant		Arrieros R.	+		+					+	+		
Roads	Arrieros S. Cano Quebrado R. Escoba Creek La Chunga Creek La Guencha Creek		+			+	+				+		+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.11 ENVIRONMENTAL IMPACT - WATER QUALITY (CONT.)

Sea Level Canal - Zone III. Lago Gatun														
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Clasification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	WC
Sediment deposition sites	Gatun Lake: - Trinidad Bay - Cano Grande - Cano Gigante Chica R. Los Hules R. (a,d)	La Laguna	+			+							+
Roads	Los Hules R.	Las Minas Creek	+			+	+				+		+
Railroad	Gatun Lake		+			+	+				+		+
Barrier dams	2 barriers that divide: -Lake Gatun -Los Hules R.	Queda Creek	+			+							+
Diversion channel	Cano R. (d) Quebrada de Chica R. (d)		+			+							+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.1.j Environmental Impact - Water Quality (Cont.)

Sea Level Canal - Zone IV. Continental Divide													
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Imp Cla D	I	T	P	ENVI DRE	C H	SW	AP	N	Pe	WC
Excavation			+			+							+
Dredging			+			+							+
Sediment deposition sites	Caimito R. (a) Bernardino R. Aguacate R. Pescado R. El Arado R. Viejo R. Lirio R. La Guabita S. La Jicotea Creek Naranjal Creek Mojica Creek San Jose Creek	Pasar Creek Buique Creek Limones Creek	+		+								+
Construction Towns (g)	Caimito R.		+		+	+		+			+		+
Roads	Caimito R. Congo R. El Arado R. Pescado R. Naranjal Creek		+			+	+				+		+
Tidal Gates	Caimito R.		+			+	+				+		+
Rivers that will be used as freshwater barriers	Caimito R. (b) Pescado R. (b)		+			+							+

Codes of impact classification:
D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes
DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Water
PA = Particles in the Air N = Noise Pe = Pesticide
WC = Water coloration

Table 6.1k Environmental Impact - Water Quality (Cont.)

Sea Level Canal - Zone V. Pacific													
Construction	Highly impacted Seas, Rivers & Streams	Less impacted Rivers & Streams	Impact Classification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	W
Sediment deposition sites	Pacific Ocean		+			+							+
	Caimito R. (a)		+		+								+
Jettys	Pacific Ocean		+			+					+		+
Dredging	Caimito R.		+		+						+		+
Rivers that will be used as freshwater barriers	Caimito R. (b) Martin Sanchez R. (b)		+			+							+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

Table 6.11 Environmental Impact - Water Quality (Cont.)

Sea Level Canal - Additional														
Construction	Highly impacted Seas, Rivers & Strea	Less impacted Rivers & Streams	Impact Clasification				ENVIRONMENTAL IMPACT						
								CONTAMINATION					
			D	I	T	P	DRE	H	SW	AP	N	Pe	W
Impoundments (North of actual canal)	Gatun R.		+			+	+						+
Quarry	Cerro Azul (h)		+		+					+	+		
Crushing plant	Cerro Azul		+		+					+	+		
Temporary Jetty	Pilon Port (Caribb.)		+		+						+		+
Spilway - Diversion Channel	Lagarto R. (b)		+			+	+						+

Codes of impact classification:

D = Direct I = Indirect T = Temporal P = Permanent

Environmental impact codes

DRE = Deforestation, runoff and erosion H = Hidrocarbons SW = Sewage Waters

PA = Particles in the Air N = Noise Pe = Pesticide

WC = Water coloration

6.1.5 Epidemiology and Public Health

During and after construction, the creation of suitable habitats for some hematophagous insects could increase, particularly mosquitos. During construction, conditions may be favorable for the increase of malaria vectors, such as *Anopheles albimanus*, and *Aedes aegypti*, the vector of Dengue fever and Urban Yellow fever, which breeds in artificial water containers. After construction, other water-dependent vectors (*Culex ocossa* - Venezuelan Equine Encephalitis) may find suitable conditions for proliferation and further increase the risk of disease transmission to human hosts. Vertebrate and insect fauna of the region also are associated with other diseases, such as leishmaniasis, Chagas disease, encephalitis, and sand fly fever. For a full treatment of these diseases and vectors, refer to Section 5.4.4.

6.1.6 Air Quality/Noise Impacts

Construction equipment and vehicles may generate volatile organic compounds and various oxides of nitrogen. At times, exhaust fumes from diesel engines can be thick enough to obscure visibility, and protracted exposure to these fumes may have an adverse effect on the health of nearby vegetation and wildlife. During the dry season, airborne dust may also contribute to a local reduction of air quality and may adversely affect the health of nearby vegetation and wildlife. In general, the relatively short duration of these activities at a single location, in conjunction with an existing, relatively unpolluted airshed suggest that these impacts may be minimal.

Motor exhaust noise, horns, generators, and other construction equipment and activity has the potential to temporarily disturb terrestrial fauna located some distance from the project area. It is anticipated that most animals may tend to move away from the area, but others may be attracted, not necessarily to the source of the noise, but to the human presence it signifies. Animals that could be attracted include scavenging marsupials, such as *Didelphis* ssp. and less commonly, certain carnivores.

6.2 ACTIVITY SPECIFIC IMPACTS

Certain activities associated with the construction, operation, and maintenance of either alternative have similar, characteristic impacts. These are described below.

6.2.1 Roads

The major direct environmental impact of roads is erosion. Unless roads are carefully sited, constructed, and maintained, severe erosion can occur. Improper drainage in areas of high precipitation can ruin roads and erode adjacent lands, particularly where the terrain is steep. Even during periods of low rainfall, a short but intense rain can erode large swaths

downstream of the drainage ditches. The resulting gullies, channels, and trenches could conceivably cause the loss of many tons of fertile topsoil annually, with a concomitant drop in crop productivity and habitat loss. Slips and landslides, particularly in steep terrain, may both accompany and exacerbate erosion.

Depending on their design, roads can have adverse impacts on adjacent wetlands (lagoons, marshes, estuaries, inland deltas, mangroves, and tidal flats). Roads built on raised levees or embankments which interfere with cross drainage or do not allow movement of water can permanently impair the biological cycles and productivity of wetland ecosystems. Roads can also function as dams and cause flooding by blocking water flows and increasing runoff. Increased silt loads and eroded materials reaching water sources may decrease productivity, increase turbidity, and degrade water quality.

Roads, as well as other linear structures and facilities, have the potential to fragment terrestrial habitat by creating barriers to movement for some species of plants and animals. Terrestrial and arboreal mammals, amphibians, and reptiles could find their way blocked by cuts, fills, and/or ditches. Smaller animals may be reluctant to cross the open spaces created by roads, however, suitable habitat would be created or enhanced for species that inhabit the edges of forests. Some larger mammals may utilize rural roads that do not receive heavy traffic as travel corridors. Plant species that require animals for seed dispersal may also be prevented from re-colonizing areas effectively partitioned by linear facilities. Increased traffic on main and secondary access roads may increase mortalities in wildlife populations.

Additional indirect impacts are expected if roads provide access to formerly remote lands. These induced impacts include land use changes and resource exploitation that are difficult to quantify and may be difficult to manage.

Streams and receiving waters may experience increases of bedload and suspended sediment from erosion associated with roads. High levels of fine sediments may seal rubble and gravel substrates, decreasing spawning area for fish, egg survival, emergence of fry, and hiding cover for fingerlings. Pool volumes may also be decreased, resulting in direct loss of living space.

Changes in overall water yield are anticipated from watersheds, as well as peak and low-flow events in streams.

6.2.2 Dams and Reservoirs

Even relatively small dams can cause irreversible environmental changes over a wide geographic area and thus have the potential for significant impacts. The area of influence of a dam may extend from the upper limits of the catchment of the reservoir to as far

downstream as the estuary, coast, and offshore zone. The effects of flooding land to form the reservoir and the alteration of riverine water flows far overshadow the general construction impacts (e.g., dust, erosion, noise). The entire biological environment within the watershed can be profoundly affected.

The creation of new artificial lakes may significantly effect water flow, aquatic biota, and sedimentation patterns. During dam construction and the filling of reservoirs, there may likely be an increase in the turbidity of adjacent waters. An increase in the concentration of nutrients (especially nitrogen and phosphorus) and a decrease in dissolved oxygen in the new reservoir may result from the decomposition of flooded vegetation.

Fertilizers and agricultural chemicals reaching the impounded water could also increase the nutrient availability. This may support reservoir fish populations and raptors that feed on them, and can stimulate the growth of aquatic weeds such as water lettuce, water hyacinth, *Hydrilla*, and undesirable algal mats. Hydrogen sulfide, methane, and other products of anaerobic decomposition are noxious to aquatic life. Eutrophication may be compounded as suspended particles and nutrient-rich silts also become deposited in the reservoirs. In addition, these nutrients would no longer be available to downstream vegetation.

Riverine fisheries and dependent terrestrial biota are expected to decline with changes in water regime. Changes in water temperature and quality, loss of spawning habitat, and creation of barriers to fish movements are all likely impacts. The creation of fisheries habitat in the new reservoir, however, may benefit waterfowl and other species that forage in lentic (lake) rather than lotic (river) habitats.

Estuarine and mangrove biota are particularly sensitive to fluctuations in salinity, temperature, and water quality. Changes in flows which affect these factors may alter species composition and distribution. Changes in water regime and nutrient balance may also have a profound impact on estuary and mangrove productivity and diversity. Marine fish and shrimp species which feed or spend part of their life cycle in the estuary and mangroves may also be negatively impacted. Alterations in watercourses, which result in the creation of endorheic conditions, may amplify these impacts. The term endorheism refers to an area where streams occur, but do not reach the ocean, because streamflows are obstructed or diverted to a reservoir basin or other landlocked terminus.

The creation of new dams and spillways in the study area may also allow the introduction of exotic species, such as the peacock bass (*Cichla ocellaris*) and the aquatic weed *Hydrilla verticillata* into some (e.g. Largarto or Indio) river basins. However, the greatest impact on wildlife may come from the loss of habitat flooded during reservoir filling and land use changes in the watersheds. Migratory and other more localized movements of wildlife may

be disrupted. Habitat for certain aquatic-dependent fauna including waterfowl, reptiles, and amphibians could be increased.

6.2.3 Channel Excavation, Dredging, and Spoil Deposition

Dredging, or underwater excavation has many of the same impacts as terrestrial dredging and construction, along with additional impacts on aquatic ecosystems. Additional impacts can be anticipated due to the blasting operations, that may kill off organisms in the vicinity of the blast zone. These activities also can produce impacts through the physical removal of the resources by dredging, and the smothering effects of their deposition on undisturbed areas, or those that have re-established an equilibrium after earlier depositions. Potential aquatic effects include oil spills and discharges; contaminant release from sediment resuspension and surface runoff; point source discharges, and habitat destruction. A temporary increase in turbidity at dredging sites may decrease light penetration and associated photosynthetic activity. Possible saltwater intrusion into ground or surface water may alter species composition and diversity.

The pelagic eggs and larvae of commercial fish and shrimp species in the Gulf of Panama are distributed primarily in nearshore waters. They may be subjected to increased turbidity, elevated bacterial densities associated with organic-rich sediments, and loss of buoyancy induced by brackish waters. Possible negative impacts on eggs, larvae, and juveniles include delayed or abnormal embryonic development, stunted growth, or death. Increased turbidity from smaller sediment particles generally reduces visibility and decreases the ability of sight-foraging fish to obtain food, thus reducing feeding habitat. Ultimate effects could be reduced or negligible for commercial, artesanal, subsistence, and sport fisheries catches. The extent of affected areas cannot be predicted, but impacts could encompass the entire Gulf and beyond.

The primary terrestrial impacts of dredged materials or spoil deposition are related to changes in land use. Terrestrial impacts may include loss of extant habitat, disturbance of particularly sensitive adjacent habitats (e.g., wetlands and mangroves), and loss or disturbance of sensitive and endemic species. Land disposal of dredged materials in confined and unconfined systems can impact underlying groundwater, contaminate surface runoff, and lead to erosion and sedimentation changes due to hydrologic changes of channel deepening and widening.

6.2.4 Lock and Tidal Gate Construction

The construction impacts attributable to these project features may be generally related to the sheer magnitude of the proposed facilities, rather than any particular activity unique to these project elements. The large scale of construction for the locks and tidal gates, however, has the potential to generate erosion and dredging impacts can be significant.

Additional habitat loss may also occur at these locations. However, taking these effects in consideration with the overall anticipated consequences of excavating and dredging the channel, the significance of these impacts are diminished.

6.2.5 Other Infrastructure

Ancillary facilities, such as the worker villages, camps, power stations, transmission lines, and maritime development facilities, may cause additional impacts in the study area.

6.2.5.1 Worker Villages and Camps

Construction of worker villages and camps may create impacts common to any construction activity. However, other specific impacts are associated with camp operation. Operational impacts may be greatest where villages are located in areas in or adjacent to formerly remote and relatively undisturbed habitats.

The largest direct environmental impact of camp development may be direct loss of land and associated habitat. The five camps may be closed following long-term use, but the villages may be permanently maintained. Contamination of water by human waste is also a potential impact associated with the camps, along with the spread of diseases and zoonoses (diseases transmitted from animals to man). It is also likely that the land outside the camp may be further affected by windblown litter and the open and clandestine dumping of solid wastes.

However, impacts from occupation of the worker camps may not be confined within the camp boundaries. It is unlikely that the camp may be able to provide for the needs of an ethnically diverse work force that may be participating in the construction of the project. Even if nearby "infrastructure" and satellite development is limited, the immediate environs may be subject to increased hunting, fishing, and recreational pressures. Thus, adjacent forests, wetlands, and other habitats containing rare and endangered species may be threatened by an influx of workers.

Most animals may retreat from the vicinity of the camps in response to noise and human activity. Nighttime lighting may cause some animal species to avoid the area, but may likely attract insects, which could benefit some species of bats and nocturnal insectivores, and increase the risk of transmission of disease by biting insects. Populations of animals such as the 9-banded armadillo (*Dasypus novemcintus*), opossum (*Didelphis* spp.), several native rats (*Sigmodon* spp.), as well as introduced rodents (*Rattus* spp. and *Mus musculus*) are expected to increase in the vicinity of the camps. These animals tend to out-compete and displace their native counterparts. Hunting by village and camp residents may reduce

populations of game species and increased traffic in and around the camps may contribute to higher wildlife mortality.

6.2.5.2 Maritime Development

Maritime development (jetties, approach channels, canals, waterways, quays, and breakwaters) may generate localized, and possibly regional environmental impacts. When this development is associated with sensitive estuaries or inland fresh water, it may have more far-reaching effects. The impacts of maritime development may differ by location, based on the type of facility and variations in geography, hydrology, and ecology.

The alteration of natural waters and the construction of man-made structures can directly impact a water body and indirectly impact adjacent natural communities in the project environs. Mangrove swamps, salt marshes, estuaries, seagrass beds, and coral reefs are particularly susceptible to disturbance.

Dredging and spoil disposal activities for port development and maintenance can induce short- and long-term impacts on aquatic systems, including: degradation of marine resources (beaches, estuaries, coral reefs, fisheries), resuspension and settlement of sediments, partitioning of toxic contaminants and reintroduction to the water column, contaminant uptake by and accumulation in fish and shellfish, increased turbidity causing decrease in light penetration and associated photosynthetic activity, short-term depletions of dissolved oxygen, modified bathymetry causing changes in circulation, possible saltwater intrusion to ground-water and inland surface water, altered species diversity and structure of benthic communities, fluctuations in water chemistry, changes in shoreline structure, and loss of habitat and fisheries resources.

6.2.5.3 Power Stations and Transmission Lines

Two electrical power-generating facilities are briefly mentioned in the ECE Report (April, 1993). Specific details of the locations, construction methods, and operation of these facilities and associated gas and transmission lines have not yet been fully developed, therefore specific impacts cannot yet be determined. It is anticipated that the power stations may be located near the tidal gates and locks. However, general impacts common to these types of facilities are well understood. These include disturbance of the immediate area surrounding the powerhouse and transmission line right-of-way, as well as effects of thermal effluent and smoke-stack discharge.

6.2.5.4 Quarries

In addition to habitat loss and general construction impacts, the greatest impact attributable to quarries and their associated crushing and batching plants are those affecting air quality

and soil erosion. The crushing, handling, and transport of thousands of kilograms of rock per hour during the dry season may generate significant quantities of fugitive dust. Aeolian (wind-caused) erosion of stockpiled soils, stone, and aggregate may contribute to these impacts. The impacts of erosion were discussed previously. Finally, heavy equipment at these facilities and along roadways may generate high noise levels.

6.2.6 Operations

The increased maritime traffic that may accompany the completion of the proposed project may increase the incidence of discharges of ballast, oily bilge, anti-fouling materials and sewage. The shipping of pesticides, petrochemicals, and radioactive and other hazardous materials increases the risk of severe damage to the biological community should a spill occur, and an inadequate contingency planning process not be in place.

Shoreline development may increase as support infrastructure develops. This may create additional stress to aquatic systems through point discharges of sewage, process and cooling towers, and accidental releases, unless corrected by design and construction. Surface runoff from port and harbor facilities may further increase the pressure on wetlands and mangrove swamps.

Nighttime lighting along the canal may cause most animals to avoid the area, but may attract and concentrate certain insect populations, which may, in turn, attract nocturnal insectivores.

A summary of the applicable environmental laws and regulations are presented in Section 5.4.1.

6.3 ALTERNATIVE SPECIFIC IMPACTS

Impacts beyond those previously described, attributable to one or the other project alternative are discussed in this section. The general and characteristic effects of new roads, for example, is expected to differ by project alternatives because of dissimilarities in geography, extant habitat types, and amount of existing development and infrastructure.

Due to the lack of specific information regarding the existing environmental conditions within the areas that may be potentially affected by the construction of either alternative, a quantification of the effects cannot be provided. Therefore, only a qualitative assessment is presented herein.

Although there is sufficient information to provide a general feel for the potential impacts that may occur associated with the High-Rise Canal Alternative, specific, quantifiable impacts cannot be determined. As less site specific information is available for the Sea-

Level Canal Alternative, the impacts identified are of a more general nature. Specific quantifiable impacts cannot be identified with the level of information provided for the analyses performed for this component.

6.3.1 High-Rise Canal

As all human activities have an impact on the environment, it is important that these be identified and recognized as such, in particular in projects such as this one, that may have far reaching effects. Impacts can sometimes be avoided by careful planning or by changes in project design. However, in other cases, impacts can only be mitigated and/or ameliorated, when these are inevitable.

The excavation and construction associated with this alternative may increase the barrier effect of the existing canal. The effectiveness of the High-Rise Lock Canal as a barrier to dispersal of vertebrate fauna must be viewed in the context of land use changes that have occurred in the region over the past century. Large areas have been subjected to deforestation and agricultural conversion. This has fragmented wildlife habitat and reduced faunal diversity in the region, limiting the chances of dispersal across the Canal.

Although the existing canal has provided a barrier to the movement of terrestrial species, it is by no means a complete barrier. Epidemiologic studies have shown that diseases associated with monkeys have moved across the existing canal. However, the associated deforestation of the spoil placement areas may increase the barrier effect. Where some animals were able to cross in the past, even less may be able to do so in the future.

The impacts on implementation of this alternative may be greater on terrestrial resources. The largest contiguous blocks of remaining forest lie in the region affected by this alternative, and may thus be more severely affected by the impacts associated with this alternative. In all cases, a detailed survey should be performed in order to identify potentially sensitive resources that should be protected. Whenever possible, design changes should be implemented to leave the sensitive resources undisturbed. Disturbed forest species do not disperse as effectively as typical non-forest species. Many forest birds, for example, may not cross even relatively small clearances. The amount of existing habitats affected by this alternative is shown in Table 6.2.

Table 6.2 Direct Impact Areas for the High-Rise Lock Canal Alternative

150,000 DWT Alternative						
Activity	Area		Ecosystem			
	Total	%	W	F	OA	U
Construction of access roads	72.6	0.2%	2.4	54.8	12.2	3.2
Construction of worker camps, villages and logistics bases	33.5	0.1%		33.5		
Gaillard Cut excavation	756.1	1.7%	54.0	273.4	357.8	70.9
Lake Gatun excavation	72.0	0.2%	7.2	43.2	18.0	3.6
Ciri River Dam and reservoir	13,000.0	39.3%		6,800.0	10,200.0	
Indio River Dam and reservoir	22,000.0	50.8%		13,200.0	8,800.0	
Placement areas	2,013.0	4.7%	10.0	1,640.0	363.0	
Canal Excavation	1,332.3	3.1%	61.2	820.8	375.8	74.5
Total	43,279.5	100.0%	134.8	22,865.7	20,126.8	152.2
%	100.0%		0.3%	52.8%	46.5%	0.4%

200,000 DWT Alternative						
Activity	Area		Ecosystem			
	Total	%	W	F	OA	U
Construction of access roads	72.6	0.2%	2.4	54.8	12.2	3.2
Construction of worker camps, villages and logistics bases	33.5	0.1%		33.5		
Gaillard Cut excavation	756.1	1.9%	54.0	273.4	357.8	70.9
Lake Gatun excavation	72.0	0.2%	7.2	43.2	18.0	3.6
Indio River Dam and reservoir	22,000.0	56.0%		13,200.0	8,800.0	
Trinidad River Dam and reservoir	17,000.0	33.1%		5,200.0	7,800.0	
Placement Areas	2,013.0	5.1%	10.0	1,640.0	363.0	
Canal Excavation	1,332.3	3.4%	61.2	820.8	375.8	74.5
Total	39,279.5	100.0%	134.8	21,265.7	17,726.8	152.2
%	100.0%		0.3%	54.1%	45.1%	0.4%

W = Wetlands
F = Forests
OA = Open Areas
U = Urban Areas

6.3.1.1 Roads

Given the absence of specific information on proposed road alignments, few impacts beyond those generally common to road construction and operation can be predicted. The impacts of roads on terrestrial resources for the High-Rise Canal may primarily affect forested areas. The impacts from road construction for the Sea-Level alternative may affect primarily deforested areas in the southern portion of the project, and partially forested areas in the north. Existing roads associated with the Panama Canal have already caused the impacts common to such linear facilities. Increased access to forested areas may compound impacts that can occur in these areas from construction activity.

New roads on the margin of the High-Rise Locks may cross six rivers and one stream: the Culo Seco, Grande, Conga, Sierpe, Velásquez, and Agua Clara Rivers and the Victoria Stream. In addition to the crossing, construction activities may likely affect each of them for some distance upstream. The Agua Clara River may be crossed by a new road, very close to where the River empties into Bahia de Limon. Pelagic and soft-bottom marine communities in Bahia de Limon may likely be impacted.

6.3.1.2 Dams and Reservoirs

The High-Rise Lock Canal alternative includes the construction of several major dams. If the 150,000 DWT configuration is selected, the Rio Indio and Ciri Grande dams would be constructed after the year 2060. If the 200,000 DWT configuration is selected, the Rio Indio dam would be required only after the year 2020, and the Rio Trinidad dam would be required after the year 2060. Connection of the Indio River with Lake Gatun may allow the migration of peacock bass (*Cichla ocellaris*) into the Indio River basin. As has occurred in Lake Gatun, this predatory fish may most likely displace the local native ichthyofauna. Noxious water weeds, particularly *Hydrilla verticillata* and the water hyacinth *Eichornia crassipes*, may also probably become established.

Other impacts associated with the creation of the reservoirs include the loss of terrestrial habitat. The ECE Report indicates that, depending on the option selected, the expected impoundment areas for these dams would cover 39 km^2 for the 200,000 DWT option (17 km^2 for the Rio Trinidad and 22 km^2 for the Rio Indio), and 32 km^2 for the 150,000 DWT option (13 km^2 for the Rio Ciri and 19 km^2 for Rio Trinidad).

The areas covered by the proposed impoundments of the Trinidad and Ciri dams currently have between 20 to 30% forest cover. The area of the proposed impoundment for the Rio Indio has between 40 and 50% forest cover. The flora and fauna of these areas have not been adequately assessed. These areas should be properly surveyed, to better evaluate potential impacts. Approximately 25 species of freshwater fish that are endemic to the study

area may suffer impacts (including local or complete extinction) from dam and reservoir construction.

6.3.1.3 Channel Excavation, Dredging, and Spoil Deposition

The impacts discussed in this section do not include the existing impacts that may be due to the ongoing Gaillard Cut Widening Project. Those are considered part of the baseline condition from which the additional impacts from the proposed alternative begin. The spoil disposal discussed herein is only for the spoils generated by the proposed alternatives. The canal widening and deepening operations for the High-Rise Lock alternative may require the removal and disposal of approximately 357 million cubic meters of dredged spoil. Dredging and disposal operations may affect an area of approximately 35.9 km^2 within Lake Gatun, 5.2 km^2 outside of the breakwaters at Colon, and 7.5 km^2 near the Pacific approach. As indicated previously, dredging operations affect benthic organisms directly by destroying or smothering them or clogging filtering mechanisms. It can also provide new substrate for colonizing organisms. Dredging operations can also affect water quality, not only by the amount of suspended sediment which increases turbidity, but also through the release of dissolved materials that had been locked in bottom materials.

The High-Rise Lock alternative involves excavation of 241,788,000 m^3 of spoil, to be deposited at 9 sites west of the existing Canal, between the Agua Clara River (D-1) in the Atlantic region, east to the Gatún locks and north of Lake Gatún to south of Victoria Stream in the Pacific region (D-9).

Most of the spoil (215,353,000 m^3) may be deposited from placing area D-3, in the Culo Seco River, to the end of Gamboa Pass (D-9). These spoils may affect 1,640 hectares of forested habitat, 363 hectares of pastureland and 24 hectares of wetlands, causing additional wildlife and habitat losses, the forced movement of mobile species away from areas of disturbance, and the formation and isolation of forest fragments, with all the ecological impacts associated with this process.

These disturbances, combined with past land use changes in the region, may likely increase the effect of the proposed, High-Rise Lock Canal as a barrier to the dispersal of terrestrial species. In addition, rivers and streams directly impacted by spoil placement are: the Agua Clara, Culo Seco, Corotú, Cueva, Mariposa, Mandinga, Grande, Sierpe, and Cocolí Rivers and the Conga Stream.

The widening of Gaillard Cut to accommodate additional ships and construction of the new Pacific locks is estimated to require extensive dredging, blasting, and excavation. All of these activities may affect local flora and fauna, both aquatic and terrestrial.

Excavated materials are planned to be deposited in area D-2. This area of forest is close to the Barro Colorado Island, and represents a potential faunal migration pathway. As with D-1, it is strongly recommended that an alternate deposition area be identified. The possibility of depositing these materials into W-4 should be investigated.

The deposition of dredged and excavated materials in areas D-3 through D-9 may cover 20 km^2. Most of this area currently contains extensive secondary forests. Areas D-4 through D-9 may also have unexploded ordenance from adjacent military facilities. In addition, the boundaries of the recently created Interoceanic Park may include portions of some of these spoil areas. This requires an additional evaluation, in order to establish the configuration and control activities of these spoil areas, so that they are not in conflict with the park.

6.3.1.4 Locks

Lock construction may affect the surrounding terrestrial and aquatic environment, not only by the disturbance caused during excavation and construction activities, but also from spoil disposal. The spoil from the construction of the new locks on the Atlantic side is proposed to be deposited in area D-1. This area has almost 100% forest cover, contains healthy populations of forest-dependent fauna, and likely represents a significant biotic reserve near the Caribbean. Identification of an alternate area for deposition, such as the W-2 placing area, is strongly recommended.

6.3.1.5 Other Infrastructure

Potential impacts of these facilities tend to be highly site specific. A worker camp located in mature forest may have different impacts that one located on land previously dedicated to agriculture. Therefore, impacts beyond those common (and previously described) to such facilities cannot be determined until the specific locations of the quarries, camps, marine development, and power facilities are decided upon during final design.

6.3.1.6 Recirculation of Lock Water

One of the concerns associated with the High-Rise Lock Alternative is the potential need to increase the available water by the recirculation of water from the locks, which may include seawater.

As indicated in Part III, Section 1 - Chapter 2 of the ECE Report (April, 1993), the proposed water usage plan recognizes that during specific combinations of dry years and increased ship transits, the available water from the combination of the Lake Gatun, Alajuela and Indio reservoirs may be insufficient. For this reason, pumping stations and recirculating basins may be required at each Canal entrance. Estimated volumes of water

to be pumped varies from 1,459 MCM to 1,890 MCM in the year 2060, for the 150,000 DWT and 200,000 DWT cases respectively.

The current ship transit system mixes a small amount of seawater with the freshwater in the lower lock chamber. As ships move into the canal system, this seawater is diluted, but is eventually lifted into Miraflores or Gatun lakes. This gradual increase in salinity has been documented at both ends in previous studies. The implementation of a recirculating system may tend to gradually increase the salinity within the lakes. It is possible that an appropriate engineering design can reduce this possibility.

Consequences to the aquatic environment in the Panama Canal and Lake Gatun from the increase in seawater from the operation of locks may vary according to the salinity of the effluent and the frequency and duration of pumping during operations. Fouling organisms could cause economic problems, commercially important species might be introduced which would be positive economic factors, and the introduction of new species might have adverse effects on an existing ecosystem. An increase in the salinity of the Panama Canal system would likely facilitate the survival of time of marine organisms and transoceanic migration, permitting the colonization of the system by euryhalinic marine species.

Not only the magnitude of the seawater dilution, but also the length of time organisms are subjected to dilution may be critical. Plants, principally algae, can be expected to show the earliest response to changes. It is assumed that none of the existing stream, marsh, or swamp plants of Lake Gatun could grow in saline waters. Marine algae capable of thriving in brackish water include green algae of the genera *Rhizoclonium*, *Chaetomorpha*, *Cladophora*, *Ulva*, *Monostroma*, and others. The seagrass *Diplanthera wrightii* may also invade if salinities reach 15 ‰ or higher. There are also red algae that can thrive in salinities >5 ‰. Addition of marine algae to the Canal system would increase primary productivity and provide food and habitat for numerous other organisms.

An increase in salinities of 1 to 10‰ may likely result in loss of most freshwater fauna, and salinities from 10 to 15‰ may permit acclimation and colonization by marine species. The latter would likely occur in a sea-level canal. Salinities of approximately 2 to 8 ‰ appear to represent a biogeographic barrier, inhibiting colonization by adults of both marine and freshwater species.

If seawater is thoroughly mixed with the non-stratified freshwater of Lake Gatun, a fairly homogeneous water column without stratification would probably result, except for remote backwaters and inlets. Freshwater assemblages would die off and marine organisms would invade and colonize, forming new communities.

Conversely, if saline water settles to the bottom of the lake and does not mix, a chemocline may be formed and a stagnation basin or single, deep, stable, salty monimolimnion may develop. In these anoxic conditions, freshwater benthos may be killed, and secondary consumers (bottom-feeding fish) may either die from loss of food resources, may migrate to shallower lake depths, or may move into rivers and streams. Along with this, anaerobic microorganisms may thrive, creating hydrogen sulfide and other toxic products, exacerbating the abiotic-stagnating and oxygen-depleting actions of seawater.

Nutrients would tend to be locked in bottom sediments and not be available to higher consumers. Oligohaline water in the littoral zone may surely have a deleterious effect on many aquatic plants. There would be a total lowering of productivity and eventually extinction of all stenolimnetic species.

Chemical constituents may have unexpected effects. Potassium, a nutrient salt, may increase eutrophication. Other dissolved salt ions can influence the toxicity of insecticides residing in the Lake's waters. If a salt of a toxic metal (other than a chloride) is run into a system containing much sodium chloride, it may become a mixture of the original salt and the chloride of the metal, and may have an altered toxicity.

Since marine organisms vary in their abilities to osmoregulate, different groups may invade at different salinity levels. Although numerous stenohaline marine forms are poor volume regulators and live in normally saline waters, many can actually tolerate brief and even extended (hours to days) exposure to dilute seawater. Some organisms can adjust to new salinity regimes and have been able to invade new oceans and seas. In general, invertebrate larvae are less tolerant or, at best, as tolerant of salinity fluctuations as the adults. However, the life cycles of many marine invertebrate groups, especially freshwater and estuarine forms, include resistant stages which are capable of weathering tremendous changes in environmental conditions while being transported long distances.

Numerous marine crustaceans in Panamanian coastal waters, particularly intertidal forms, have wide salinity tolerances and are pre-adapted to move into areas of low salinity. Salinities above 10‰ in the Canal would result in rapid colonization by saltwater crustaceans and local extinction of the present freshwater crustacean fauna. There would be few, if any, barriers to prevent interoceanic migration by a very large number of euryhaline decapod species.

The effect on larvae is unclear. Species of the commercial shrimp in Panama (see 5.2.2.1) all have larval stages which occur in salinities of 2 to 8 ‰; they migrate to higher salinities as they mature. Freshwater and brackish water shrimps (Atyidae, Palaemonidae) often complete their larval development in such low salinity waters. Thus, while there may be few adults in this salinity, a saline Canal may serve as a migratory route for larval stages of some decapods.

Some sponges are capable of boring into calcareous substrates and weakening and destroying bivalve shells and coral reefs. The effects of Pacific coast excavating sponges (if they were to cross through saline Canal waters) on Caribbean sponges might be important since the reefs near Colón are relatively well developed and certain sites there are valuable both for scientific study and for future tourism.

Principal fouling organisms are already present at the Canal entrances. Mollusks which may cause fouling problems are common in the Panama area. For mollusks, raising Canal salinity from 0 to 5‰ would not only eliminate the freshwater species, but might also cause an explosive increase in the numbers of the bivalves *Brachidontes*, *Isognomon*, or *Mytilopsis* in Lakes Miraflores and Gatun. The presence of dense populations of bivalves and their production of large quantities of feces and pseudofeces may markedly alter the substrate and the composition of solute.

The ecology of Lake Gatun would be changed significantly by such a development. At very least a new animal community would appear associated with the reefs of bivalves along the shores and on shallow bottom surfaces of the locks, Canal, and Lake. The recent invasion of the Great Lakes area by the zebra mussel is an example of the potential small bivalves possess for rapid colonization, fouling all subtidal surfaces, clogging pumping stations and mechanical structures, and community domination. A salinity range of 3 to 8‰ in the Canal would have little effect on the passive exchange of mollusks between the Caribbean and the Pacific, but could still support a mass colonization of the Canal by encrusting bivalves. Without further knowledge of larval forms, it is difficult to predict these changes accurately.

Other fouling invertebrates are bryozoans (moss animals), whose attachment follows closely the establishment of algae. *Bugula neritina* is the major species on both coasts that is expected to enter the Canal. Bryozoans produce a secondary effect in supplying clean, abundant crevices for the attachment of other fouling organisms. Hydroids such as *Tubularia* and *Sertularia* form dense, bushy masses and could feasibly cause mechanical problems with engineering features and seawater pumping systems.

Salinization of the Canal route would increase the efficiency of the Canal as a passageway for marine fishes. At least 30 species would be expected to make the crossing, the most probable being snook, jacks, mullet, snappers, and other euryhaline and semi-euryhaline forms. There would be changes in competition for fish habitat, increased inter-breeding, modification of food chains, and for some species, changes in gene flow and population genetics. Drastic impacts on freshwater fishes would result from the addition of new marine predators and competitors. Physiological effects would be particularly pronounced at salinities of 10‰ and higher, since this is the concentration at which freshwater fish begin to lose body fluids through the skin and gills by diffusion.

More information on seawater concentration and volume in the affluent; physiological studies on reproductive, larval, and adult stages; and baseline studies to define extant fauna are all necessary before precise predictions about salinization impacts can be prepared.

6.3.1.7 Maintenance

Maintenance dredging may be performed in the primary canal, reservoirs, marine approach channels, and harbor basins as needed to maintain depth and width and assure safe access for large vessels. The dredge material from maintenance dredging typically presents a greater disposal problem than deeper sediments removed during construction dredging, as superficial sediments are composed of recently deposited materials that may be contaminated. The younger sediments are likely to contain natural and anthropogenic contaminants from atmospheric fallout, erosion of local land surfaces and channel banks, fallout from biological activity in the water column, sediment transport from inland waters, point source discharges, and runoff from surrounding areas.

The impacts of spoils deposition may be similar to those previously described. Patterns of deposition of dredged materials have already been well established. Employment of existing equipment, including the world's largest dip dredge, would certainly continue. The increased width of the canal would require, however, increased maintenance and dredging. The settling patterns of sediments raised by dredging would be altered and areas that have reached biological equilibrium could again become unbalanced.

The Pacific entrance already experiences high turbidity, due to domestic sewage discharges, port-related activities, tank farm operations, and high turbidity flows from the locks and several small streams (Curundu, Maria Salas, and Velasquez creeks). Bank erosion and bottom sediment disturbance by ship traffic also contribute to the turbidity, which could extend several miles beyond the seaward entrance.

6.3.2 Sea-Level Canal

The construction of a sea-level canals may cause a large variety of impacts. These include direct effects of excavation of the channel, together with the elimination of existing natural habitats in the spoil placement areas; the dredging of an extensive approach channel in the Bay of Panama; construction of breakwaters at both entrances; the splitting of Lake Gatun; construction of new dams, diversion schemes and spillways, to name a few.

Terrestrial Migration

One effect of the sea-level canal may be to reduce the possibility of the natural flow of terrestrial organisms between North and South America. At the same time, the possibility for the movement of marine biota between the Caribbean Sea and the Pacific Ocean

increases significantly. It is important to note that these two effects can produce serious repercussions in the stability of terrestrial and aquatic ecosystems.

The Panamanian isthmus still functions as a dispersal route between continents, although the rate of interchange has slowed as equilibrium has been reached. As habitats continue to change with land use and climatic changes, new opportunities for dispersal continue to occur. As forest clearing causes local extinctions, the presence of the intact land bridge leaves open the chance for natural re-establishment of species, should the land use change and the forest be allowed to recover. This is particularly a concern for Central America, where the amount of existing forest is small and continuing to rapidly dwindle.

The question of whether the current Canal constitutes an aquatic barrier for the dispersion of terrestrial animals across the Panamanian isthmus was considered by Bennett (1976), who concluded that the narrow width of the Canal south of the entrance to the Chagres River in Gamboa (Gaillard or Culebra Cut) and the presence of forest cover on both sides of the Canal, probably interfered little with the crossing of a majority of bird species, and not at all for mammals that could swim or fly across the Canal. Arboreal mammals however, would have more difficulty crossing the gap, except where existing bridges over the Canal can act as dispersal corridors. The Canal therefore appears to be a partial barrier to the dispersal of certain mammals, but is probably not completely effective.

The effectiveness of the existing Canal as a barrier can also be inferred from studies on Forest Yellow Fever conducted by investigators at the Gorgas Memorial Laboratory from the 1940s to the 1980s. This type of Yellow Fever has been introduced in waves into the forests eastern Panamá (1949, 1956, 1965, 1971 1979). Monkeys are the normal host for this pathogen that is transmitted by arboreal mosquitos. A case of this form of Yellow Fever, detected in 1950 on western side of the Canal, was the first evidence of the spread of the virus west and north of the Canal since the eradication of the disease in Central America in 1925. Historical records indicate that this wave caused the death of several hundred humans and almost totally eradicated the extant populations of Howler monkeys in the region (Galindo, 1979). The movement of the virus across the Canal in 1950 probably resulted when infected monkeys swam across the canal and were bitten by mosquitos, which then transmitted it to other monkeys on the western side of the Canal.

A Sea Level Canal would compound the difficulties to dispersal encountered by many terrestrial species, including terrestrial mammals, plants with large, animal-dispersed seeds, and many invertebrates. Even birds would be affected, as studies in Amazonia indicate that many forest interior birds do not cross non-forested areas, such as rivers or roads. While the existing canal is already such a barrier, it is quite narrow in places, and at Lake Gatun only a few hundred meters separate lake shore habitat on either side of the canal. The opportunities for chance dispersal here are therefore much greater over the long run (thousands of years) than they are for the proposed sea-level canal. Animals and seeds

currently have a chance of surviving a swim or float across Lake Gatun, an opportunity which may not be present in the areas where the sea-level canal is within a steep-sided, entrenchment or where land animals are intolerant to crossing a saline aquatic environment.

The excavation and construction of the sea-level alternative may also reduce regional biological diversity by creating an effective barrier that may isolate a large "island" of habitat. This diamond-shaped "island" may be bordered on the southeast by Lake Gatun, on the southwest by the Sea-Level Canal, on the northeast by the Chagres River and on the northwest by the Caribbean. Most of the wildlife in this area may be effectively "marooned" in this fragment, and experience the problems associated with the reproductive isolation of local populations (see Section 6.1). The amount of terrestrial habitat affected by this alternative is shown in Table 6.3.

Table 6.3 Direct Impact Area Sea-Level Canal Alternative

Activity	Area Affected		Ecosystem									
	Hectares	%	W	M	G	P	A	F	OA	U	L	O
Access Road Construction	72.6	0.21%	2.4					54.8	12.2	3.2		
Construction of Work Camps, Villages and Logistics Bases	33.7	0.10%	0.2					33.5				
Northern Excavation	660.0	1.89%	33.0		198.0	165.0		264.0				
Gatun Excavation	525.1	1.50%	78.7		183.8	78.7		183.3				
Continental Divide Excavation	562.6	1.61%	28.1		281.3	196.0		56.3				
Pacific Excavation	176.0	0.50%	8.8	26.4	79.2	44.0		17.6				
Upper Gatun Dam	11,000.0	31.43%			3,850.0	3,300.0		3,850.0				
Dry Placement Areas	4,959.0	14.17%	152.0	450.0	1,970.0	1,504.0	54.0	829.0				
Wet Placement Areas on Land	540.0	1.54%	135.0	162.0	189.0	5.4					260.0	2,640.0
Breakwaters	312.5	0.89%										312.5
Approach Channels	16,160.2	46.17%	89.8	808.4								15,262.0
Total	35,001.7	100.00%	528.0	1,446.8	6,751.3	5,293.1	5,263.1	5,288.5	12.2	3.2	260.0	18,214.5
%	100.00%		1.51%	4.13%	19.29%	15.12%	0.15%	15.11%	0.03%	0.01%	0.74%	52.04%

W = Wetlands
G = Grasslands
A = Agriculture
OA = Open Areas
L = Lakes and/or Rivers

M = Mangroves
P = Pastures
F = Forests
U = Urban Areas
O = Oceanic (Caribbean and/or Pacific

Marine Migration

The effects of a salt-water passage connecting the Atlantic and Pacific Oceans could be far-reaching. The potential impacts include introduction of predators, competitors, parasites, and diseases for which the resident biota have no adaptations.

The fresh water of Lake Gatun in the existing Panama Canal forms a somewhat effective barrier to the migration of marine organisms between the Pacific and Caribbean. The construction of the Sea-Level alternative however, would likely allow unimpeded interoceanic colonization. Historically, man's introduction of "exotic" species has had repercussions that range from detrimental to serious. The scientific literature is documents numerous reports of the failures and disappointments of planned and accidental introductions and invasions. A few examples are provided below to illustrate the point.

European rabbits introduced in Australia virtually devegetated the country and decimated the national sheep industry; lampreys that reached the Great Lakes in the United States through the Welland Canal, devastated fish populations and commercial fishing; zebra mussels have also reached the Great Lakes and as encrust virtually every under-water surface which displaces most aquatic biota; European starlings introduced into the United States in the 1800's now occur across the entire continent and out-compete many native birds for nesting sites and forage, and; rodents introduced to virtually every island that receives oceanic traffic have caused extensive reductions in native terrestrial and sea bird populations.

A major difficulty in assessing the effects of organismal migration through a sea-level canal is the lack of a previous example that is directly applicable to the conditions present in Panamanian marine waters, combined with the specific characteristics of terrestrial ecosystems and the proposed construction. A detailed study of the marine consequences of a Central American interoceanic canal was conducted by the National Academy of Sciences - National Research Council (1970). The discussion below summarizes many of the issues raised in that document, which are still valid today.

Caribbean and Pacific waters off the coast of Panama differ primarily in their temperature and salinity regimes, their productivity, and respective community structures. Both are tropical marine ecosystems with rich, varied biotas and characteristics common to both. Caribbean substrata are occupied by long-lived species while ephemeral species are common in the eastern Pacific.

The net flow of seawater in a sea level canal may be from the Pacific to the Caribbean, but it is not known if inter-oceanic migration may follow that same direction. It is also not known to what extent tidal gates and freshwater locks may restrict the passage of organisms. Most marine species are capable of tolerating some dilution of their aquatic environment

for varying periods of time, so that any effective biological barrier must be either very large (as Lake Gatun) or otherwise extremely effective within a short distance or time interval.

Faunal exchange through the present Canal has occurred in the past and continues today, but conclusions regarding the amount and consequence of such exchange vary because little is known of the historical and current composition of fauna on either side of the isthmus. That migration may occur through the proposed sea-level canal is not disputed, but the rate, extent, and consequences of colonization in both oceans are questionable.

Active, strong-swimming organisms such as fish and sharks may likely make the transit first. Also included among the first colonizers may be fouling organisms such as barnacles, bryozoans, ascidians, and hydroids. The latter could be passively transported by Canal currents, on the hulls of ships, and in ship ballast water. Planktonic larvae and other microscopic organisms might also survive pumping into ballast tanks.

Non-fouling bryozoans and marine grasses, both of which grow in shallow water, may colonize the shoreline and thereby spread through the Canal. The expansion of seagrasses into the Panamanian Pacific, where they are uncommon, might be beneficial. Bryozoans introduced into warm waters often disperse rapidly and form colonies, but eventually die and establish a substrate for other marine organisms. This might have considerable impact on previously stable communities. If Canal maintenance operations allow, mangroves may invade the Canal edges, creating new habitat and promoting further mixing of marine assemblages associated with the prop roots. Plankton and potential Canal colonizers may be most sensitive to barriers placed in the Canal.

A possible major consequence of exotic species introduction through a sea-level canal could be deleterious effects on the Gulf of Panama fisheries. Existing stocks of shrimp, fish, and mollusks currently provide rich harvests and there remain additional unexploited fisheries resources. Existing species however, could ultimately be replaced by ecologically similar, but economically less valuable species. This might particularly apply to the penaeid shrimps, which are the basis of the shrimp fishery today.

Penaeid shrimps have an inshore euryhaline juvenile stage that might be amenable to transport through a canal. The young of some fishes, when they become large enough to swim actively, seek out estuarine or other shallow water areas (such as a sea-level canal) to use as nursery grounds. Conversely, incoming fish species may enhance commercial and sport fisheries potential in an area. Eastern Pacific grazing-fish populations are food-limited while their Caribbean counterparts are predator-limited. Consequences of new fish predators in the Caribbean can only be speculated. The outcome of transmigrations of pelagic forms via a sea-level canal is therefore difficult to predict.

Another principal source of concern is the potential dispersal of pathogens or parasites from one ocean to another, where they might find closely related hosts lacking natural resistance. Marine examples include the die-off of Atlantic eelgrass during the 1930s from the protozoan *Labyrinthula*, and protozoan (*Eimeria*) infections of herring and pilchards. The western Atlantic sea urchin *Diadema* has recently been devastated by an unidentified virus. Short- and long-term fluctuations in populations of invertebrates and fish have been related to viruses, bacteria, fungi, and other parasites. Breaching of land and freshwater barriers would allow exchange of parasites and pathogens.

Man-made disturbances may also trigger toxicity cycles such as fish-poisoning (i.e. ciguatera). When benthic surfaces are denuded, ecological succession is permitted leading to establishment of toxic algae that act as a starter mechanism. The admixture and interaction of the biota from both oceans might catalyze a toxicity cycle in the Panamanian region, destroying certain shore fisheries.

Transmigration of harmful marine species may also have impacts on human health and safety, particularly in recreational areas of beaches and coral reefs. The venomous Pacific sea snake (*Pelamis platurus*), even though the incidence of its biting is extremely low and its bites are rarely fatal, would have no real difficulty moving through the canal when aided by a current. There are also venomous cone snails (*Conus*), toadfishes (Thalassophryninae), fireworms (*Hermodice*), sea urchins with needle-sharp spines (*Diadema*), and stinging jellyfish capable of crossing the isthmus. Some sharks, particularly *Carcharhinus leucas* and *C. limbatus*, prefer inshore habitats and often invade estuaries. *C. leucas* has been known to attack man and is common along the tropical continental coast near river mouths, but rarely strays into offshore waters. The canal could provide prime habitat for these large sharks and their numbers could increase along the Atlantic coast.

Coral reefs are highly complex natural communities whose structure can be upset with the introduction of a new species. Establishment of the Pacific crown-of-thorns seastar *Acanthaster planci* in the Caribbean has great potential in disrupting Atlantic coral reefs. Populations of this starfish have been responsible for wide-spread damage to coral reefs throughout the coral reefs of the South Pacific and the Great Barrier Reef in Australia. It has also been reported in the Gulf of Chiriquí, west of the Bay of Panamá, where reportedly has been able to consume between 18 to 47 percent of the live cover of a 20 ha. reef in four months. In laboratory tests, this corallivorous seastar prefers Atlantic corals over Pacific corals.

Natural protection in the Pacific Ocean has been found to be due to the presence of two species of crustacean symbionts associated with pociloporid corals. The shrimp *Alpheus lottini* and the crab *Trapezia ferruginea* protect the coral from the starfish by physically attacking it. When these symbionts are missing, the starfish can totally decimate the reef.

Although pociloporid corals exist in the Caribbean Sea, there are no similar symbionts. If nutrient-rich Pacific waters pass through the canal into the nutrient-poor Atlantic, conditions may combine to produce phytoplankton blooms that are conducive to larval development, settlement, and metamorphosis of this asteroid. The high diversity of Caribbean corals would provide an ideal diet for this predator.

Heavy predation pressure is exerted on Pacific corals by a number of snails (*Jenneria*) and fishes. Puffer fish (*Diodon* and *Arothron*) are particularly voracious. The presence of these corallivores on Caribbean reefs would surely alter coral community structure. In general, there is more grazing pressure in the Eastern Pacific. Low algae and sponge cover is maintained by voracious, specialized predators. As calcareous algae and sponges contribute greatly to reef formation, impacts on them would affect the health of the Caribbean reefs.

Eliminating less obvious or lower profile components of the reef system can also be disastrous. The barber shrimp (*Stenopus*) cleans fishes of their external parasites. If a transmigrating species were to eliminate this shrimp by predation or competition, the fishes would lose their biological ectoparasite control and would be prone to heavier parasitic infection.

In other habitats, intertidal flora and fauna buffer the coastline from the mechanical pounding of the waves and protect the shore from the erosive forces of the sea. Migrants from the intertidal, with their adaptations to withstand extreme environmental variations, might be expected to successfully cross the canal and establish themselves. Altering or eliminating this community could result in loss of the coastline to sea erosion.

In the marine aquatic environment, biological consequences may at first be experienced locally and may then have chain effects influencing the ecology of areas thousands of miles from the canal site. These effects have the potential of regional, ocean-wide, and global distribution.

Many diverse opinions are held on the possible outcomes of mixing organisms from two oceans. These conflicting views are primarily a function of the lack of adequate baseline data for most habitats and relevant research on the repercussions of inter-oceanic migration. It is therefore impossible at this time to state unequivocally what the specific or general impacts of a sea-level canal may be without the necessary knowledge and understanding of local biota and natural processes.

Proposed Fresh-Water Barrier

In Part IV. Section 1, Chapter 2 of the ECE Report presents a freshwater barrier system. This system is based on the collection of rainwater, primarily from the western portion of

the Lake Gatun watershed. However, they do not present a detailed analyses off the possible effects.

Based on their evaluation, they expect that 1,200 MCM/yr from Reservoir E and 700 MCM/yr from the Rio Caimito. They have considered that the projected traffic of 2,100 ships through 2020, may increase to 5100 in the year 2060. Three alternatives were proposed. The first one is pouring freshwater into the lock chambers. This alternative was discarded, due to the following considerations: 1) A large volume of water must be injected in a short period of time. 2) Using three lock chambers increases the complexity of the system. 3) The available volume of freshwater may not be sufficient. 4) No evidence that this type of barrier would be effective.

The second alternative proposed was injecting freshwater in the segment between the tidal lock and tidal gate. In this case, water would be diverted from the retention dams in the lake, as well as allowing as many streams and rivers to drain into the canal section. Due to the large volume, the adequate mixing of fresh and marine waters becomes critical. Based on the available water from Reservoir E and the rivers, it was estimated that the volumes would range from 968 MCM for a dry year, 1,535 MCM in an average year, and 2,517 MCM for a wet year. The capacity of the canal section is estimated at 160 MCM.

The ECE Report indicates that appropriate mixing of water may occur if the ratio of available fresh water to sea water in the canal section is 10:1. Results from the ECE Report's analysis indicate that this ratio would not be accomplished during a dry year and would be marginal in an average year. Therefore, the 10:1 ratio is anticipated to be exceeded only during wet years. The lack of water to preserve the fresh water and avoid creating brackish conditions, does not make the current model effective. The presence of a potential salt water wedge or layer remaining in the bottom of the canal would render the barrier ineffective. As many species of marine organisms are able to withstand brackish water conditions, the increase in salinity in the canal section would allow these to pass from one ocean into another.

In order for the barrier to be effective, it would require being as foolproof as possible. It is known that certain species of marine organisms have been able to cross the existing canal. A small channel may not be as effective as the existing Lake Gatun. In addition, Lake Gatun has a constant flow of water out into the oceans. This condition has been an important control in the movement of planktonic organisms. The Sea-Level Canal would not have as great a positive flow, which may allow the movement of larvae and eggs across the isthmus.

Behavioral inhibitions of many open water fish makes them reluctant to enter the confines of the existing locks when entering from the ocean. Fish that have entered either of the

approach channels would have overcome this inhibition, and would not be deterred by the presence of the locks or tidal gates.

Additional combinations of thermal and fresh water should be evaluated and tested. Based on the information provided, the current design of the freshwater barrier does not seem to be an effective impediment to the migration of marine biota.

6.3.2.1 Roads

Detailed alternative- or site-specific impacts cannot be determined at this time, given the level of information on proposed alignments, although an estimate of the area impacted by these facilities is presented in Table 6.3.

The area southwest of Lake Gatun already shows evidence of a high degree of human-caused disturbance and the remaining forest fragments have lost most of their ecological value. However, the remaining mature forest northwest of Lake Gatun may be disturbed and further fragmented as a result of this alternative.

New roads on the margin of the Sea-Level Canal may cross a total of seven rivers and 14 streams: the Caño Quebrado, Arrieros, Santa Cruz, El Amado, Congo, Caimito and Lagarto Rivers; and the Santa Marta, Lagartito, La Chunga, La Escoba, La Guancha, Las Minas, Naranjal, Aguacate, Las Lajas, Prudente, Juan Redonda, Pasar, and two unnamed streams.

On the Caribbean coast, the Caño Quebrado River and the Santa Marta Stream empty into marine waters with intertidal, pelagic, and soft-bottom benthic communities. The mouth of the Lagarto River is an estuary and is in close proximity to a coral reef.

On the Pacific side, the Caimito River may have two road crossings; this river has an estuary bordered by mangroves. The perimeter road for the spoil placement area to the east of the Caimito mangroves may cross one river and six streams: the Aguacate River and the Las Lajas, Prudente, Juan Redonda, Pasar, and two unnamed streams. The marine and freshwater aquatic communities associated with the above rivers and streams may be impacted, but the type and extent of effects cannot be ascertained without knowledge of the organisms found in these habitats and more details on construction methods and schedule.

6.3.2.2 Dams and Reservoirs

The Sea-Level alternative includes the construction of a spillway from Reservoir E (the western portion of Lake Gatun) to the Lagarto River. The spillway may be used during the construction operations, and later may only be used during high water conditions. However, this spillway may allow the migration of peacock bass and aquatic weeds into this basin,

where they may have a negative effect on the local communities, as has already occurred in Lake Gatun. Aquatic weeds may also provide new habitat for other aquatic biota.

The spillway may cross and have direct impacts on the El Pepino and Lagarto Rivers as well as two unnamed streams. The volume of water moving from the spillway into the Lagarto River may have the potential of increasing erosion during its use, and possibly causing localized flooding during rainy seasons or very wet years.

In addition, this alternative requires the construction of the Upper Gatun Dam. As indicated in Section 6.3.1.2, this impoundment may inundate a large area, destroying the existing flora and fauna in the impoundment area, while creating new freshwater aquatic habitat. The Gatun River reservoir may likely destroy aquatic habitats in the Escandaloso River and in the Diablo, Salto, Bonita, and Dormida Streams.

As little is known about the biology and ecology of these terrestrial and aquatic communities, a definitive impacts analysis cannot be performed until baseline information becomes available.

6.3.2.3 Channel Excavation, Dredging, and Spoil Deposition

Dredging activities for the Sea-Level Canal Alternative may occur at the Caribbean and Pacific approaches, as well as a limited amount within for barrier dams in Lake Gatun. Spoils for the Caribbean approach may cover 8.8 km^2 (W-1), and within Lake Gatun they may cover 2.6 km^2 (W-2). The spoils within Lake Gatun may also be used to help construct the barrier dam.

The greatest amount of dredging may occur for the Pacific approach, where a channel in excess of 20 km may be constructed. The dredged materials may be placed in two areas, covering 5.4 km^2 (W-3) and 17.6 km^2 (W-4). Area W-3 is located on land, and may result in a partial loss of mangroves and wetlands. Impacts here may include the loss of valuable, recognized nursery areas for commercial fishes and shrimp. Area W-4 is west of the approach channel. Impacts here may be of a greater scale, as this proposed channel and spoil areas have the potential of affecting current patterns, water quality, and turbidity, that may be swept towards the mangrove areas of Punta Chame. This area is recognized as the most significant mangrove stand on the western side of Panama Bay.

The course of the Sea-Level Canal and the construction of diversion dams may affect sections of seven rivers and six streams, including: the Caño Quebrado, Arrieros, Santa Cruz, El Amado, Congo, Caimito, and Martín Sánchez Rivers; and the Lagarto, Chunga, La Escoba, La Guancha, Ancha, and Naranjal Streams.

Spoil placement on terrestrial sites may directly impact Lake Gatun, nine rivers, and 14 streams. The rivers include the Arrieros, Caño Quebrado, Pescado, Viejo, Lirio, El Arado, Paja, Bernardino, and Congo Rivers; the streams are the Santa Marta, Blanca, Lagartito, La Escoba, La Chunga, Candilera, Caño Gigante, La Guabita, Laguito, Monte Viejo, La Jicotea, Naranjal, and San José.

On the Caribbean side, a coral reef occurs at the mouth of the Punta Grande River; this reef may experience heavy siltation originating from the upstream spoil area. The Caño Quebrado River and Santa Marta stream also drain into marine waters with pelagic and soft-bottom communities that may be impacted by suspended sediments.

Near the Pacific entrance, spoil placement may impact mangrove, estuarine, and riverine habitat in the Caimito River area. Spoil dumped onto the marshes and swamps east of the mouth of the Caimito River may also directly affect the Pasar, Bique, Limones, and Las Lajas Streams. There could also be cumulative impacts to fisheries from the combination of increased sedimentation and increased fishing pressure.

6.3.2.4 Diversion Channel

The diversion channel to be excavated on the western margin of the Sea-Level Canal may divert streams and rivers away from the Canal towards the western arm of Lake Gatun, which may be cut off from the rest of the lake by barrier dams. Channel construction may destroy river, stream, and wetland habitats downstream from the channel through actual construction activities and by water diversion. The following may be directly impacted: (1) the Tinajones River, (2) the Queja, Caño Quebrado, La Mendoza, de Chico, and 21 unnamed streams, and (3) the Los Hules wetlands and other wetlands associated with other rivers and streams emptying into Lake Gatun. The channel itself may provide additional space/substratum for development of lotic communities.

6.3.2.5 Tidal Gates

Tidal gate construction may affect the surrounding terrestrial and aquatic environment, not only by the disturbance caused during excavation and construction activities, but also from spoil disposal.

6.3.2.6 Other Infrastructure

Potential impacts of these facilities tend to be highly site specific. A worker camp located in mature forest may have different impacts that one located on land retired from agriculture. Therefore, impacts beyond those common (and previously described) to facilities cannot be determined until the specific locations of the quarries, camps, some marine development, and power facilities have been established.

6.3.2.6 Operations

Maritime traffic that may accompany the completion of the proposed alternative may increase the incidence of discharges of ballast, oily bilge, anti-fouling materials and sewage. The shipping of pesticides, petrochemicals, radioactive and other hazardous materials, increases the risk of severe damage to the biological community should a spill occur.

Shoreline development may increase as support infrastructure develops. This may create additional stress to aquatic systems through point discharges of sewage, process and cooling towers, and accidental releases. Surface runoff from port and harbor facilities may further increase the pressure on existing wetlands and mangrove swamps.

Nighttime lighting along the canal may cause some animals to avoid the area, while attracting and concentrating certain insect populations, which may also tend to attract nocturnal insectivores to the area.

6.3.2.7 Maintenance

Maintenance dredging may be performed in the primary canal, reservoirs, marine approach channels and harbor basins as needed, to maintain canal depth and width and to assure safe access for large vessels. As stated previously, the dredged materials from maintenance dredging typically present a greater disposal problem than deeper sediments removed during construction dredging, as superficial sediments are composed of recently deposited materials may contain natural and anthropogenic contaminants from the erosion of local land surfaces and channel banks, fallout from the atmosphere or from biological activity in the water column, sediment transport from inland waters, point source discharges, and runoff from surrounding areas. Impacts of spoils deposition may also be similar to those previously described.

Maintenance dredging for this alternative could have significant impacts which could extend into the Caribbean basin. As the net water movement may be from the Pacific to the Atlantic, contaminated materials could conceivably reach the Atlantic, and be deposited in coastal waters, producing negative effects on fisheries, intertidal communities, mangroves, and estuaries.

It is anticipated that highly turbid conditions would be created at the Pacific entrance to the Sea-level Canal that are similar to those of the existing Canal.

Table No. 6.4. Impact Summary

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
GENERAL								
1. Microclimatic changes in disturbed areas	-	D	L,S	L	D	+	+	Y
2. Reduced air quality (localized)	-	D	S	L	D	+	+	N
3. Increased noise levels (localized)	-	D	S	L	D	+	+	N
4. Changes in topography	-	D	L	L	I	+	+	Y
5. Increases in pathogens, insect pests and verctors	-	P	L,S	L,R	I	+	+	Y
GENERAL TERRESTRIAL								
1. Loss, modif., frag. of habitat	-	D	L	L,R	D,I	+	+	Y
2. Disturbance of habitat	-	D	S	L	D	+	+	N
3. Loss of biodiversity	-	D	L	L,R	D,I	+	+	Y
4. Direct plant & wildlife mortality	-	D	S	L	D	+	+	Y
5. Compaction & erosion of soils	-	D	L,S	L	D	+	+	Y
6. Loss of sensitive plant & wildlife spp.	-	P	L	L	D	+	+	Y
7. Introduction of exotic plant & wildlife spp.	-	D	L	L,R	I	+	+	Y
8. Local displacement or disturbance of wildlife	-	D	S	L	D	+	+	N

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
GENERAL FRESHWATER AQUATIC								
1. Increased sedimentation	-	D	S	L	D	+	+	Y
2. Alteration of waterflows	-	D	L	L	D	+	+	Y
3. Reduction in water quality	-	D	S	L	D	+	+	Y
4. Introduction & proliferation of undesirable aquatic flora & fauna	-	D	L,S	L,R	I	+	+	Y
5. Destabilization of stream banks	-	D	L,S	L	D	+	+	Y
6. Changes in aquatic biodiversity	+,-	D	L,S	L,R	D,I	+	+	Y
GENERAL MARINE								
1. Increased sedimentation	-	D	S	L,R	D	+	+	Y
2. Alteration of currents	-	D	L	L	D	+	+	?
3. Reduction in water quality	-	D	L	L	D	+	+	Y
4. Introduction & proliferation of undesirable aquatic flora & fauna	-	D	L,S	L,R	I	+	+	?
5. Changes in aquatic biodiversity	+,-	D	L,S	L,R	D,I	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
ACTIVITY – SPECIFIC								
I. ROADS								
A. Erosion	-	D	L,S	L	D	+	+	Y
B. Effects on existing drainage patterns	-	D	L,S	L	D	+	+	Y
C. Creation of barriers to animal movement	-	D	L,S	L,R	D	+	+	Y
D. Provision of wildlife movement corridors	+	D	L	L,R	D	+	+	Y
E. Increase in direct wildlife mortality	-	D	L	L	D	+	+	N
F. Increased access to remote areas	-	D	L,S	L,R	D	+	+	Y
II. DAMS & RESERVOIRS								
A. Flooding (loss) of terrestrial habitat	-	D	L	L	D	+	+	Y
B. Loss of terrestrial flora & fauna	-	D	L	L	D	+	+	Y
C. Creation of aquatic habitat	+	D	L	L	D	+	+	Y
D. Reduction of water quality	-	P	S	L	D	+	+	N
E. Increase in lotic biodiversity	+	D	L	L	I	+	+	Y
F. Decrease in lentic biodiversity	-	D	L	R	D,I	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
G. Alteration of upstream & downstream flows	-	D	L	L	D	+	+	Y
H. Changes in estuarine & mangrove habitats	-	D	L	L	I	+	+	?
I. Introduction of exotic aquatic plants & animals to impoundments & river basins	-	D	L	L	D	+	+	Y
J. Disruption of migratory & local wildlife movements	-	D	L,S	L	D	+	+	?
III. CHANNEL EXCAVATION, DREDGING, AND SPOIL DEPOSITION								
A. Reduced water quality	-	D	L	L	D	+	+	Y
B. Loss or modification of aquatic habitats	+,?	D	L,S	L	D	+	+	Y
C. Alterations in species composition, diversity & abundance	-	D	L	L,R	I	+	+	Y
D. Saltwater intrusion into ground or suface waters	-	P	L	L	I	+	+	?
E. Increased sedimentation	-	D	S	L,R	D	+	+	Y
F. Loss or disturbance of terrestrial habitat from spoils deposition	-	D	L,S	L	D	+	+	Y
G. Loss or disturbance of flora & fauna	-	D	L,S	L	D	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
IV. LOCK AND TIDAL GATE CONSTRUCTION								
A. Habitat loss	-	D	L	L	D	+	+	N
B. Erosion	-	D	S	L	D	+	+	N
C. Disturbance of wildlife	-	D	S	L	D	+	+	N
V. WORKER CAMPS & VILLAGES								
A. Increased access to remote areas	-	P	L,S	L	D	+	+	Y
B. Loss of habitat	-	D	L,S	L	D	+	+	Y
C. Reduced water quality	-	D	L,S	L	D	+	+	N
D. Increased incidence of disease	-	P	L,S	L	D	+	+	N
E. Impacts to adjacent habitats from waste disposal	-	P	L,S	L	D	+	+	?
F. Increased human pressure on wildlife populations	-	D	L,S	R,L	D	+	+	Y
G. Introduction of vertebrate & insect pests	-	P	L,S	L	I	+	+	Y
VI. MARITIME DEVELOPMENT								
A. Altered hydrologic regimes	-	D	L,S	L	D	+	+	Y
B. Disturbance to adjacent habitats	-	D	L,S	L	D	+	+	Y
C. Loss of habitat	-	D	L	L	D	+	+	Y
D. Increase in sedimentation	-	D	L,S	L	D	+	+	Y
E. Reduced water quality	-	D	L,S	L	D	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
F. Saltwater intrusion to groundwater & inland surface waters	-	P	L	L	D	+	+	?
G. Alterations in species diversity, abundance, and composition	-	P	L	R	I	+	+	Y
H. Introduction of toxic contaminants	-	D	L,S	L	D	+	+	Y
VII. POWER STATIONS AND TRANSMISSION LINES								
A. Reduction of air quality from smokestack discharge	-	D	L	L	D	+	+	?
B. Reduction of water quality from thermal effluents	-	D	L	L	D	+	+	?
C. Loss & disturbance of habitat within transmission line and pipeline right-of-ways	-	D	L,S	L,R	D	+	+	?
VIII. QUARRIES								
A. Reduction of air quality	-	D	S	L	D	+	+	Y
B. Reduction of water quality from fugitive dust	-	D	S	L	D	+	+	Y
C. High noise levels from equipment	-	D	S	L	D	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
IX. OPERATIONS								
A. Contamination of aquatic and terrestrial habitats from toxic spills	-	P	L,S	L,R	D	+	+	Y
B. Disturbance of local wildlife populations	-	P	S	L	D	+	+	N
ALTERNATIVE SPECIFIC IMPACTS								
GENERAL IMPACTS								
A. Barrier to migratory and local wildlife movements & dispersal of plants	-	D	L	L,R	D	+	+	?
B. Deforestation and fragmentation of large, contiguous forested areas	-	D	L	L,R	D	+	+	Y
C. Creation of marine migration corridor between the Pacific Ocean and Caribbean Sea	+,-	D	L	R	D	+		Y
I. ROADS								
A. Increased access to forested areas	-	D	L	R	D	+	+	Y
B. Reduction of water quality from stream crossings	-	D	L,S	L	D	+	+	?

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
C. Disturbance of marine communities in Bahia de Limon	-	D	S	L	D		+	?
D. Disturbance and fragmentation of habitats northwest of Lake Gatun	-	D	L	L	D	+		Y
E. Disturbance of marine communities at the mouths of the Caimito, Lagarto, Caño Quebrado, and Santa Marta rivers	-	D	L,S	L	D	+		Y
II. DAMS AND RESERVOIRS								
A. Introduction of exotic species into Rio Indio basin	-	D	L	R	I		+	?
B. Loss of terrestrial habitat in impounded areas	-	D	L	L	D	+	+	Y
C. Loss or disturbance of wildlife in or adjacent to reservoirs	-	D	S	L	D	+	+	Y
D. Introduction of exotic plants and animals into the Lagarto and El Pepino River basins through the spillway	-	P	L	R	I	+		?
E. Increased flooding along the spillway	-	P	S	L	I	+		?
F. Loss of habitat, flora, and fauna associated with the upper Gatun reservoir	-	D	L	L	D	+		Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
G. Creation of aquatic habitat in the upper Gatun reservoir	+,-	D	L	L	D	+		Y
H. Loss and disturbance of wildlife in flooding of upper Gatun reservoir	-	D	S	L	D	+		U
I. Modification of aquatic habitats in Escandaloso River and Diablo, Salto, Bonita, and Dormida Streams	-	P	L	R	D	+		?
III. DIVERSION CHANNEL								
A. Destruction of riverine and wetland habitats from diversion of water to western arm of Lake Gatun	-	D	L	R	D	+		Y
B. Creation of lentic habitats	+	D	L	R	D	+		?
IV. CHANNEL, EXCAVATION, DREDGING, AND SPOIL DEPOSITION								
A. Occurrence of unexploded ordinance in spoil deposition areas	-	P	S	L	D		+	Y
B. Impacts to protected areas (Interoceanic Park of the Americas)	-	D	L	L	D	+	+	Y

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
C. Loss of mangroves and wetlands from spoil deposition in W-3 placing area	-	D	L	R	D	+		Y
D. Hydrologic and water quality impacts from spoil deposition at W-4 placing area	-	D	L,S	L	D	+		Y
E. Disturbance to Punta Chame mangroves	-	P	L	R	D	+		Y
F. Impacts to seven rivers and six streams from construction of diversion dams	-	D	L	R	D	+		Y
G. Reduction of water quality in Lake Gatun, nine rivers, and 14 streams from spoils deposition	-	D	L,S	R	D	+		Y
H. Impacts to marine communities at mouths of Punta Grande, Caño Quebrado, and Santa Marta Rivers from increased sedimentation	-	P	L,S	L	D	+		?
V. LOCKS								
A. Loss or disturbance of terrestrial and aquatic habitat and associated wildlife	-	D	L,S	L	D		+	N

Table 6.4. Cont...

IMPACT	BENEFICIAL (+) ADVERSE (-)	(D)EFINITE OR (P)OSSIBLE	(L)ONG OR (S)HORT TERM	(R)EGIONAL OR (L)OCAL	(D)IRECT OR (I)NDIRECT	SEA LEVEL	HIGH RISE	SIGNIFICANT IMPACT (YES OR NO)
VI. OPERATIONS								
A. Salinization of freshwater aquatic systems	-	P	L	R	D		+	Y
B. Bank erosion and disturbance of bottom sediments from ship traffic	-	D	L	R	D	+	+	?
VII. MAINTENANCE								
A. Impacts to terrestrial and aquatic habitats from contaminated spoils	-	P	L	L	D	+	+	?
B. Impacts to marine communities from deposition of contaminated materials in coastal waters	-	D	L	L	D	+	+	Y

6.4 COMPARATIVE ANALYSIS OF ENVIRONMENTAL IMPACTS

The data available and the time/schedule constraints of the current study do not allow for a quantitative comparative analysis of impacts for the two alternatives. However, a basic qualitative analysis is possible considering the key issues listed in Section 4.0 (Objectives & Scope of Work). This analysis is provided in Table 6.4, which presents impacts classified as major or minor, beneficial or adverse, definite or possible, short or long range, regional or local and direct or indirect. Similarly, the following categories have been established: general, general terrestrial, general aquatic, specific according to activity and specific for each alternative.

Under the category of general impacts for both alternatives, it is recognized that significant impacts may occur in the microclimate of the specific habitats affected, air quality and in noise levels. In addition, significant impacts may occur to the topography, and the conditions for increased breeding by insect pests and disease vectors may also occur.

Impacts on the microclimate, air quality, noise and topography are definite and local. With the exception of topography, they may also be direct impacts. Microclimate impacts may be of long or short duration, while the changes in topography may be long term impacts.

The possibility of increasing disease vectors are possible, short and long term, local and general and indirect to the construction activities.

General impacts from either alternative includes the establishment of additional barriers to migration; dispersion of plants and animals, deforestation; fragmentation of contiguous forests, and loss of biodiversity. In the High Rise Lock Alternative, larger areas of contiguous forest may be affected than in the Sea Level Canal Alternative. This is only because the prior access restrictions to the western shore to Gaillard Cut prevented deforestation. This is not the case in the Sea-Level Canal area, where unrestricted deforestation of the area south of Gatun Lake have virtually eliminated the forested areas. The only significant forested areas associated with the Sea-Level Canal Alternative are located north of Lake Gatun. The planned disposal areas may disrupt much of the remaining forests here.

In these, the impacts are definite, of long duration, direct, negative, local and regional. The increase in migration barriers and loss of biodiversity may be significant, of long duration, negative, local and regional.

The construction of the lock and gate structures for both the Sea-Level and High Rise Lock Canal alternatives, there may be localized, significant impacts due to the loss of habitats.

The possible introduction of exotic plant and animal species into the Rio Indio or Rio Lagarto watersheds may have significant, long term, direct and negative impacts on these ecosystems. The creation of the reservoirs at the Gatun, Indio, Trinidad or Ciri rivers does have the potential to have a positive effect in the creation of additional lotic habitats. However, it may also have a negative effect in the loss of forested habitats. Both of these impacts may be long range, and definite. The unknown nature of the existing conditions within these areas the definition of the significance of these impacts uncertain.

The maintenance activities from both alternatives may have possible negative long term local direct impacts of unknown significance from deposition of potentially contaminated materials from dredging activities.

Roadway construction may have various impacts in both alternatives. The increase in access to previously inaccessible areas may bring about an increase in population. There may also be a impacts to water quality from roadway and bridge construction. In these impacts, the effects may be negative, definite and direct. They may also be of short duration and regional in the forested areas. Positive impacts may occur from the incidental creation of migration corridors through the roadways, for certain large mammals.

Both alternatives may also have the potential to have erosion problems and disturbance of the bottom sediments with resulting negative, definite, long term direct impacts of unknown significance. In the High Lock Canal Alternative, additional impacts may occur due to the possible presence of unexploded ordenance in the currently proposed spoil deposition areas (D-3 and D-4). In addition, it is possible that many of these deposition areas are planned within the new Interoceanic Park of the Americas. These effects may be long and short term, significant and negative.

The High Lock Canal Alternative may have negative, definite, short term, local, direct and indirect impacts upon the marine ecosystems of Bahia de Limón, but their significance cannot be determined at this time, due to the lack of site specific information.

Operations associated with the High Rise Lock Canal may promote additional salinization of Gatun and Miraflores lakes. This may be increased through the proposed recycling basins. These effects may be long term, negative, significant impacts.

The Sea-Level Canal Alternative may also create a significant, long duration, local and regional impact with the potential for migration of marine biota. However, it is uncertain what negative or positive impacts may occur.

The Sea-Level Canal Alternative may produce fragmentation of habitats north of Lake Gatun, and in the marine communities at the estuaries of the Caimito, Caño Quebrado and Santa Marta rivers, causing negative, definite, local, direct and significant impacts. The

division of Lake Gatun may remove approximately 26 km^2 of aquatic habitat between Escobal and Lagarterita, and the draining of La Laguna may remove approximately an additional 10 km^2. These may also be long term, direct, definite, local and possibly regional significant impacts.

The diversion scheme, part of the Sea-Level Canal, may have significant, negative, long range, definitive effects on the wetlands found in La Laguna. However, the small associated reservoirs may create additional lotic habitats, which may have a minor, positive, long range impact.

The removal of the mangroves at Puerto Caimito may have a long range, significant, negative impact on this habitat. In addition, the dredging activities for the Pacific Ocean approach channel may have the potential to create additional long range, significant negative impact on the marine habitats and the fishing industry.

The Sea-Level Canal Alternative may cause significant, direct and negative impacts on the associated protected areas of the Interoceanic Park of the Americas, and for the loss of mangroves and wetlands with concomitant degradation of water quality from spoil deposition areas W-3 and W-4, as well as the mangroves in Punta Chame, the seven rivers that may be affected by the construction of dams and reservoirs in addition to the nine rivers and fourteen creeks that may be affected by spoil deposition, roadway construction and increased sediment loads.

Other potential effects from this alternative includes those caused by the construction of the tidal gates and/or lock. There is an associated loss in terrestrial and aquatic habitats, which may cause direct, long and short term, minor negative impacts.

In general terms, the impacts associated with the construction of the Sea Level Canal Alternative appear to be of greater significance, scope, magnitude and regional effects than the High Rise Lock Canal Alternative. Additional information is summarized and presented in Table 6.4. These findings are consistent with those of the 1970 Anderson Report of the Interoceanic Canal Study.

7.0 MITIGATION RECOMMENDATIONS

The following mitigation measures were designed to maintain wildlife and botanical resources through the management of existing habitat and protection of historical habitat diversity. Efforts to mitigate for impacts of the proposed projects on biological resources are directed at preserving ecosystem integrity and enhancing the biodiversity in the vicinity of the proposed project. This approach is based on: 1) the importance of the availability of a variety of biological resources in maintaining species richness, and 2) the relation of wildlife species diversity to existing habitat diversity.

It must be noted that in the absence of site specific information to evaluate potential impacts, it becomes even more difficult to provide specific mitigation measures. Consequently, only qualitative measures can be recommended, together with the mitigation approach and strategies.

7.1 MITIGATION APPROACH

General mitigation measures are presented to avoid or reduce significant impacts of the project alternatives on the biological environment. The level of detail provided is necessarily limited because much of the baseline information was collected from surveys, studies, and reports of a regional rather than site-specific nature, and because of the conceptual nature of the project description. Mitigation measures, therefore, have been broadly defined and are applicable for typical construction activities and practices over the entire project area. With few exceptions, the measures were not designed for a single species, facility, or location. Rather, an approach was developed to mitigate for general types of impacts on existing resources.

Simple avoidance is typically the most effective way to eliminate potential impacts on biological resources. In the many cases where complete avoidance is not feasible, partial avoidance should be pursued. This "on-site" protection has the potential to preserve species and habitat that could be rehabilitated and returned to essentially pre-disturbance conditions. If on-site mitigation is not possible, then the possibility of relocating the sensitive resource should be considered. Resource relocation is expected to have a relatively minor effect for wildlife, which will move on their own or be difficult to capture and relocate. Similarly, many plants species have narrowly defined niche requirements and resist transplantation.

In cases where relocation is not a viable alternative, the type and extent of the resource that will be lost should be recorded and off-site compensation determined as part of a formal mitigation plan. The flow chart presented in Figure 7.1 was developed to illustrate the mitigation process. The following discussion was prepared to interpret the process leading to construction, as depicted in the mitigation flow chart, and provide a more detailed explanation of each activity and decision nexus.

A. Conduct Reconnaissance Surveys: Prior to construction, biologists would conduct reconnaissance surveys to determine the presence or absence of sensitive resources. For the purposes of this discussion, the term survey is defined as an exercise conducted by qualified biologists in which a set of qualitative and/or quantitative observations are made within a restricted period of time, without any preconceptions of what the findings ought to be.

B. Sensitive Resources Identified? Sensitive resources are generally those that are legally protected, rare or highly unusual, or those animals or plants which play a critical role within an ecosystem (keystone species). The term can apply to ecotypes as well as individual species. Mature tropical forest, for instance, is considered sensitive. The sensitivity of the mangrove forest, likewise, in not necessarily based on the scarcity of a certain species of mangrove, but on the important ecological functions they provide when performing as a unit. If sensitive resources are not observed within the area of potential effect, construction activity using general, on-site mitigation measures can commence. If it is determined that sensitive resources do occur in the area of potential effect, then proceed with the next step in the process.

C. On-site protection possible? Measures that can protect on-site resources include: avoidance; establishment of buffer zones; marking, flagging, and posting of signs; scheduling construction to avoid sensitive time periods (e.g., crepuscular activity and breeding seasons) and; measures to encourage natural revegetation of temporarily disturbed habitats. With the implementation of applicable on-site protection, in addition to the general mitigation measures, construction activity could commence. If the projected impacts cannot be ameliorated on-site, then relocation options should be carefully evaluated, designed, and conducted prior to construction.

D. Relocation of Sensitive Resources Possible? If relocation can be an practicably achieved, construction could proceed. However, resource relocation may not be a viable alternative for a variety of reasons. Areas where relocation is not feasible or realistic or where resources will be irretrievably damaged, should be recorded prior to initiation of construction.

E. Implement Relocation Measures: Sensitive plants could be removed by transplanting into adjacent undisturbed habitat. In some cases, collection of seeds, top soil containing seeds, cuttings, shoots, rhizomes, spores, and other reproductive elements could be used for propagation in nurseries or botanical gardens, prior to replanting. When disturbance will be temporary and short-term, the materials should be stored and replaced on site. Sedentary animal species may be trapped and relocated, more mobile species would naturally move away to avoid disturbance.

F. Record Unavoidable Loss of Resources: In areas where sensitive resources cannot be saved, the type and extent of irrevocably committed biological resources should be recorded before construction (utilizing standard mitigation measures) proceeds. This record could be used as a basis for determining the appropriate level of off-site compensation.

7.2 GENERAL MITIGATION MEASURES

The following mitigation measures have been designed to reduce potential impacts of general construction, regardless of the nature of the specific activity. It is anticipated that these measures will be further refined to address site-specific conditions and actual construction practices and modified in response to a monitoring of their effectiveness. Impacts and proposed mitigation measures are also illustrated in Table 7.1.

7.2.1 Construction Mitigation Measures

Many remaining impacts to biological resources can be avoided or reduced during final design planning or project construction. Specific protocols can be established and followed during project construction to avoid and reduce short-term impacts to vegetation and wildlife. They are listed below:

A. Schedule Management: Manage construction schedule to avoid periods of highest biological activity (e.g., dawn, dusk, breeding seasons). Critical interruptions in breeding cycles could be easily circumvented though judicious scheduling.

B. Construction Phasing: Phase construction to limit impacts on wildlife and their habitats to relatively small portions of an area at any given time. Prudent project management can be one of the most effective ways of alleviating potential adverse cumulative impacts of a localized activity.

C. Fencing/Warning Signs: Install temporary fencing and/or signs to define and delimit construction zones. This will prevent inadvertent destruction of resources that can be avoided, particularly in areas of temporary disturbance. Given the expected ethnic diversity of the construction workers, graphics rather than text are recommended.

D. Buffer Zones: Provide buffer zones around active nests or burrows of sensitive wildlife species (e.g., raptors). These zones may also function as erosion filters.

E. Access Restriction: Construction activity should be limited to the smallest possible area needed for efficient construction. Establishing construction zones and restricting workers and equipment to those zones will decrease the amount of surface

disturbed. Implementation of this measure is certainly consistent with the prime avoidance strategy and will serve to reduce or eliminate disturbance to adjacent sensitive resources. Access roads no longer needed for construction should be closed to prevent immigration and public access, so as to prevent exploitation of previously undisturbed habitat.

TABLE 7.1
MITIGATION RECOMMENDATIONS

A. General Mitigation Approach

1. Conduct reconnaissance surveys.
2. Identify sensitive resources.
3. Protect resources on-site.
4. Relocate sensitive resource.
5. Record unavoidable loss of resources.

B. General Mitigation Measures

1. Schedule management.
2. Construction phasing.
3. Fence/warning sign installation.
4. Buffer zone establishment.
5. Access restriction.
6. Worker education and orientation.
7. Erosion control and soil protection.
   - Erosion control plan development.
   - Proper location of roads and facilities.
   - Avoidance of springs, seeps and steep grades.
   - Use of bridges, culverts and waterbars to reduce washout.
   - Construction of roads during the dry season.
   - Placement of brush piles downslope from surface disturbances.
   - Road surfacing.
   - Revegetation of temporarily disturbed areas.
   - Stream protection through use of berms, straw, fabric barriers or maintenance of vegetation.
   - Fire prevention and suppression practices.
8. Insect vector control program.
9. Air quality protection.
   - Air pollution control plan.
   - Dust control.
   - Equipment maintenance.
   - Use of pollution control technologies.
10. Hazardous materials handling and storage.
   - Spill contingency plan.
   - Disposal protocol.
   - Staff training.

TABLE 7.1
MITIGATION RECOMMENDATIONS

C. High-Rise Lock Canal Mitigation

1. Avoid use of D-1 and D-2 placing areas.
2. Follow general mitigation approach at each location where construction will occur.
3. Analyze dredge spoils.
4. Use silt screens to control sedimentation and turbidity.
5. Special sedimentation control at sediment placing area W-1.
6. Protect Caribbean coral reefs from sedimentation and suspended solids.
7. Clear woody vegetation from impoundments prior to inundation.
8. To control sedimentation in the newly created reservoirs and prevent a loss of storage capacity:.
   - Prevent conversion of remaining forest to agriculture.
   - Implement reforestation and soil conservation activities within watersheds.
   - periodically remove sediments by flushing, sluicing or release of density currents.
9. Maintain minimum flows upstream and downstream of reservoirs to reduce disruption of lentic fisheries.

D. Sea-Level Canal Mitigation

1. Conduct biological baseline studies.
2. Additional grading of land surrounding diversion dams to promote wetlands development.
3. Store topsoil to agist in revegetation with native plants.
4. Investigate options (freshwater, thermal or other barriers) to prevent interoceanic marine species

E. Development of Mitigation Plan

1. Include specific information on types and amounts of habitat and wildlife affected, mitigation locations, construction design and site preparation.
2. Address air quality, water quality, erosion and topsoil management, road closure, revegetation and restoration, reservoir and floodplain management, vector control and general construction practices.

TABLE 7.1 MITIGATION RECOMMENDATIONS		
F.	Monitoring Program	
	1.	Establish the purpose and ultimate objectives of the monitoring program.
	2.	Identify the agencies or individuals responsible for administering and executing the program.
	3.	Establish location of the monitoring sites.
	4.	Establish the timing, number and types of samples to be collected (benthic and suspended sediments, benthic and pelagic biota, known bioaccumulators) and measurements to be made f(salinity, turbidity, temperature, dissolved oxygen, biological oxygen demand, pH, chemical composition, etc.).
	5.	Description of the analytical methodologies to be employed.
	6.	Establish standards and acceptable ranges for results.
	7.	Identify actions to take if the standards are exceed.
G.	Habitat Compensation	
	1.	Use records of unavoidable losses of biological resources to determine level of off-site mitigation and develop specific compensation formulas.
	2.	Acquire or manage adjacent natural areas for compensation.
	3.	Organize a habitat area planning (HAP) team to oversee mitigation and compensation activities.

Prior to construction, a detailed road closure plan should be developed. The closure plan should include, at a minimum, maps and detailed road locations, information on the timing of closures, and explicit closure practices by road or road type. Typical closure measures include returning roads to their original slope and contour, as well as revegetation. The plan may include provisions for transplanting trees from disturbed areas as an erosion control measure and as part of the relocation procedure.

F. Worker Education: Conditional to beginning work, construction workers should receive a resource protection briefing. The program should contain information on the sensitive and protected resources, the mitigation measures, and the importance of mitigation compliance. It is anticipated that this information, along with a safety briefing, could be presented as the workers are being in-processed.

G. Erosion Control and Soil Protection: Erosion can have profound consequences on biological resources, therefore erosion control measures should be incorporated into every project phase and activity. The development and implementation of a comprehensive erosion control plan is critical if biological resources are to be

protected. The plan should include detailed measures to reduce and control erosion. Facilities and roads should be carefully located so they can drain properly; avoid springs, seeps, and steep grades wherever possible. Roads should cross streams at right angles. Bridges, culverts, and waterbars should be employed to reduce washout.

Facilities and roads should also be constructed during the dry season, as wet-weather construction is costly in terms of time, money, and environmental damage. Sediment movement can be minimized by building brush piles downslope from surface disturbance. Paving, or road surfacing with gravel can substantially reduce erosion. Cut and fill areas should be revegetated, or treated to enhance natural revegetation. Culverts, dams, weirs, and roads should be properly maintained.

One technique used to prevent eroded soils from reaching a stream is to leave a strip of undisturbed vegetation between the project component and the watercourse. This will serve to intercept sediment-bearing surface flows. In general, the steeper the slope affected, the greater the width of the undisturbed swath that should be retained. Other means of protecting streams include the use of berms, straw, or fabric barriers.

Fire suppression practices should also be addressed. Fires, whether planned, accidental, and natural, remove trees, shrubs, and understory plants that stabilize soils. Measures should be implemented to prevent brush piles that are located between roads and watercourses from burning.

H. Insect Vector Control: Implement suitable techniques and practices to reduce creation of vector habitat, utilize biological or chemical control as required.

I. Air Quality Protection: Develop and implement and air pollution control plan which includes limiting operations when dust is problematic, avoiding the creation of large tracts of open land, the maintenance of construction equipment, and the use of pollution control devices and technology.

J. Hazardous Materials Handling: Establish safe practices for handling and storing chemicals, oils, equipment fluids, fuels, pesticides, herbicides, and other hazardous substances. Develop spill clean-up and disposal protocols. A team should be trained, equipped, and staffed to handle aquatic spills.

7.2.2 Alternative Specific Mitigation Measures

As indicated in the beginning of this section, in the absence of information regarding the specific areas where the potential impacts may occur, it is not possible to identify specific mitigation actions that can be taken. Only a general approach and specific mitigation

measures can be identified for each of the proposed alternatives, and are described in the following sections.

7.2.2.1 High-Rise Canal

The most extensive impacts associated with the High-Rise Canal alternative result from the deposition of excavated spoils during the Gaillard Cut widening process, and construction of the new locks. This includes the areas designated at D-3 through D-9.

The D-3 area borders a small inlet, and is known to consist primarily of tropical forest. bordering the water. The D-4 through D-6 areas also consist primarily of tropical forest, but are farther inland. There is an inlet that leads from the Gaillard Cut to D-4, to the Rio Mandinga. The fill activities will completely bury this watershed. A similar situation exists in D-6, where the Rio Grande will be filled.

The D-7, D-8 and D-9 fill areas contain a gradation of forest cover, diminishing as one approaches the Pacific Ocean. However, significant areas of forest are found in D-7, along with the Rio Congo, which will also be buried.

Due to the new Interoceanic Park of the Americas, most of these deposition areas may already be within the park boundaries. Limitations on the potential uses of these areas may force relocation of the proposed spoil areas. In order to reduce the potential impacts that may be generated, additional areas should be located farther west, where they will lie outside the park boundaries, in areas that have already been affected by human activities. This may increase the hauling distances between 5 to 10 additional kilometers.

Fill area D-1 will be receiving materials from the construction of the new locks at Gatun. This area is predominantly mature tropical forest with a diverse flora and fauna and considerable ecological value. The possibility of placing excavated materials into the adjoining wet placing area W-2 should be explored as an alternative. A similar situation exists with placing area D-2, that will be covering up a portion of tropical forest near Punta Bohio. This area is adjacent to wet placing area W-4. Deposition alternatives should be explored at this site as well.

Prior to construction, spoil deposition areas should be carefully surveyed to identify potentially valuable environmental resources. These should be recorded and their protection in place should first be considered. Depending on their location, this may entail modification of the configuration of the spoil area, in order to avoid damaging the resources. If this is found to be impossible, then measures should be taken to relocate the resources. In the case of flora, propagation by cuttings or seed banks may be established, as applicable for the individual species. If relocation is not feasible, survey records should be used to evaluate the potential for mitigating their loss offsite.

Dredging and placement of spoils will have various effects on the quality of water and its associated biota. Clamshell dredging methods, indicated in the ECE Report, can have a greater impact than suction dredging. An evaluation of the different available dredging methods should be performed, in order to select the method that causes the least impact.

Excavation and dredging destroy benthic habitat. The suspension of sediments in the water column may lead to an increase in dissolved solids. Some of these may be toxic to the biota, either directly or indirectly from bioconcentration in edible species. Impacts associated with the placing areas are similar, in that there will be an increase in suspended and dissolved solids. Benthic habitats will be destroyed as they are covered by the dredged materials. Other impacts to aquatic habitats may be produced by the erosion and rainfall runoff from the terrestrial operations. These also may cause changes in water quality, and can also affect the habitats by reducing the depths of streams due to increased sediment deposition.

Mitigation measures for the aquatic placing areas should include an initial analysis of the composition of the sediments to be dredged. This will allow an evaluation of the potential for release of heavy metals or other toxic substances into the water. Physical control of sedimentation and turbidity can be achieved by the careful use of silt screens. These should be used wherever dredging, placement of spoil, or runoff from land can bring in eroded materials into Lake Gatun. Mitigation measures for the marine dredging and spoil placement operations should be similar to those performed within Lake Gatun. However, special considerations for the control of sedimentation and suspended solids should be taken in placing area W-1. Prevailing ocean currents are to the east, and will tend to take suspended sediments towards the coral reefs located on the northern shores of Galeta, Largo Remo and Payardí islands. These coral reefs represent important habitats that should be protected.

Major impacts are expected in the areas of the proposed dams and impoundments. The impoundment for the Indio River dam will cover between 19 and 22 km^2, depending on the option selected. Based on the evaluation of aerial photographs, the Indio River area appears to consist of a patchwork of forested and non-forested areas. The non-forested areas are a combination of agriculture, pastures, grasslands and logged out areas. Some areas appear to have as much as 50% to 60% forests, but this proportion declines to between 50% and 40% forest as one approaches the western edge of Lake Gatun. The area from the west end of Lake Gatun to the Caribbean declines to between 40% and 30% forest cover.

The areas of the Ciri, Grande, and Trinidad river dams and impoundments cover 13 and 17 km^2, respectively. These areas have long been transformed by human activities and currently have between 10% and 15% forest cover. The non-forested areas are primarily grasslands and pastures. There is a minimal amount of agriculture in these areas. Mitigation in these areas will first require a reconnaissance biological survey to identify

existing natural resources. Access to the Trinidad and Ciri Grande basin areas is limited, and access to the Rio Indio basin is very difficult. Aerial photographic coverage of these areas is incomplete, out of date and mostly in black and white. Once the initial survey has been performed, additional specific mitigation strategies of protection in place, relocation, or offsite compensation will have to be formulated.

To reduce impacts on water quality and the proliferation of aquatic weeds in the new reservoirs and downstream, impairing dam discharge, woody vegetation should be cleared from the inundation zone prior to flooding (nutrient removal). To control sedimentation in the newly created reservoirs and prevent a loss of storage capacity, land use in the affected watersheds should be controlled (especially the prevention of conversion of remaining forests to agriculture), reforestation and soil conservation activities should be implemented within the watersheds, and sediments should be periodically removed by flushing, sluicing, or the release of density currents. Minimum flow should be maintained in rivers up- and downstream of the reservoirs to reduce disruption of riverine fisheries from changes in water quality and limnology.

7.2.2.2 Sea-Level Canal

Recommended mitigation measures for the Sea-Level Canal alternative are more complex than those for the High-Rise Lock Canal alternative, due to the increased activities that will be performed here. Terrestrial mitigation efforts should follow the same pattern as established above, with the exception that a much greater area must be evaluated. No surveys of this area were performed as part of the Unipan-ANCON Biological Inventory

Terrestrial habitats in the southern portion of the Sea-Level Canal project area are generally of lower quality than those associated with the High-Rise Lock alternative. In this area, most of the forests have already been removed to accommodate agricultural activities. Placing areas D-14 through D-17 will be affecting primarily grasslands with sparse forest cover. However, small forest fragments remain within these areas and will require full reconnaissance surveys.

Within placement areas D-9 through D-13, terrestrial habitats on the banks of Lake Gatun, near the area scheduled for isolation contain a mixture of wetlands, submerged areas, small forest fragments and grasslands. Placement Area D-13 together with the construction of the worker camp, perimeter road and sea-level canal, will obliterate the wetland and forested areas associated with the mouth of the Pescado River. Mitigation efforts will depend on the results of reconnaissance surveys of these areas. The same steps for on-site protection or relocation of flora and fauna should be applied here. Consideration should be given to relocating the diversion channel to the edge of the lake, so that most of the wetlands can be preserved.

Placement areas D-1 through D-7 are located between the north shore of Lake Gatun and the Caribbean. Limited information was available to evaluate the conditions in these areas, and there was not full aerial photographic coverage.

Major wetland areas will be eliminated in the project area, either through the excavation of the canal through the mouth of the Rio Pescado, the creation of the diversion of the Cano Quebrado, Quebrada Chica, La Mendoza, and Los Hules rivers, as well as the creation of the barrier dams E, F and G, together with subsequent dewatering of the impounded areas.

Partial mitigation will be achieved with the creation of the small dams for the diversion channel on the Cano Quebrado, Quebrada Chica, La Mendoza, and Los Hules rivers, but additional grading of the surrounding areas should be performed to promote the development of wetlands. As an additional measure, topsoil from the existing wetlands can be excavated and spread along the banks of the proposed impoundments, to assist in revegetation of these areas with native wetland plants.

Aquatic impacts are associated with the dredging and spoil placement activities in the Caribbean and Pacific Ocean, as well as the potential for migration of marine biota through the sea-level channel. The impacts from the effects of dredging and spoil deposition can be reduced through careful use of sediment control techniques, such as silt screens, and through the use of suction dredges, rather than clamshell dredges.

The potential migration of marine biota through the sea-level canal may be mitigated by the construction of a biological barrier. A fresh-water barrier has been hypothesized in the ECE Report. As presented, it does not appear that this system may be effective. The lack of available fresh water in dry years would render this system inoperative. In addition, a positive flow of fresh water coming out of both ends of the sea level canal may be effective in preventing intrusion of saline water. However, a sea-level canal may be incompatible with this concept, and would require constructing locks at both end, and keeping the level of fresh water higher than the surrounding sea. In effect, this would duplicate the existing canal system. Unless additional sources of fresh water can be obtained, and other barrier methodology, such as electronic or thermal components are included, it may not be possible to create an effective barrier. It is not possible to provide a determination on the effectiveness of these concepts without further studies.

7.3 GUIDELINES FOR MITIGATION PLANS AND MONITORING PROGRAMS

Prior to construction, a detailed Mitigation Plan must be developed. It should include, at a minimum, precise information regarding implementation, types and numbers of species/habitats, specific mitigation locations, construction design details, and site preparation descriptions. The Plan should include components that address air quality,

water quality, erosion and topsoil management, road closure, revegetation and restoration, reservoir and floodplain management, vector control, and general construction practices.

The recommended option for the organization of the Monitoring Plan would be to divide the project into geographic zones that coincide with the engineering divisions. Local impacts and corresponding mitigation will be quite similar within each zone. The High-Rise Canal, for instance, has been divided into four construction zones; Zone I is the Atlantic approach, Zone II is the Lake Gatun crossing, Zone III is roughly divided between terrestrial (dry) excavation and dredging (wet) excavation within the Gaillard Cut, and the Pacific approach comprises Zone IV. The potential alternative- and activity-specific (e.g., road construction) impacts will have distinctly different local consequences on marine and estuarine resources in the Atlantic (Zone 1) versus the Pacific (Zone IV).

To ensure that the goals and objectives of the Mitigation Plan are met, an integral Monitoring Program should also be developed. This may be a separate document or incorporated into the Mitigation Plan. For this report, monitoring is defined as the regular surveillance carried out to ascertain the extent of compliance with predetermined mitigation goals and standards and the extent of deviation from them.

The Monitoring Program that is developed and implemented should be comprehensive and include, at a minimum: the schedule, criteria for success, actions to be taken in cases of noncompliance or when measures are not succeeding in providing the expected degree of mitigation, and the entity responsible for monitoring.

The portion of the monitoring program for dredging activities, for example, should contain at least the following information:

1. The purpose and ultimate objective(s) of the monitoring program.

2. The identity of the agencies or individuals responsible for administering and executing the program.

3. Location of the monitoring sites.

4. The timing, number, and types of samples to be collected (benthic and suspended sediments, benthic and pelagic biota, known bioaccumulators) and measurements to be made (salinity, turbidity, temperature, dissolved oxygen, biological oxygen demand, Ph, chemical composition).

5. A description of the analytical methodologies employed.

6. Standards and acceptable ranges for results.

7. Actions to take if standards are exceeded.

7.4 HABITAT COMPENSATION

Habitat compensation is recommended to ensure that there is no net loss of habitat quality and regional biological diversity. The ultimate of such compensation is to ensure that species richness and diversity are not diminished due to construction and operation of either project alternative.

When it is not possible to avoid or reduce impacts on biological resources within the project area, measures are proposed to compensate for unavoidable losses of habitat. The preferred strategy is to protect, when possible, similar (in-kind), unaffected habitat within the project area (on-site) to replace those resources affected by the project. However, in the course of the project, biological resources like those in spoil deposition areas, will be irrevocably lost, with little or no chance for on-site rehabilitation. It is recognized that this protection is not a replacement, and that a net loss of habitat will occur.

Losses which cannot be reduced or avoided through mitigation onsite should be recorded, as described in the conceptual approach. This information will be used to determine the type and amount of offsite compensation, however, as most other similar habitat within the project area has also already been lost or degraded from logging, agricultural clearing, and other activities, in-kind replacement of lost resources may not be possible or practical. In these cases, calculations of unmitigated losses will be used to determine the appropriate level of offsite, out-of-kind compensation.

The Mitigation Plan should thus include specific habitat compensation formulas, agreed to by all concerned parties. These formulas will assist design and value engineering in projecting costs and encourage the avoidance of particularly sensitive resources. Through this mechanism, a clear financial incentive to avoid biological assets will be established if, for example, the per hectare replacement value for mangrove forest is ten times that of agricultural lands.

Under certain circumstances, then, the acquisition, preservation, and maintenance of similar (in-kind) or different (out-of-kind) habitat in or near the study area may be the most practical means of compensating for a regional reduction in biological diversity caused by loss or fragmentation of project area lands. Relatively large, contiguous blocks of habitat are required to avoid the adverse effects of habitat fragmentation on animal and plant populations.

The acquisition of undisturbed habitat adjacent to existing natural areas may be the best way to provide for conservation of regional floral and faunal diversity. These newly acquired areas could then be placed under legal protection, significantly reducing the possibility of

future habitat loss or fragmentation in these areas. Even a landscape with impoverished remnants is better than one with none at all. Forest remnants can serve as important catalysts for forest regeneration and sources of botanical endemism. Ideally, smaller fragments should be connected by forest corridors and the landscape should include several forest tracts larger than 1000 ha (D. Janzen, personal communication).

Management of these offsite mitigation lands should emphasize the value of these habitats to special status plant and animal species. Long-term increases in the quality of the mitigation parcels could be achieved by restricting multiple-use activities (timber harvest, agriculture, livestock grazing) and through direct habitat improvements. Any actions taken will depend upon how and what species are used to indicate habitat quality. In some cases, indicator species may be species status species that will experience direct losses of habitat from project construction and operation. In other cases, keystone species most sensitive to habitat disturbance will be identified to represent groups of animals that exploit similar resources in similar ways (=guilds).

Several locations for potential habitat acquisition within the study area have been identified for potential acquisition:

1. A relatively large, contiguous block (approximately 14,000 ha) of mature tropical moist forest occurs south of Barro Colorado island, from the vicinity of Cerro Gigante eastward to the south shore of Lake Gatun, south of Gamboa.

2. An approximately 1,400-ha block of mature tropical moist forest is situated east of the Gatun locks.

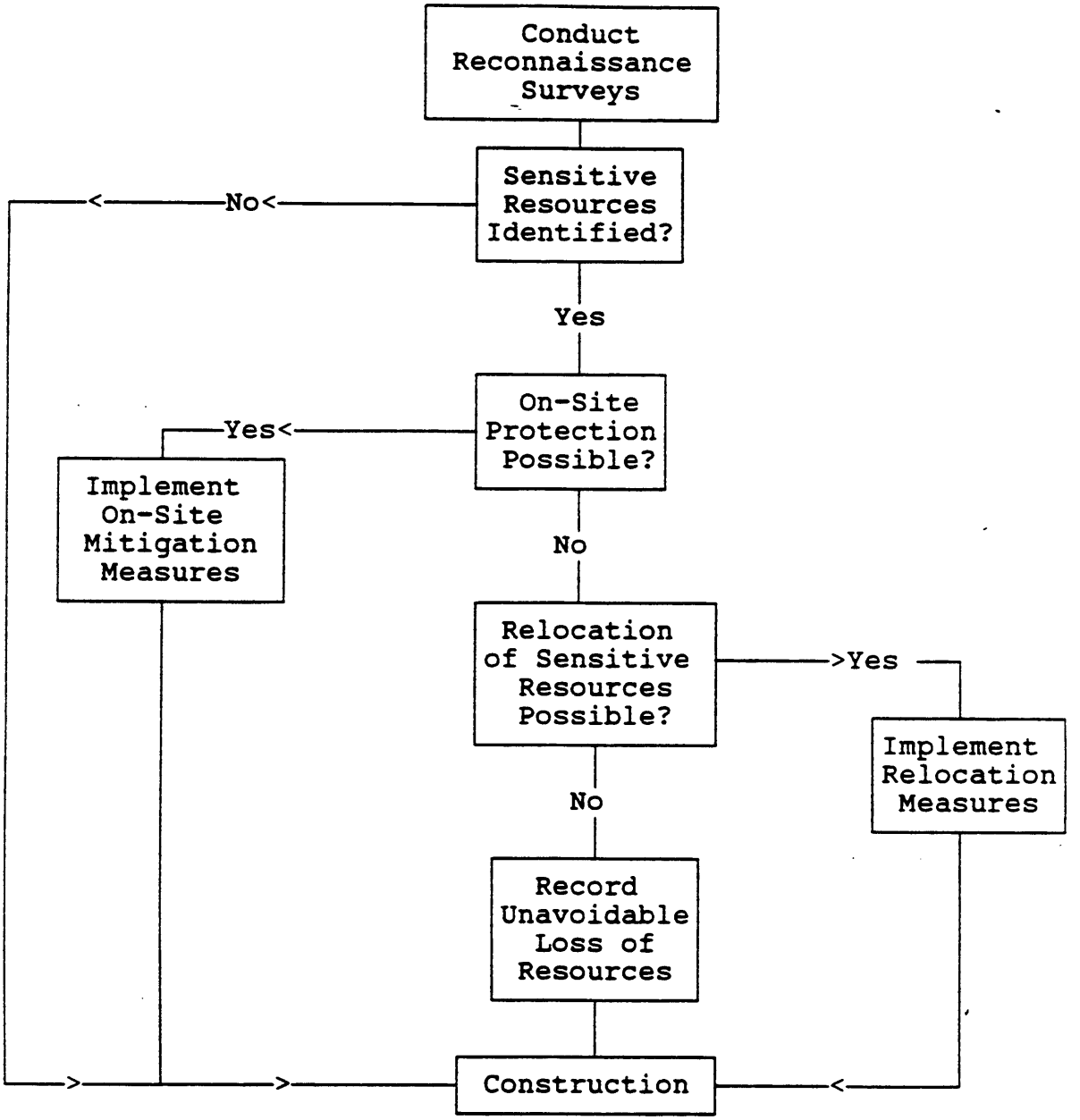
3. Approximately 140 ha of freshwater wetlands occurs at the mouth of the Rio Trinidad. This large wetland could however, be lost by construction of the sea-level canal.

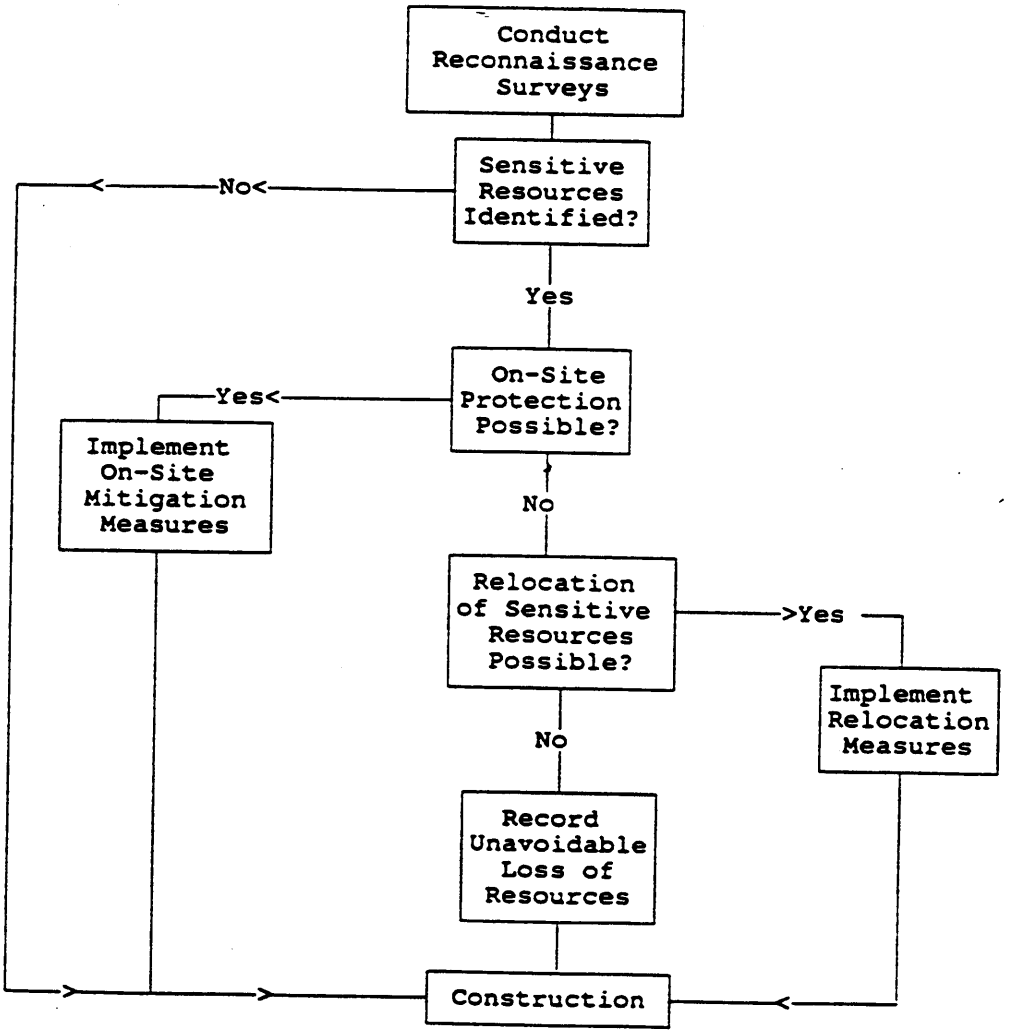
Large areas of mature tropical moist forest and freshwater wetlands also still exist east of the existing canal, in the Districts of Colon and Chagres in the Province of Colon. A portion of the mitigation funds assigned to habitat acquisition should be reserved in the form of an endowment. The endowment funds should be used to protect the habitat acquired or used to provide protection to existing reserved but unprotected lands. The establishment of legal protection can be less than effective if not enforced. For example, there is a substantial amount of mature forest in the Upper Chagres River basin (Chagres National Park) that is protected by law, but lacks sufficient funding to provide adequate enforcement. Endowment funds could also be applied to develop educational programs designed to increase local awareness of the value of the protected resources, and to develop

"ecotourism" as a way to offset the financial implications of discontinuing consumptive resource exploitation in protected areas.

A Habitat Area Planning (HAP) Team, consisting of project proponents and representatives from concerned government agencies, the University of Panama, and relevant conservation organizations (e.g. ANCON, STRI) should be formed to provide input into habitat compensation and mitigation policy decisions throughout the construction and operation phases of the project. The HAP team will decide which portion of the compensation lands to propose for multiple-use management and which to manage exclusively for biological resources. They will contribute to decisions on how indicator species will be used to guide habitat management efforts, will be ultimately responsible for guiding enhancement activities, and will jointly develop a Mitigation Habitat Management Plan, detailing management schemes for each area designed for long-term management, including wildlife habitat improvement work.

Construction Mitigation
Biological Resources





ENVIRONMENTAL ANALYSES STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

CONSTRUCTION MITIGATION
BIOLOGICAL RESOURCES

DAMES & MOORE

FIGURE 7.1

8.0 RECOMMENDATIONS FOR FUTURE STUDIES

Recommendations for further environmental studies have been divided between those common to both alternatives, those specific to the High-Rise Lock Canal Alternative, and those specific to the Sea-Level Canal Alternative. The associated time frames and cost estimates are provided as guidelines for future investigations.

8.1 GENERAL RECOMMENDATIONS

As indicated in Section 6.0, certain impacts may be common to both alternatives. In a similar fashion, certain future studies should be performed, regardless of the alternative chosen. The need for the following future studies have been identified as follows:

8.1.1 Habitat Mapping

The optimal mitigation strategy has been determined to be avoidance of disturbance to biological resources. This strategy requires that resource locations be known with a relatively high degree of certainty. Before resources can be avoided, a fairly detailed mapping of their specific location and extent must be performed. Sensitive species tend to be closely associated with a distinct community or habitat type. Therefore, studies designed to develop detailed maps of the major and critical habitat types in the project area should be prepared.

Maps containing this level of detail will be critical for determining the least environmentally damaging alternatives for site development and road alignment. These maps will also assist in determining potential resource relocation or compensation sites. The information contained on resource maps is crucial for ascertaining potential site-specific impacts, and for developing Mitigation and Monitoring Programs, including which areas should be monitored. Habitat maps will also document the existing environmental baseline conditions and provide a standard to measure the effectiveness of mitigation.

Areas should be mapped along the proposed canal right-of-way and where deposition of spoil materials, roadways (primary and secondary), labor villages, camps, equipment laydown areas, quarries, dams, impoundments, dredging, powerline transmission corridors and other construction activities may occur. It is Dames & Moore's opinion that areas of impact should be considered all land within a one (1) kilometer radius from the boundary of the immediate construction, deposition (wet & dry) areas, roadways and all other canal related facilities. In this fashion, comprehensive maps of current terrestrial and aquatic habitats could be obtained.

Mapping activities should begin prior to the selection of the final engineering design, so that the results can be taken into consideration in this process. Maps should not be limited to the flora found in these areas, but should also include the fauna that may be affected. This should include vertebrates as well as invertebrates.

The estimated time frame for this activity would be approximately four to eight weeks of field activities, performed by four field parties assigned to each alternative. An additional four to six weeks may be required to cover the estimated impact areas of the proposed dams. It is estimated that costs for these activities may range between $100,000 to $200,000.

8.1.2 Final Project Description

Habitat maps, showing existing biological resources and establishing baseline conditions for the proposed project area, must be supplemented by a comprehensive and detailed project description. The maps will report what resources occur in the project areas, while the project description depicts the actions that may affect those resources. These two components are absolutely necessary to accurately assess potential site-specific impacts to those resources and develop appropriate mitigation strategies designed to reduce or eliminate those impacts.

The description should include complete discussions and full details (including accurate maps) of proposed project activities and facilities. For a project of this magnitude, the development of detailed Construction, Operations, and Maintenance Plans will be essential.

The estimated time frame for this activity would be approximately eight months to a year. It is estimated that costs for these activities may range between $500,000 to $1,000,000.

8.1.3 Aerial Photography

The current investigation has been hampered by the lack of complete aerial photographic coverage of the study area. Aerial photography provides important information that allows investigators an opportunity to observe details in the context of potentially affected areas. A full set of color aerial photographs, at a consistent scale (1:18,000 is sufficient) should be commissioned. These should cover the entire area of the High-Lock and Sea-Level Canal routes, all deposition areas, as well as all proposed impoundment areas (Upper Gatun, Indio, Ciri and Trinidad rivers), all diversion channels, minor impoundments and spillways.

The estimated time frame for this activity would be approximately six to eight weeks. It is estimated that costs for these activities may range between $100,000 to $200,000.

8.2 BIOLOGICAL BASELINE STUDY RECOMMENDATIONS

One of the most critical items for the design of a complete biological baseline study, will be the definition of the specific areas that may be affected directly by the construction activities. Among the most important ones are the placing areas for dredged and/or excavated materials, as well as the canal trace areas and the impoundment areas of the dams. As indicated in Section 6.0, important impacts may occur in the areas where project

support activities, such as roadways, bridges, breakwaters, batching and crushing plants, quarries, construction villages and camps will be. Once these locations have been better defined, a complete, directed baseline study can be performed, improving the estimates of the effects of the alternative projects.

During the activities for the Environmental Analyses Component, several data limitations were encountered. Some of the items that are listed below are recommendations for future studies, and others are methods used to overcome these limitations. There are several general recommendations that could improve the value of data collected for the Biological Inventory.

These recommendations are an outgrowth of some of the data limitations discussed in this report.

- For some taxonomic groups, data on flora and fauna should be reported according to habitat type and not sampling site. Most sites sampled included several distinct communities, which should be described or discriminated during data collection. This has special importance for flora - the basis for describing habitats. In addition, some habitats should be sampled more extensively, including agricultural areas, freshwater wetlands, rivers, streams, mudflats, and extensive areas of mature forest.

- In some cases (notably for mammals), the data in the Biological Inventory are incomplete. Sampling should also be conducted in January through April to cover much of the dry season. In the specific case of mammals, the available material began during the sampling activities of January. No information was collected for the previous quarters. The investigation for mammals should be extended to cover a complete year.

The estimated time frame for this activity would be approximately sixteen to twenty months, and should include both alternatives and the estimated impact areas of the proposed dams. It is estimated that costs for these activities may range between $2,500,000 to $3,500,000. This does not include the preparation of the final project description. These studies should include sampling sites within the estimated impact areas. With respect to the High-Rise Lock Canal Alternative, they should include all the dry deposition sites, with particular emphasis placed on D-1 and D-2. A full biological inventory should be performed in the area affected by the reservoirs for the Indio, Ciri and Trinidad dams. Special care should be taken in areas D-4 through D-7, due to the possibility of unexploded ordenance. Should the evaluation of the limits of the new Interoceanic Park of the Americas preclude the use of these areas for spoil deposition, additional areas further west may have to be identified and surveyed.

With respect to the Sea-Level Canal Alternative, a complete biological inventory is required. Particular care should be taken in evaluating the forested areas north of Lake Gatun. In addition, an evaluation of the Rio Lagarto watershed and spillway area requires investigation.

Additional studies should also evaluate the results of the final sampling activities of the current Biological Inventory component, as well as its final report.

8.2.1 Vegetation

The use of 1 km transects through a variety of different habitats at each sampling location yielded data in the Biological Inventory which represented species and densities averaged over the various habitats crossed by the transect line. Data must be collected so as to be more useful in describing the component habitats.

In areas where forested habitat will be cleared to create new canal alignments, reservoirs, spoil deposition sites, or other project facilities, formal forest inventories should be conducted to determine forest cover, timber volume, and the number and species of trees with commercial value. In addition, a general study of flora should be conducted in these areas to determine the presence of sensitive species or those with medicinal, cultural, or commercial value. This information can be used to develop techniques for relocating plants using seeds, rhizomes, spores, or cuttings. Reproduction of such species should be first studied in nurseries or botanical gardens to improve success rates for relocation efforts.

The estimated time frame for this activity would be approximately four to six months of field activities, in order to cover the estimated impact areas of the proposed dams. It is estimated that costs for these activities may range between $250,000 to $400,000, and are included within the amounts indicated in Section 8.2.

8.2.2 Mammals

In general, sampling methods must also be used that detect smaller rodents (e.g. *Heteromys, Orozomys*), and bats. The method used in the Biological Inventory to sample bats (mist nets placed near ground level) misses many bat species which fly at higher altitudes in open air or occur in forest canopy. A stratified sampling using mist-nets at several levels will more accurately reflect the diversity of bat species in the study area. As indicated above, the study period should last for a minimum of one year, in order to evaluate transient and migratory mammals. Estimated costs associated with this investigation may range between $85,000 to $100,000, and are included within the estimate indicated in Section 8.2.

8.2.3 Avifauna

Additional information is required to adequately assess the avifauna in the potential impact areas. This should include the habitat types represented at each sampling location, and information needs to be developed concerning the association of bird species with specific ecosystems. Future studies should begin with the classification of habitats and data tables should present the results on this basis, and would allow a picture of avian diversity in the study area. In addition, it should include a discussion of rare, threatened, or endangered species in the study area that could be important in assessing future impacts. Costs and timing for these investigations would range from $100,000 to $150,000 and would last between sixteen and twenty months. These costs are included in the estimate indicated in Section 8.2.

8.2.4 Insects

The biological characterization of the study area presented in this report integrates information from the following sources: (1) Biological Background Report, (2) The revised Interim Reports, (3) Quarterly Biological Inventory Reports, (4) Design and Engineering Reports, (5) Additional laboratory and field studies, and (6) Studies of other canals. To effectively assess potential impacts of the proposed project alternatives, future studies should include a description of the existing biological conditions in terms of: (1) vegetation associations, (2) functional classification of biota, (3) the number and type of species within each community type, (4) species interactions, (5) the role of species-habitat relationships in ecosystem dynamics, and (6) a discussion of species of medical, agricultural, and ecological importance.

Sampling stations should also include all representative areas of the potential impact zones of each alternative. In addition, more representative sampling methods that would capture a wider variety of insects should be used. Future efforts should also concentrate on insect vectors that could colonize habitats affected or created during the construction, operation and maintenance of the selected alternative and also utilize the following techniques: CDC-light traps, T-10 traps, UV.traps, Manning traps, Magoon traps, Malaisse traps, host-baited traps, and a more prolonged exposure of human "baits".

Costs and timing for these investigations would range from $100,000 to $150,000 and would last between sixteen and twenty months. These investigations are also included as part of the estimate indicated in Section 8.2.

8.2.5 Herpetofauna

A series of studies should be performed that allow the development of basic information on the biology, distribution, and ecology of amphibian and reptile populations in representative

habitats within a study area encompassing both the High-Rise Lock and Sea-level Canal Alternatives.

As indicated in the previous sections, more comprehensive studies within the proposed impact areas may be required. Each study should include sampling during both dry and rainy seasons, so as to reflect temporal patterns and population dynamics. Biological baseline information should be developed for areas west of the city of Colon and in the regions of the Ciri, Trinidad, and Indio rivers, where new access roads will expose these areas to increased disturbance.

Costs and timing for these investigations would range from $100,000 to $150,000 and would last between sixteen and twenty months. These costs are included in the estimate presented in Section 8.2.

8.2.6 Fisheries

The following studies should be conducted to obtain more reliable and complete information on fisheries resources in the study area. This should include an inventory of the fresh water fauna in the area of the Indio, Ciri and Trinidad rivers. In addition, it should include a program of study to identify nursery areas, reproduction, fertility and biomass of principal commercial fish species in the Gulf of Panama.

Additional information required would include a study of marine hydrodynamics to develop a model of sediment distribution in coastal waters. During the maintenance and operational phase of the proposed project, a periodic analysis of water quality and the structure of freshwater communities affected by construction, in order to study responses and recovery capacities in affected ecosystems. Inventories should be conducted at stations representative of all aquatic ecosystems affected by either of the two proposed alternatives.

Costs for these activities are estimated to range between $200,000 and $250,000 and should last between sixteen to twenty months. These costs are also included in the estimate presented in Section 8.2.

8.2.7 Epidemiology and Public Health

Studies should be conducted to determine: (1) general health conditions of local human populations in the study area, (2) the presence of arboviral and parasitic diseases such as Chagas, leishmaniasis, toxoplasmosis, and environmental factors contributing to their transmission and maintenance, and (3) population levels of insect vectors and human or animal hosts of infectious disease or parasite organisms. This information may allow some estimate of the future public health risks to incoming worker populations during project construction and operation. These costs should range between $150,000 to $200,000, and

would take between twelve to sixteen months. This amount is included within the estimate indicated in Section 8.2.

8.3 HIGH-RISE LOCK ALTERNATIVE

The High-Rise Lock Alternative possesses its own specific areas where additional studies are required. For some taxa (plants, birds) there needs to be more extensive and intensive sampling in the area of canal construction; for the Biological Inventory, sampling was more thorough in areas of proposed dams and other associated water projects. There also needs to be additional sampling in areas near Pacific coast, where communities are considerably different due to drier conditions.

The following lists some of the additional research needs that have been identified. The costs associated with these investigation are estimated to range between $1,000,000 and $1,500,000, with a duration between sixteen and twenty months. These estimates are included in the costs presented in Section 8.2.

8.3.1 Spoil Area D-1 & D-2

Area D-1 is located east of the proposed new 150,000 or 200,000 locks near Gatun. It is a remaining section of well-forested land, where Team members have observed a great variety of wildlife. Area D-2 is located east of Barro Colorado Island. It appears to have the potential to be an important migration point for terrestrial fauna. These specific areas should be carefully surveyed for their usage by local fauna and for sensitive species. In addition, engineering groups should investigate the possibility of protecting this area. The alternative of disposing of the excavated materials from construction of the locks into the W-2 spoil area, and from the widening of the Canal into W-4, should be investigated.

8.3.2 Spoil Areas D-3 Through D-5

Portions of these three spoil areas will encompass recognized wetlands and estuaries. As these are recognized as significant breeding and feeding grounds for local fauna, it is important that they be carefully surveyed, to investigate the possibility for protection during the construction process.

8.3.3 Spoil Areas D-6 Through D-8

As indicated above, these areas should be surveyed for sensitive species to evaluate the possibility of their protection or relocation. However, these areas present particular problems. It is Dames & Moore's understanding that munitions may have been disposed of in these areas. Careful site inspections must be performed to locate and properly dispose of any unexploded munitions that may be remaining.

8.3.4 Dams & Impoundments

Due to the lack of useful information on the portions of the Trinidad and Ciri rivers that may be affected by dam construction, it is important that baseline studies be performed of the project area. Available information consists of incomplete and out-of-date aerial photographs, topographic maps and unverified, anecdotal reports. Consequently, it is not possible to adequately assess the potential impacts to these areas at this time. Minimal baseline studies should include identification of the habitats found within these areas, as well as quantifying their areal extent; identification of sensitive, keystone, and other important plant or animal species; physical parameters such as rainfall, hydrology, stream-flow, and soil types, in addition to the identification of species of medical and/or veterinary importance, together with the conditions that promote their growth and expansion.

8.3.5 Aquatic Studies

Basic physical and chemical data must be collected from the rivers and streams of the Gatun and future lake watershed in order to establish present baseline for comparisons with future conditions associated with the recirculation basins, should these increase the salinization of the lake. These include:

- A study of the types of substrates, sediments and habitats encountered.
- A study of the volume of water transported by each stream and river including seasonal changes.
- A physical monitoring program along lake tributaries to determine sedimentation rates, organic matter and other physical parameters.

Biological sampling must be coordinated with physical and chemical sampling to get a better understanding of the existent interaction between river and lake waters, and fresh and salt waters.

The Biological Inventory has collected samples of biota along the lake and tributary mouths with comparable, standardized procedures. However, sample efforts must continue to obtain seasonal changes in populations, especially on planktonic and benthic organisms, adding riverine stations to the collecting effort. It is important to establish permanent monitoring stations near the entrances to the lake, in order to monitor salinization, should this begin to occur.

A survey of the biota of the rivers that form the future lakes should be performed to trace the extent of movement of Gatún species between the lake and the new reservoirs. The database on aquatic biota must include information on characteristic biotic elements of the

biota, the composition of the major marine communities, and the physiological tolerances. parasites, and pathogens of the dominant components of the biota.

Intensive studies should be carried out on certain well known organisms that may serve as the baseline for analysis of post-construction and potential salinization changes in the biota. have particular significance for ecosystem studies, have a strong likelihood of dispersing, or have special economic, social, or public health importance.

It is essential that collections of aquatic organisms be maintained in permanent repositories in order to compare changes in the lake and rivers biota should salinization starts.

Controlled laboratory experiments should be designed to expose selected marine organisms to the physical and chemical parameters they may encounter during natural dispersal. Emphasis should be placed on eurytopic species, commercial important species, dominant species in communities, and parasites that may be carried with their hosts.

An attempt should be made to correlate the breeding habits, dispersal stages, and larval stages of selected organisms with an assessment of larval stages actually predominating in the plankton. There should be included an analysis of the proportion of species with planktonic larvae. The studies should also include species behavior, protein specificity, reproduction, rate of tolerance of environmental extremes, metabolic measurements, feeding habits of larval, juvenile, and adult stages, and osmotic and ionic regulation.

Competition studies should be performed to learn how various closely related species may interact after a canal is built.

These studies should last between eighteen to twenty-four months, and costs are estimated between $150,000 to $200,000.

8.4 SEA-LEVEL CANAL ALTERNATIVE

Existing conditions in the area of the Sea-Level Canal Alternative are relatively unknown, and must be ascertained to properly evaluate the impacts of this alternative. The information reviewed for this report consisted primarily of aerial photographs, topographic maps and apocryphal reports. Although the aerial inspection of the proposed canal route revealed that much of the southern portion has been severely affected by human activities, the northern portion still has significant forest cover. Similarly, insufficient information exists to assess the potential effects that the marine approaches may have to the surrounding ecosystems.

In general, any Biological Inventory of the proposed alternative study areas should include all areas potentially affected by project activities. Biological data must therefore be

collected for all representative habitats in the sea level alternative area, including Premontane forest types occurring at the northwestern end of this route.

The following investigations are recommended to help clarify the existing conditions in this area, to provide sufficient information to adequately weigh the potential positive and negative impacts. The costs for these additional investigations may range between $1,500,000 to $2,000,000, and are included in the estimate indicated in Section 8.2.

8.4.1 Sedimentation, Erosion & Littoral Drift

The effects of construction of breakwaters on both the Pacific and Caribbean approaches have the potential to significantly alter prevailing coastal currents in these areas. This may have noticeable effects on current velocity, sedimentation rates, erosion and littoral drift. To evaluate these potential effects, reliable data on bathymetry, composition of bottom sediments, current direction, rates and seasonal variations, must be obtained to construct an acceptable model of conditions in Panama Bay and in the Caribbean Approach areas.

8.4.2 Regional Marine Biological Conditions

As a Sea-Level Canal has the potential to affect the marine biota of the Caribbean basin and the Bay of Panama, a baseline study should be performed to establish existing marine biological conditions. Due to the large number of uncertainties regarding the possible effects of the migration of Pacific marine biota into the Caribbean, it is important that existing conditions throughout the basin be properly determined. Regional information should be developed on existing and historical biological conditions within Caribbean basin and Pacific coastal communities from Ecuador through Mexico.

The recommended effort should include, at a minimum, data on fisheries (commercial, sport, and subsistence), breeding grounds, current patterns, erosion and littoral drift, flora and fauna (both vertebrate and invertebrate), coral reef health, known contamination problems. This task could easily take several years of continuous study to establish prevailing patterns in areas where information is scarce or lacking. This information is necessary to document potential impacts a Sea-Level canal. The introduction of exotic organisms through a Sea-Level Canal could be blamed for reduced fish catches in the Caribbean, without a clear understanding of local, historical fishing practices, which may have depleted breeding stocks to a point where a decrease in catches would be expected. In the absence of region-wide studies of this nature, it is impossible to predict regional impacts from the Sea-Level Canal.

A study of this type may require the cooperation of governmental and private organizations from nations within the Caribbean basin and the Pacific Ocean coast. The available historical information from all these areas may require careful evaluation, to be able to

identify existing trends of the prevailing conditions, as well as to identify additional studies that may be required to establish the current baseline. Due to the uncertainties involved in the current status of information in the adjacent countries, it is difficult to identify a specific schedule or cost to this item. However, for budgeting purposes, it is proposed that an amount ranging from $200,000 to $300,000 be considered, covering a period between 12 to 18 months for obtaining current information from the proposed study region and its evaluation. This amount is included in the estimate indicated in Section 8.2. It must be recognized that this evaluation may lead to additional investigations based on future information needs that may be identified by this study.

8.4.3 Local Biological Conditions

A comprehensive biological inventory should be conducted in areas that may be affected by construction of a Sea-Level Canal. However, future biological inventories should be structured to provide information that can be utilized directly. For example, in addition to basic identification of flora and fauna, it should include the type of habitat associated with them. Information collected on trees should not only include trunk diameters (dbh), but also an estimate of their height, crown diameter, and species composition. Sampling stations should be consistent with the areas that may be affected by the construction activities. Information regarding the local climate, geology, hydrogeology and hydrology and should be included.

Additional information regarding local use of natural resources should be included, as this information may also be useful for future socio-economic studies.

The effects of the potential migration barrier to terrestrial fauna should be evaluated. This item is particularly important in the remaining forested areas located north of Lake Gatun. As these areas may represent significant migration pathways for terrestrial and avian fauna, the potential impact that may occur with their removal may have significant consequences within and outside of the immediate region.
As with the High-Rise Lock Canal, there are certain spoil areas that appear to affect specific environmental resources. Additional investigations should be performed in the following areas:

8.4.4 Spoil Placement Areas D-1 Through D-6

These spoil placement areas are located north of Lake Gatun. This area still has significant quantities of forest. Should these forests be removed, this may create a major barrier to the movement of terrestrial fauna. Alternative spoil areas should be investigated, including using part of these materials for the construction of the barrier dams.

Although the remaining spoil placement areas south of Lake Gatun may cover larger areas, most of this habitat has been already affected by agricultural and cattle grazing activities. However, the individual placement areas should be evaluated, in order to identify potentially valuable resources that may remain in the forest fragments. This evaluation should begin with a careful analysis of existing aerial photographs, in order to identify the most significant remaining forest fragments.

8.4.5 Spoil Placement Areas D-19 & W-3

These spoil placement areas are located near the mouth of the Rio Caimito. As currently configured, they may cover mangroves and wetland areas with excavated and dredged materials. An evaluation of alternate locations should be made, in order to reduce the potential impact of removing the important habitats.

8.4.6 Diversion Scheme

The diversion scheme contemplates the interception of a number of creeks and rivers that flow into the La Laguna portion of Lake Gatun. These include Los Hules, Quebrada de Chico, Quebrada de Mendoza, Caño Quebrado and Rio Pescado. All of these have the bulk of the wetlands in the study areas. An evaluation of these wetlands should be performed, in order to provide information regarding their extent, productivity, as well as the flora and fauna present. This information would then be used to evaluate the possibility of creating artificial wetlands behind the proposed impoundments of the diversion scheme. Additional studies should be made of the potential effects of the interception and diversion of the many streams that may be affected, both to the north and south of Lake Gatun. Studies should also be made to evaluate the effects on the local flora and fauna that would be caused by the draining of La Laguna.

8.4.7 Aquatic Studies

Several studies on the characteristics of the eastern Pacific and Caribbean intertidal and subtidal communities, diversity, population changes, and oceanographic factors are vitally needed in order to distinguish them from any effects of a sea-level canal. Central American and Caribbean countries should continue to improve their programs for collection of fishery statistics under FAO and other international agency (e.g., OLDEPESCA, PRADEPESCA) auspices. More effort should be made to augment the existing database on marine resources of the region.

- More information is needed on the life-cycles and trophic relationships of fishery species, and their association with the intertidal and subtidal habitats.

- More studies on animals and plants of medical importance or potential relevance to tourism are recommended.

Basic physical data need to be collected from the coastal zones on both side of the Isthmus to establish a baseline for comparison with future conditions. These include:

- Data on wave action (swell and wind-generated) and their impact on areas off each proposed entrance to the canal.

- More detailed information on the types of shore zones, sediments and subtidal habitats occurring along each coast.

- Information on Pacific and Caribbean oceanic and coastal currents to determine the seasonal extent of coastal flow, the nature of circulation on both coasts, and the mixing processes between oceanic and nearshore waters. This coastal water may be a water supply for the Canal.

More information is needed to determine:

- how tidal gates would affect currents in the canal and how many hours the gates would have to be closed to achieve zero net flow of seawater?

- If the model proposed by Yachiyo (1993) may create an effective salinity barrier. The information provided in their report indicates that fresh-water in the locks or tidal gates may be impractical or inefficient. The available volumes of fresh water to place in between the tidal gate and the lock are insufficient during low rainfall years, and possibly marginal in normal years. It only appears to be in sufficient excess quantities in wet years, that fresh-water conditions would prevail. However, the presence of fresh-water may not be sufficient to curtail migration of marine biota or the transport of larvae and/or eggs.

Studies should be performed to evaluate feasibility and effectiveness of the different types of physical barriers, such as temperature, salinity, chemical or combinations of these and others. These studies should include biologists and engineers working together.

The Biological Inventory collected sample data from both sides of the Isthmus with comparable, standardized procedures in nearshore and canal sampling stations. However, sampling must continue to discern seasonal population fluctuations, especially for planktonic and pelagic organisms, adding oceanic stations to the collecting effort. It is important to establish permanent monitoring stations near the Caribbean entrance of the sea level canal and sampling inside the Gulf of Panama must include both upwelling and non-upwelling regions. Sampling at these stations would begin the year prior to beginning the construction

period of either alternative and continue for a minimum of two years after the completion of the High-Rise Lock Canal Alternative, and for an additional three years in the case of the Sea-Level Canal Alternative. Estimated costs for these continuing activities would be approximately $50,000 per year.

Biological sampling must be coordinated with oceanographic sampling to get a better understanding of the existent interaction between oceanic and coastal processes. A survey of the biota of the entire Caribbean, from Colombia to Costa Rica in the eastern Pacific, should be undertaken to trace the extent of movement of eastern-Pacific and Indo-Pacific species into the Caribbean and vice-versa. Any database on the marine resources must include information on characteristic biotic elements, the composition of the major marine communities, and the physiological tolerances, parasites, and pathogens of the dominant life forms.

High priority should be given to intensive studies of coral reefs, mangrove forests, subtidal soft bottom communities, and the dominant elements of the neritic biota. Intensive studies of certain organisms and habitats may provide a baseline for a better analysis of post-construction changes in ecosystems. Controlled laboratory experiments should be performed, exposing selected marine organisms to the physical and chemical parameters they may encounter during natural dispersal.

An attempt should be made to correlate the breeding habits, dispersal stages, and larval stages of selected organisms with an assessment of larval stages actually predominating in the plankton. There should be included an analysis of the proportion of species with planktonic larvae. The studies should also include species behavior, protein specificity, reproduction, rate of tolerance of environmental extremes, metabolic measurements, feeding habits of larval, juvenile, and adult stages, and osmotic and ionic regulation.

Plankton carried through the canal by currents should be monitored, particularly to test the effectiveness of the biological barrier.

An extensive survey on animal and plant parasites and pathogens should be made on both sides of the proposed sea level canal, including hosts belonging to all the major taxa. Laboratory experiments should be carried out to test for effects on the similar hosts in the opposite area. These studies should be performed together with the studies proposed in Section 8.4.2.

Competition studies should be performed to learn how various closely related species may interact after a canal is built.

8.4.8 Hydrogeologic Studies

Due to the lack of existing information, regarding the hydrogeology of the study area, an initial well inventory survey should be performed to document the existence of potable water wells, depth, water quality and identify the supply aquifers. This should serve as a starting point to develop a monitoring network along the trace of the sea-level canal. Additional monitor wells should be installed, to obtain geologic and hydrogeologic information regarding the potential shallow and deep groundwater resources in the study area. The groundwater quality can be tested periodically to measure the potential for salt water intrusion from the sea-level canal. Should additional abundant shallow or deep groundwater resources be identified, these can then be developed as future potable or industrial water sources.

It is estimated that a simplified drilling program can install approximately twenty wells through a six month period for a cost between $300,000 to $350,000.

9.0 LIMITATIONS

The Environmental Analysis was based primarily on the information provided by CAS. The bulk of this information consisted of the reports prepared for the BD/BI Component. These included the Biological Data Background Report, and the first three of four quarterly reports of the Biological Inventory. The Biological Inventory component was still ongoing at the time of our submittal. The fourth quarterly report and the final report were not available for our review during the time frame assigned to this component by CAS. On June 8, 1993, the information covering sampling activities from February to March 1993 was delivered to our office. However, this information was not reviewed as part of our study because of its arrival after completion of the analysis phase of this component.

Although the information presented in the reports reviewed by Dames & Moore was significant, the structure of data presentation induced certain limitations in its usage. Among these conditions were the location of the sampling sites. Even though most of these sampling locations were located within operational areas of the existing canal, areas that would be directly affected by construction or operational impacts of either of the two alternatives reflected very limited sampling. In addition, since the Sea-Level Canal alignment, and impoundment areas for the Trinidad, Ciri and Indio rivers were not included in the scope of the Biological Inventory, available biological information throughout Sea-Level Canal study areas was limited.

Other limitations associated with the Biological Inventory Quarterly Reports include that in many cases, notably for insects, mammals, fish and birds, the methodology used did not provide a representative sample of these organisms. Review of these reports indicated a lack of descriptions of habitats, or other suitable information necessary to relate species found with specific habitats. It should be noted that some habitats were not sampled at all, such as agricultural areas, freshwater wetlands, rivers, streams, mudflats, and extensive old forest (e.g. northern half of Soberania National Park). The absence of complete classifications represented a considerable effect on the evaluation of insects, which had been classified only to the level of families, thus increasing the difficulty for the evaluation of organisms of medical importance.

Regarding High-Lock Canal Alternative impact areas, limited sampling was included in the Biological Inventory for some taxa (plants, birds) along the existing canal alignment and areas near the Pacific coast. Sampling was more thorough in areas of proposed dams and other associated water projects. We understand that these sampling limitations resulted from military jurisdiction along the western area of the existing canal, at the level of Gaillard Cut, which limited access to investigators. Other limiting conditions were encountered in the forestry data, where certain parameters, such as chest-height diameter were presented, without an estimate of tree height.

As the first three reports of the Biological Inventory Study did not include descriptions of habitats within the impact zones of each alternative, color aerial photographs were used to

identify areas of different ecological characteristics. These color photographs covered the entire alignment of the High Rise Lock Canal and the central and southern portions of the Sea Level Canal. However, other areas of interest, such as the northern portion of the Sea Level Canal, and portions of the Indio and Trinidad rivers were covered only by a limited number of black and white aerial photographs taken from isolated flight lines.

The Environmental Analysis did not provide a thorough evaluation of the design modifications set forth in the June 1993 Annex to the ECE Report, as this document was made available for review after completion of the Draft Final Report. However, the Final Report includes a limited evaluation of the impacts associated with the more significant design modifications for the High Rise Lock canal alternative.

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APPENDIX A

BIOLOGICAL ENVIRONMENT

The biological communities described in this section are assemblages of flora and fauna with specific associations and characterized on the basis of a combination of biotic and abiotic factors. Abiotic factors can include depth, substrate type, temperature, and flow rate, in the case of aquatic communities; and soils, humidity, and climatic conditions, in the case of terrestrial communities.

A.1 Community Descriptions

Biological communities can cover extensive areas, or can be limited to small, discrete locations. For the purposes of this report, the team identified and described the principal biological communities within the study area. On the basis of the information provided in the Biological Inventory, together with an evaluation of the aerial photographs, additional existing literature, and personal experience of the Team members, a number of general community types were identified, including: Pelagic, Subtidal, Intertidal (which include Rocky Shores, Sandy Beaches and Mud Flats), Coral Reefs, Seagrasses, Mangroves, Lakes and Rivers, Freshwater Wetlands, Forests (mature & successional), Open Areas (grassland & pastures) and Agricultural communities. A brief description of the more important characteristics of each are included in the following sections.

A.1.1 Pelagic

Continental shelves are the most productive extensive areas of the world's oceans. The tropical pelagic system overlying the continental shelf (to 200 m depth) in the Gulf of Panama supports large commercial and artesanal fisheries. The driving force for this rich region is a pattern of high radiant energy coupled with alternating seasons of increased and reduced vertical transport. These successive periods of mixing due to upwelling (January through April) and stratification (May through December), with the radiant energy input, are major controlling influences on the types, numbers, and distributions of organisms found in the Gulf. Relationships have been demonstrated between coastal upwelling and the populations of plankton with penaeid shrimp (D'Croz & Kwiecinski, 1976), anchovies (Fig. A.1 and A.2), and tuna (Forsbergh, 1969).

Pelagic marine systems are comprised primarily of two kinds of organisms: those with limited powers of locomotion (plankton), and strong-swimming organisms capable of moving at will through the water (nekton). Whereas the plankton is dominated by a host of one-celled plants (algae) and invertebrate animals, the nekton are predominantly vertebrates. Two special features of the plankton are the relatively high numbers of omnivorous animals and filter-feeders. Carnivores are also numerous, forming about 5% of the numbers of the zooplankton (Wickstead, 1965).

For the sake of convenience and, since virtually all commercial marine species are permanent or temporary members of the nekton during some phase of their life cycle, fisheries information will be presented under the subject heading of *Nekton*.

Plankton

The residence time of water overlying continental shelves is restricted and, depending on the patterns of circulation, is open to influx of both inshore, coastal water and oceanic water. Thus, the shelf plankton community contains forms typical of both oceanic as well as neritic zones, and it is difficult to characterize typically shelf plankton communities for this reason.

Traditionally, pelagic systems are divided into regions on the basis of topography, hydrography and latitude rather than community. This is because phytoplankton, whose growth is a function of the energy and nutrient-salt availability in its immediate vicinity, responds rapidly to changes in the physicochemical environment, and is therefore by nature an ephemeral community.

The plankton community inhabiting the free water of the pelagic system is self-sustaining, inasmuch as both autotrophic and heterotrophic organisms are present. The plants of the plankton consist of unicellular, chlorophyll-bearing algae -- the phytoplankton -- that grow in the illuminated surface layer. Planktonic heterotrophies (usually called zooplankton) belonging to all the major groups -- bacteria, fungi, protozoans and metazoans -- occur in the entire water column, but have their highest concentration in the surface layers, close to their food supply.

Phytoplankton

The phytoplankton are small, generally less than 200 μm (Table A.1) and unable to move against currents. They grow by taking up dissolved inorganic nutrients from their immediate surroundings, and, by means of photosynthesis, converting these dissolved substances into biomass (particles). Over 99% of marine productivity depends on phytoplankton (Thurman, 1987). Factors regulating phytoplankton production include the absolute amount of radiant energy, the depth and intensity of vertical mixing, and the rate of supply of inorganic dissolved nutrients.

The Atlantic marine environment of Panama is nutrient-poor with low primary productivity (78-120 mg C/m^2 /day); primary productivity for the nutrient-rich Gulf of Panama ranges 210-700 mg C/m^2 /day (Smayda, 1966; Marra et al., 1987). Gulf annual primary production is about 255 to 280 g C/m^2, 90 g of which are fixed during the January-April upwelling season (Forsbergh, 1963; Smayda, 1963, 1966). The productive zone appears to be restricted primarily to the upper 15 m.

Most of the classes of algae are represented in the marine phytoplankton although the bulk of the biomass is contributed by only a few groups. The diatoms, dinoflagellates, and chrysophyte and haptophyte flagellates are easily the most important (Raymont, 1980). One can distinguish three basic groups by motility and size: (a) the non-motile diatoms; (b) the large motile dinoflagellates and autotrophic ciliates; and (c) the small motile nanoflagellates comprising various algal groups (Margalef, 1978).

During the rainy season in the Gulf of Pañama, a warm watermass with salinity below 30 o/oo, low phosphate concentration (0.5 μg atom/l), low chlorophyll *a* (0.5 mg/m^3), and low density of phytoplankton (20-30 cells/ml) is present in the Gulf. The prevailing southerly winds at this time hold in place the warm, diluted and nutrient-impoverished superficial waters, hindering flushing and admixture with more fertile waters. Phosphate accretion via runoff from the well-leached lateritic soils appears to be minimal; the runoff actually dilutes the inorganic phosphate reserves in the aphotic zone (Smayda, 1963).

Upwelling driven by northerly winds in the dry season vertically displaces approximately 75 m of water offshore (Fleming, 1940). This brings in a cold (17-20° C) and saline (32-35 o/oo) watermass with high phosphate concentration (2 μg atom/l), high chlorophyll *a* (3 mg/m^3), and abundance of phytoplankton (100-300 cells/ml). Mean northerly winds for three days correlate well with indices of upwelling and relative efficiency of photosynthesis, indicating the rapid response of photosynthesis to changes in wind velocity and direction (Forsbergh, 1963). Thus, the environmental conditions and ensuing biological response are very wind-dependent.

Maximum phytoplankton populations occur during the upwelling season, with a considerable decline during July, and further subsidence during November (Smayda, 1963, 1966). A regional uniformity in phytoplankton species composition is observed throughout the year in the Gulf of Panama despite regional differences in growth conditions. Diatoms overwhelmingly dominate the communities. The innermost regions of the Gulf, generally north of 8° N 30'W, are the most productive; the least productive areas are in the offing of San Miguel Bay and Parita Bay.

Phytoplankton succession is dependent on nutrient concentration and turbulence in the water column (Margalef, 1978: Fig. A.3). Unlike other groups in the Gulf, diatoms exhibit a species succession during upwelling. Smayda (1963) recognized a stable succession of three phytoplankton communities during upwelling:

a) Stage I (December and January), consisting of *Skeletonema* and *Chaetoceros compressus*,
b) Stage II (February), with *Rhizosolenia delicatula* and occasionally *Eucampia cornuta*, and
c) Stage III (March), *Nitzschia closterium*.

The above species, either singly or in combination with two to four others of those listed, comprise from 50 to 98% of the community as cell numbers: *Bacteriastrum elegans*, *B. hyalinum*, *B. varians*; *Chaetoceros affinis*, *C. atlanticus*, *C. compressus*, *C. curvisetus*, *C. laciniosus*, *C. laevis*, *C. lorenzianus*, *C. socialis*; *Encampia cornuta*; *Guinardia flaccida*; *Hemiaulus membranaceus*; *Leptocylindus minimus*; *Nitzschia delicatissima*, *N. pacifica*, *N. pungens* var. *atlanticus*; *Rhizosolenia delicatula*, *R. stolterfothii*; *Skeletonema costatum* f. *tropicum*; and *Thalassiosira aestivalis*. At least 330 phytoplankton taxa have been identified in the Gulf (Table A.2). Population densities range 1,020 to 3.2 x 10^6 during the upwelling season, and from 240 to 176,320 cells/liter during the rainy season (May to November) (Smaydá, 1965, 1966).

Centric diatoms dominate the community structure, with the highest densities of centric and pennate forms being associated with upwelling episodes. Diatoms have a contribution of 97 and 99% of the total community as biomass, and 86 and 71% by numerical abundance during the upwelling and rainy seasons, respectively (Fig. A.4). During upwelling, there is a ten-fold increase in diatom concentration and a two-fold increase in coccolithophore and dinoflagellate concentrations (Smayda, 1959). Outbursts of dinoflagellates often occur during or immediately after upwelling. The coccolithophores, dominated by *Coccolithus huxleyi* and *G. oceanica*, exhibit only comparative minor regional variations in composition and abundance.

Three main 'seasons' can be determined from phytoplankton dynamics:

1. The height of the upwelling season (March),
2. The transition to the rainy season at a time when mild upwelling winds reappear (July), and
3. The height of the rainy season (November).

In nearshore waters (the Bay of Panama), *Chaetoceros cinctus* is the most abundant species during the rainy season and *C. curvisetus* dominates in the dry season (D'Croz et al., 1991). Other common species are *Cyclotella* sp., *Nitzschia pungens*, *Rhizosolenia stolterfothii*, and *C. socialis*. D'Croz et al. (1991) identified 165 taxa of diatoms, 9 of dinoflagellates, 3 ciliates, one blue-green alga, and a silicoflagellate. This species pool remains the same throughout the year, even though rank of importance might vary. The similarity in species compositions during rainy and upwelling assemblages suggests that phytoplankton populations in the Bay of Panama are autochthonous.

During the rainy season (August), primary production is thought to be regulated by irradiance, and plant biomass is probably regulated by microzooplankton grazing (Marra et al., 1987). Less than 10% of the phytoplankton standing crop is grazed daily by zooplankton during upwelling.

In summary, the tropical inshore area of the Gulf of Panama is characterized by a seasonal phytoplankton cycle, the major pulse of which consists of a diatom response, dependent upon wind-induced fertilization of the watermass through upwelling or, possibly, on nutrient accretion through precipitation and runoff.

Zooplankton

Members of the zooplankton can be holoplanktonic, spending their entire lives in the plankton, or meroplanktonic and spending but a part of their lives in the plankton. The principal members of the holoplankton in the Gulf of Panama are copepods, appendicularians, siphonophores, doliolids, ostracods, cladocerans, pteropods, foraminiferans, chaetognaths, and ctenophores. Temporary members of the plankton such as larvae of various invertebrates and fish, and benthos migrating into the water column at night, make up the meroplankton. Dominant groups are polychaetes, gastropods, lamellibranchs, echinoderms, decapods, and cirripedes. Planktonic forms found in the Gulf that belong to both groups include medusae and fish eggs and larvae (Table A.3) (Arellano, 1974; Chang & Solis, 1982).

Zooplankton are much more amenable to geographical characterization than the phytoplankton. Shelf zooplankton can, as a rule, be differentiated from oceanic communities by the presence of meroplanktonic larvae and from inshore communities by the presence of large forms such as euphausiids that carry out extensive vertical migration. In many areas the plankton community close in-shore, approximately within a hundred meters or so of the shore, is markedly different from the community even a little farther out. This is particularly true in areas of mangrove, where populations of shrimp and crab larvae are often in excess of other plankters.

Zooplankters range in size from bacteria less than 1 μm to jellyfish up to 2 m in diameter (Table A.1). The vast majority of zooplankton, represented primarily by crustaceans, is suspension-feeding microtrophs that feed on particle suspensions by means of sieve-like devices. Copepods are the most important members, particularly in terms of biomass, of the zooplankton.

Macrozooplankton abundance in the Gulf of Panama lags the seasonal maximum in primary production two to three months (Fig. A.6) (Forsbergh, 1969). Both phytoplankton and zooplankton usually follow aggregated, or contagious, distributions. The seasonal trend in the phytoplankton - zooplankton relationship is direct when plant production is high and inverse when plant production is low. (Fig. A.6). Zooplankton responds to phytoplankton changes more slowly than does phytoplankton to nutrient changes.

Zooplankton are most abundant in the top 100 m and are dominated in the rainy season by copepods, ostracods, crustacean larvae, appendicularians, chaetognaths, and pteropods, in

that order. In order of decreasing numbers, copepods, ostracods, crustacean larvae, fish eggs and larvae, chaetognaths, pteropods, and appendicularians are the predominant plankters in the dry season. During part of the year, the zooplankton is composed primarily of larvae of mantis shrimps (*Squilla parva* and *S. panamensis*; Bayer et al., 1970) (Chang & Solis, 1982). Most microzooplankton (foraminiferans, radiolarians, acantharians, and tintinnids) show abundance maxima in the top 30 m.

Fish eggs and larvae can also comprise a significant portion of the plankton (Arellano, 1974; Chang & Solis, 1982; UNIPAN/ANCON, 1992)). Although knowledge of the reproduction of Gulf fish is limited and fragmentary, available data indicate the majority of species spawn pelagic eggs (Table A.4). Medusae appear in March, concurrent with an increase in fish larvae.

Nekton

Nektonic species in the Gulf of Panama are often fast-swimming, open-ocean forms that visit the Gulf for purposes of feeding. Bony fishes comprise the majority of nekton in the Gulf of Panama. Some of the more common groups of large nekton that frequent the central portion and the southern reaches of the Gulf near the continental shelf edge include sharks, amberjacks and pompano, dolphins, mackerel and tuna, and swordfish (UNIPAN/ANCON, 1992).

The largest schools of fish within the Gulf are species of the families Clupeidae and Engraulidae, the anchovies and herring. At least 29 species are present in Gulf waters (Table A.5). Their primary habitat is shallow water along coastal shoreline in the northern fringes of the Gulf (Figs A.7, A.8), where their diet consists of plankton and detritus.

One of the few nektonic invertebrates in the Gulf is the dart squid *Loliolopsis diomedeae*, which hovers near the bottom during daylight hours and ascends at night to feed in surface waters.

Cetaceans are mostly infrequent visitors to Panamanian waters, however the Gulf of Panama spotted dolphin *(Stenella graffmani)* and pilot whales (*Globicephala*) sp. are seen regularly in the Gulf of Panama (N. Smythe, pers. comm.). Sightings of the sperm whale *Physeter catodon*, the long-beaked dolphin *Stenella longirostris*, and the little bottle-nosed dolphin *Tursiops nuuanu* along Pacific coasts have been recorded. Humpback whales (*Megaptera novaeangliae*) are found in the southeastern sector of the Gulf in July and August. Southern stocks of this whale use the Panama Bight for breeding grounds after feeding in Antarctic waters. Marine mammals registered in the Caribbean are the Gulfstream spotted dolphin *Stenella plagiodon*, the fin whale *Balaenoptera physalis*, and the blue whale *B. musculus* (Handley, 1966).

Fisheries

The principle fisheries of Panama are based on shrimp and industrial fish, which are the most valuable and produce the greatest tonnage, respectively (Tables A.6, A.7, and A.8). Both, though, are produced mainly for commercial export markets. Exported fishery products in 1991, in order of descending value, were shrimp, fish (fresh/frozen), lobster, fishmeal, fish oil, and canned sardines (Table A.9). Total 1991 export value was approximately $74.8 million. The third largest fishery is for miscellaneous marine species that are marketed within the country. The landings are made by local independent (artesanal) fishermen, by small fishing cooperatives, and by shrimpers who retain a portion of their associated fish catch for sale on the local fresh fish market (Table A.10). The most important of these include corvina, red snapper, Spanish mackerel, groupers, jacks, snook, and mullet (Bullis & Klima, 1972).

The life cycles of shrimp in the Gulf of Panama appear to be related to upwelling as catches are greatest in May through July, about three to five months after peak upwelling. The annual catch-per-unit-effort of white shrimp in the Gulf is directly correlated to the degree of upwelling (Forsbergh, 1969). White shrimp (*Penaeus occidentalis*, *P. stylirostris*, and *P. vannamei*), red shrimp (*P. brevirostris*), and seabob (camaroncillo or titi) shrimp (*Xiphopenaeus riveti* and *Protrachypene precipus*) are the most numerous of the commercial shrimps taken by shrimp fishermen (Table A.6). White shrimp are usually fished near the coast in 4 to 12 fathoms (Fig. A.9) (Obarrio, 1959). The brown shrimp (*P. californiensis*), carabalí shrimp (*Trachypenaeus byrdi* and *T. faoea*), and the Fidel shrimp (*Solenocera* sp.) are also taken, but play a minor role in the shrimp fishery (D'Croz, 1976).

A number of other invertebrates make up a smaller portion of the Gulf fisheries. These include scallops, octopus, squid, the Pacific Melongena snail, and spiny and shield slipper (sand) lobsters (Tables A.6, A.7, and A.10).

The Gulf of Panama is the main source of the tropical anchovy, *Cetengraulis mysticetus*, the most important Panamanian fishery species in tonnage. Anchovy inhabit the shallow mud flats along the coast of the Gulf of Panama and are rarely found beyond 8 km from the shoreline (Fig. A.8). They feed principally on live and dead phytoplankton (Bayliff, 1963, 1969). Anchovy biomass values are related to the mass of diatoms present in the water column and are highest two months after chlorophyll *a* concentrations reach their peak.

The spawning season for anchovy commences with the onset of upwelling and juveniles are abundant when there is a high standing crop of phytoplankton (Table A.4; Forsbergh, 1963). Figure A.12 illustrates the basic trophic structure in the Gulf of Panama, emphasizing the dynamics of anchovy standing crop fluctuations with plankton during the dry and wet seasons.

A substantial reduction fishery, supplying fishmeal and oil, is supported by the anchovy stocks fished by local vessels. Combined anchovy and herring catches from 1981 through 1990 were 81 to 95% of the total national fishery production, with 76,000 to 244,000 metric tons harvested annually (Table A.6).

The tuna resources of the region are harvested at present by large purse-seine vessels operated by nations other than Panama. These vessels are permitted by the government of Panama and registered under the Panamanian flag. Although the closest major fishing effort for tuna in the Panama Bight is beyond the 100-fathom isobath, tuna are also caught at shallower depths in the southeast and southwest areas of the Gulf of Panama. Yellowfin (*Thunnus albacares)* and skipjack *(Katsuwonus pelamis*) tuna are the two most abundant species and migrate to the northern part of the Panama Bight in April and May when food is plentiful (Forsbergh, 1969). Zooplankton comprise a considerable portion of the stomach contents of both species (Alverson, 1963). Total yearly catches from 1980 through 1988 ranged 1,200 to 16,900 metric tons (Table A.8). Three-fourths of the 1980s tuna catch was yellowfin. Some bigeye tuna (*Thunnus obesus*) are also part of the fishery.

Additional resources in the Gulf that have commercial potential are squid and various species of demersal fish (Table A.11).

Knowledge of the fishery resources of the Caribbean coast is fragmentary. The low productivity in this region is typical of waters bordering eastern coastlines and catch rates are not sufficient to sustain large fisheries. Small quantities of brown shrimp (*Penaeus aztecus* and *P. braziliensis*) are occasionally taken. The incidence of coastal pelagic schoolfishes (anchovy, herring, scad, jacks, and Spanish mackerel) is too infrequent to encourage commercial efforts. Tuna and demersal species (grunts, snapper, and corvina) are also much less abundant than in the Pacific (Table A.12).

Subsistence fishing is an important aspect in the economy of small local human populations along both coasts, but no data are available on how widespread or intensive these fishing activities are and which species are selected (see Cubit et al., 1987).

A.1.2 Subtidal

The continental subtidal zone is located from the low tide line down to approximately 200 m depth (the edge of the continental shelf). The largest part of this zone is composed of soft bottoms (sand and mud) and in some occasions, by hard substrates. On the Caribbean side north of the entry to the Canal, the continental shelf reaches 200 meters at a distance of 20 km from the coast. In the Pacific Ocean, the platform reaches 200 meters at a distance of 170 km from the south entry of the Canal (Battelle, 1970). Thus, there is a more extensive subtidal zone in the Pacific than in the Caribbean.

The principal physical factors that influence the subtidal zone are 1) light penetration, 2) wave action, 3) depth of the thermocline, 4) substrate type and stability, 5) salinity, 6) oxygen concentration in the sediments, and 7) currents (Hiscock et al., 1980). The waters of the continental shelf are characterized by variable physical conditions. These fluctuations in environmental conditions are greater than those in nearby epipelagic regions of the open sea. The most important physical factor acting upon subtidal communities is wave action.

The salinity in these subtidal benthic habitats varies little, except on rare occasions near river outfalls. The salinity does not change sufficiently to have an ecological impact. Nutrients are rarely limiting and productivity is much higher than in similar regions of the open sea. This is due to the abundance of nutrients originating from upwelling and runoff from rivers. This high productivity supports large and diverse populations of zooplankton, benthic communities, and fish.

In these shallow waters, the interaction of waves and upwelling creates turbulence. Long wave periods and large storms also have effects that extend to the bottom of these shallow waters. On soft bottoms, the passage of these waves can cause great turbulence on the bottom, affecting the stability of the substrate. The particles of the substrate can be moved and resuspended. Wave action also determines the type of particles making up bottom substrates. Strong wave action removes the fine particles and keeps them in suspension, leaving the larger particles behind.

Caribbean Substrates

There are two sediment types in this area of the Caribbean. The first occurs within the Lemon Bay breakwater, where sandy sediments prevail in front of Gatun Locks. The water from the locks contributes fine sediments that are scattered throughout Lemon Bay. The size of the sediment particles decreases throughout the Bay, where clayey sediments prevail. Dramatic changes in the sediments are observed throughout the coast beyond the breakwater, due to the fact that this area receives the full force of wave action. A classification of the sediments according to their size is presented in Table A.13. Sand/mud is common west of the breakwater where the Chagres River empties; it is also present in the Bahia Las Minas area (UNIPAN-ANCON, 1992). Table A.14 contains the percentage of sand and clay in six stations of the coasts of the Caribbean. On the east side, rock-coral substrate prevails; the west side is dominated by sand/clay bottom.

Pacific Substrates

On the Pacific continental shelf of Panama, substrates are composed primarily of sediments $<80\ \mu m$. More than 90% of the sediments near the entrance to the Canal are mud. This pattern is common throughout the Gulf down to a depth of 25 m.

The quantity of sandy sediments increases near Punta Chame, to the west of the Canal entrance (UNIPAN-ANCON 1992). Table A.14 shows the percentages of sand and mud from the eight stations in the Pacific coast of Panama. The area of Punta Mala on the Azuero Peninsula to the Gulf of San Miguel in Darien, is dominated by muddy sediments. The central part of the Gulf is dominated by a mixture of sand, mud and coral fragments. The area is bisected by the Las Perlas Archipelago, where coralline and rocky bottoms prevail.

Benthic Communities

Benthic organisms inhabiting soft sediments are usually divided into two principal groups: the epifauna and the infauna. The epifauna consists of those organisms that live on the substrate, and the infauna are those that live beneath the surface in the substrate. A third group is composed of fish and mobile invertebrates associated with the bottom.

The only major study of benthic communities in Panama is by Bayer et al. (1970). Bayer et al. (1970) used a "recurrent groups" method of analysis (Fager, 1957) to create a table of invertebrate associations which showed the principal associations of benthic organisms with relation to depth.

The principal associations or communities found in the study area are shown in Table A.15.

1. Crab - shrimp communities

a. Stomatopod - Portunid Community (Caribbean): This is the most commonly recurrent association in the Caribbean. In the study area, it was found west of the entry of the Canal, always in sandy and muddy bottoms. The depth varies between 18 and 59 m, with an average of 38 m. The irregular sea urchin *Brissopsis elongata* digs in the mud and feeds on detritus. The mantis shrimp *Squilla obtusa* is a high level predator on the trophic chain and feeds on small penaeid shrimps. The swimming crabs *Lupella forceps* and *Portunus gibbesii* are also top predators.

b. Portunid Community (Pacific): These communities are found on sandy and muddy bottoms with an average depth of 66 m. The bivalve *Microcardium panamense* feeds on detritus, but may not be eaten by the local predators. The two portunid crabs, *Portunis xanthusii affinis* and *P. acuminatus* may eat small crustaceans. The crab *Calappa* and others possibly prey on gastropods. Portunid crabs are a food source for yellowtail tuna in the north part of the Panama Bight.

c. Stomatopod Community, Mud (Pacific): This community has the most extensive distribution in the Bay of Panama, extending within the interior perimeter of the arc to depths of 15 to 38 m, with an average of 23 m. The bottom is covered with soft

mud. A large concentration of biomass is found here. The mantis shrimps *Squilla parva* and *S. panamensis* are the most dominant species with densities of more than 10 individuals/m². Productivity in this area is high. The trophic base of this community is the bivalves *Lophocardium sp.*, *Trachycardium sp.*, *Laevicardium sp.*, *Chionopsis sp.*, *Eurytellina sp.*, *Cyclinella sp.* and others. They serve as food for the gastropods *Natica sp.*, *Solenosteira sp.*, *Mitra sp.* and *Nassarius sp.* Other crabs and gastropods, like *Conus sp.* and *Polystira sp.*, feed on polychaetes and other organisms. Among these invertebrates, the mantis shrimps (*Squilla* spp.) occupy the highest predator level. Species of *Penaeus* shrimps are common and feed on detritus. These serve as food for numerous fish and invertebrates.

2. Echinoderm Community

a. Crinoid - Starfish Community (Caribbean): This community was found at eight stations along the Caribbean coast at depths between 55 and 97 m, with an average of 67 m. The hard bottom is made of coral or rock - coral. The feather stars *Comactinia* and *Nemaster* probably eat plankton and suspended organic matter, while the seastar *Tethyaster* and *Narcisssa* prey on bivalves.

3. Shrimp - Fish Community (Pacific)

This community is of great economic importance. It is composed of anchovy *(Cetengrulis mysticetus)* and commercial shrimp. This benthic community is found on rocky bottoms from Punta Mala to the Gulf of Coiba. The most common fish species are snappers (*Lutjanus guttatus, L. argentiventris, L. peru, Carangoides ortrynter* and *Calamus branchysomus*). The most important species in these soft-bottom areas are *Polydactylus panamensis, Bairdiella spp., Larimus acclivis, Diacterus peruvianus* and *Hemicaranx spp.* Other important benthic invertebrates in the shrimps *Penaeus occidentalis, P. stylirostris, P. vannamei, Protrachypene precipua, Trachypenaeus bardi* and *Xiphopenaieus riveti.*

4. Snail Community (Caribbean)

This community is found in the Gulf of San Blas. It is found in muddy bottoms, between 18 and 57 m, with an average of 41 m. The scallop *Pecten laurentii* is found in this area, together with the gastropods *Antillophos candei, Costelloleda sp.* and *Pitar aresta.* The gastropod *Polystira albida* feeds on the abundant polychaete fauna.

5. Sponge Community (Caribbean)

The sponge community is abundant in the Caribbean to depths of 33 and 73 m, with an average of 54 m. In this group are found the scallop *Aequipecten*, the filter-

feeding bivalves *Microcardium* and *Tellina*, the irregular sea urchin *Brissopsis*, and the sea cucumber *Jaegerothuria*; the latter two feed on detritus. The snail *Strombus pugilis* is primarily vegetarian but can be omnivorous. The crustaceans are generally predators or carrion feeders, eating small-invertebrates. The gastropod *Murex olssoni* and the sea star *Echinaster sentus* are predators.

6. Starfish Communities (Caribbean)

a. *Metula* - *Luidia* Community: This is the deepest community in the Caribbean, found between 119 and 179 m. The bivalve *Nucula* is a filter feeder, and *Cuspidaria* feeds of organic matter particles. The gastropods of the genus *Metula* possibly prey on small bivalves, as does the seastar *Luidia*. The snail *Calliostoma* is a grazer and feeds on algae and organic detritus.

b. Sea Urchin - Starfish Association (or, *Pylopagurus* - *Astropecten* Association): This community is associated with sand and coral. It occurs at depths between 91 and 96 m. The sea urchin *Paleopneustes* feeds on detritus, while the crustaceans *Pylopagurus* and *Portunus* are predators. The starfish *Astropecten* preys on small species of bivalves.

7. Gastropod Community, Sand (Pacific)

a. *Crucibulum* Association: This is a small association that is restricted to sandy bottoms. It is found at an average depth of 24 m. Various gastropods such as *Cancellaria sp.* and *Crucibulum sp.* are characteristic of this community.

b. *Eupleura* Association: This is a small association found in sandy bottoms at about 55 m depth. These gastropods are predators and probably feed on small bivalves.

c. *Dardanus* Association: This is a small association found on sand and mud bottoms to about 55 m. The hermit crab *Dardanus* uses shells of *Bursa*; the latter feeds on bivalves and polychaetes. Voss et al. (1969) estimated that the hermit crab densities exceeded 2 individuals/m^2. The shells of *Bursa* are commonly covered by hydroids.

d. *Psammotreta* Association: This small association is found on sandy bottoms to depths of 55 m. The gastropod *Ancistrosyrinx* likely feeds on polychaetes; *Psammotreta* feeds on detritus.

e. *Scalina* Association: This small association is found on sand and mud bottoms at an average depth of 66 m. The gastropod *Nassarius* is abundant in this association

and feeds on dead organisms. Many species closely related to *Scalina* are associated with solitary coral.

f. ***Clathrodrilla* Association**: This is the deepest association in the Gulf of Panama, being found in soft sand bottoms and mud at an average depth of 80 m. The scallop *Cyclopecten* is a filter-feeder that serves as food for fish. The gastropod *Clathrodrilla* feeds on polychaetes.

8. Crab - Octopus Community (Pacific)

This is the second most abundant community found in the Gulf of Panama. It is characteristic of hard bottoms and is found down to a depth of 68 m. The most important predator is the octopus *Octopus selene*, which occurs in densities up to 1.5 individuals/m^2. *Chione sp.* is the most common clam and may have an important role in the food chain. Many predators such as *Polinices* and *Cymatophos* feed on *Chione*. Crabs of the genera *Mursia, Parthenope, Hypoconcha* and *Collodes* serve as food for octopus.

Undoubtedly, many fish species participate in the trophic structure of this community. The benthic invertebrates constitute an important fishing resource, primarily the white shrimp (*Penaeus occidentalis, P. stylirostris, P. vannamei*). *Argopecten circularis* (conchuela), *Anadara tuberculoso* (black shell), *Crassostrea rizophorae* (oyster), *Panulirus gracilis* (lobster), *Cardisoma crassum* (blue crab), *Octopus selene* (octopus), and squid represent important benthic resources that are fished by subsistence fishermen.

Summary

Hard-bottom communities in the Caribbean have very little in common with those in the Pacific. The former are essentially coral in origin and are associated with coral reefs (e.g., the echinoderm communities). A similar community is not found in the Pacific, but may exist in the area of Las Perlas island. Hard-bottom habitats in the Gulf of Panama are represented mostly by the octopus - crab community and the crab *Dadanus* association.

Throughout the Gulf of Panama in the area between Punta Mala (Los Santos province) and the Gulf of San Miguel (Darien province), between 10 and 30 m, there are extensive zones of sandy sediments where the predominant organisms are burrowing bivalves, portunid crabs, penaeid shrimp, cyllarid lobster (China lobster), and stomatopods (mantis shrimp). The crab - shrimp community probably extends into calmer waters where is replaced by the shrimp - fish community, which supports the local shrimp fishery. The productive soft-bottom communities in the Pacific have no comparable counterparts in the Caribbean.

The biomass in Pacific muddy bottoms is three times greater than in the Caribbean (Bayer et al., 1970). Filter-feeding bivalves form the base of the food chain of these communities, serving as food for predatory snails. Polychaetes are food for crabs and some snails. In the crab - shrimp community, the likely dominant predators the mantis shrimps *Squilla parva* and *S. panamensis*. This community thrives in soft mud. The crab - shrimp and fish - shrimp communities have the greatest biomass and are of great economic importance in the Gulf of Panama.

A.1.3 Intertidal

The intertidal zone is characterized by being partially exposed during the normal tidal cycle. For the purposes of this report, three major subdivisions have been identified. These depend primarily on the energy provided by wave action. Due to the energy input, there is a segregation of sedimentary materials. In high energy environments, all fine particles are suspended and are washed away. In low energy environments, these may be deposited and form part of the substrate. High energy environments have been identified as rocky shores. Low energy environments are identified as mudflats. Intermediate energy conditions are classified as sandy beaches.

A.1.3.1 Rocky Shores

Intertidal rocky shores are very different on opposite sides of the Isthmus of Panama. Pacific rocky shores present a typical vertical zonation for this substrate type, while Caribbean habitats are represented by fossil coralline boulders and exposed shores.

Physical factors that influence intertidal rocky shores are 1) temperature, 2) desiccation and, 3) sunlight. Biological factors that influence intertidal rocky shores are 1) competition for space, 2) predation, and 3) grazing (Nybakken, 1982).

According to Nybakken (1982), tidal amplitude is not so important for faunal zonation as for other intertidal ecosystems because 1) the topography of the ecosystem allows a great change in exposure time to air with a very short vertical movement; 2) a species may well be able to exist above the critical tide level if the rocky shore is exposed to persistent violent wave action; and, 3) caves, overhangs and crevices remain moist when exposed areas are dried out.

Tidepools associated with rocky shores are found on both sides of the Isthmus of Panama. They may occur at any level in the intertidal; however, low-level tidepools are not much different from the surrounding ocean, due to little exposure to air. High and midlittoral pools are exposed to air for longer periods of time, especially on the Pacific shore (Nybakken, 1982).

Larger pools with greater water volumes demostrate less fluctuation in physical parameters, such as temperature, salinity and oxygen (Nybakken, 1982).

During exposure at low tide, there is an increase in pool water temperature and salinity when evaporation occurs; at the same time, oxygen is depleted. When the water cools, the opposite phenomena occur. When pools are exposed during heavy rains, salinity decreases very rapidly; when the tide returns, there is a sudden, abrupt return to normal conditions. So, organisms that inhabit tidepools must be adapted to considerable and sudden physical changes (Nybakken 1982).

Cobble beaches are rare along the Caribbean and Pacific coasts of Panama. When they occur, it is always in association with rocky shores. There is very little information on cobble beaches, other than species common to these areas. They will be treated here as a component of rocky shores.

Caribbean

Caribbean rocky shore substrates are composed primarily of fossil coral reefs and coralline rubble. There are tidepools, and intermediate sandy and muddy areas. There is very little information about these areas, most of it coming from the fossil record (Brattstrom, 1985) and a study (Abele, 1972a,b) on resident decapod crustacean fauna.

Brattstrom (1985) identified five zones along Caribbean rocky shores (Province of Colon, Rep. of Panama) based on the fossil record. Those zones are 1) a *Lithothamnia* zone, 2) the mixed algae zone, 3) the barnacle-vermetid zone, 4) the spray zone, and 5) the maritime zone. This zonation also presently occurs on boulders on top of reef platforms and along exposed rocky coasts.

The *Lithothamnia* zone extends subtidally to a maximum of 5-20 cm above medium low tide level (MLTL) on boulders, and to a maximum of 60-100 cm above MLTL on exposed shores. The characteristic semisessile species of the *Lithothamnia* zone of boulders and exposed zones are corals (*Gorgonia* sp., *Siderastrea radians*, *S. siderea*, *Porites astreoides*, *Favia fragum*), tube-building polychaetes, snails (*Fissurella rosea*), clams (*Arca imbricata*), sea cucumbers (*Ophiocoma echinata*), sea urchins (*Diadema antillarum*), and ascidians (Brattstrom, 1985).

Within the *Lithothamnia* zone, there is a distinctive mixed algal zone that ranges 10 to 65 cm above MLTL on boulders and 10 to 160 cm MLTL on exposed shores. The characteristic algae genera of the mixed algal zone on boulders are *Ralfsia*, *Pocockiella*, *Sargassum*, *Laurencia*, and *Ectocarpus breviarticulatus*. On exposed shores, the mixed algal zone is more complex. *Ralfsia expansa* and *Ectocarpus breviarticulatus* form distinct belts below 100 cm. *Giffordia mitchellae* and *Ralfsia expansa* dominate 100 to 140 cm. Between

140 and 160 cm the dominant species are *Chaetomorpha* sp., *Ectocarpus breviarticulatus*, *Centroceras clavulatum*, and *Laurencia papillosa*. *Sphacelaria novae-hollandiae* is found between 130 and 160 cm above MLTL. The most common semisessile and motile animals that inhabit the mixed algal zone are *Megalimma vesiculosum*, *Spirobranchus giganteus*, serpulids, *Chthamalus proteus*, *Megabalanus stultus*, *Acanthochitona spiculosa*, *Fissurella nodosa*, *Nerita peloronta*, *Nerita versicolor*, *Littorina nebulosa*, *Spiroglyphus annulatus*, *Purpura patula*, *Barbatia candida*, and *Eucidaris tribuloides* (Brattstrom, 1985).

The barnacle-vermetid zone is a narrow zone characterized by dominance of the barnacles *Chthamalus angustitergum*, *Megabalanus stultus*, and the vermetids *Petaloconchus varians* and *Spiroglyphus annulatus*. This zone occurs only on boulders between 20 and the 60 cm above MLTL (Brattstrom, 1985).

A "naked" or white area occurs on both boulders and exposed shores above the mixed algal zone. It consist of a layer of microscopic algae. At several Caribbean sites, this is a well defined, intermediate area between the mixed algae and spray zones. It is, however, not so well defined in Panama, where it corresponds to the spray zone. Its lower limit is difficult to determine because there is no distinct faunal change between the zones (Brattstrom 1985).

There are 67 species of decapod crustacea on Caribbean intertidal rocky shores. The most abundant are *Calcinus tibicens*, *Paralionera dispar*, *Clibanarius tibicen*, *Cataleptodius floridanus*, *Pachygrapsus transversus* and *Clibanarius tricolor* (Abele, 1972a,b).

Pacific

The basaltic shores of the Pacific coast range from gentle slopes to vertical faces. Continuous rock substratum is frequently split by crevices and channels, with a few massive stationary boulders and small sandy beaches (Abele, 1972b; Lubchenco et al., 1984). Large areas are exposed twice a day during normal low tides. The major environmental feature is upwelling of cold water during the dry season. In general, this is a high energy habitat, affected by heavy wave action, with regular tidal cycles (Abele, 1972a; Lubchenco et al., 1984).

Pacific rocky shores (Taboguilla Island, Gulf of Panama) have been divided into five vertical zones by Lubchenco et al. (1984), based on tidal level and substratum irregularity. Those zones are 1) the splash zone (> +3.6 m, from the highest spring tide level up); 2) the high zone (+3.6 to +2.1 m); 3) the middle zone (+2.1 to -0.1); 4) the low zone (-0.1 to -1.8); and, 5) the very low zone (-1.8 to -3.4). Table A.16 presents the most important characteristics of each zone.

There are over 200 benthic sessile and mobile species that inhabit Pacific intertidal rocky shores, plus about 21 species of fishes that frequent them (Lubchenco et al. 1984). Table A.17 lists the most important organisms that inhabit these shores, their trophic status and tidal zonation; Table A.39 list the bird species associated to panamanian marine habitats trophic chains.

In the high zone, most available space is dominated by sessile species. It contains the highest density of sessile individuals, but the lowest species diversity of all the zones. The most numerous sessile species are the particle-feeding barnacles *Chthamalus fissus* and *Euraphia imperatrix*. Mobile animals include the herbivorous gastropods *Littorina aspera*, *Littorina modesta* and *Nerita scabricosta*. The herbivore crab *Grapsus grapsus* grazes along the entire slope during low tides. It avoids submersion, even when its algal food is more abundant at lower levels. The predatory gastropods *Acanthinea brevidentata* and *Thais melones* migrate upshore during high tides to feed on sessile species (Glynn 1972, Lubchenco et al., 1984).

In the mid zone, most available space is dominated by algal crusts. This zone contains species diversity and population densities higher than the high zone, but lower than the lowest zones. The most abundant sessile species are the particle feeders barnacle *Chthamalus fissus*, the particle-feeding mussel *Brachidontes semilaevis* and the microcarnivore anemone *Anthopleura dowii*. Mobile animals include the herbivore limpets *Siphonaria gigas* and *Fissurella virescens*; the herbivore chitons *Chiton stokesii* and *Acanthochitona hirudiniformis*. The major predators are the gastropods *Acanthina brevidentata* and *Thais melones* and the crab *Eriphia squamata* (Glynn, 1972; Lubchenco et al., 1984).

In the low zone, most available space is also dominated by algal crusts. This zone contains a lower density of sessile individuals, but a greater species diversity than the higher zones. The most abundant sessile organisms are the particle-feeding barnacles *Chthamalus fissus* and *Balanus inexpectatus*, the mussel *Brachidontes semilaevis*, and the larger rock oyster *Chama echinata*. Additional solitary sessile species include two species of microcarnivore anemones; five species of particle-feeding vermetids; four species of particle-feeding, sedentary polychaetes; seven species of particle-feeding, solitary tunicates; and a species of herbivorous, crevice-dwelling, sea cucumber. Mobile species include the herbivorous mollusks *Siphonaria maura*, *Fissurella virescens* and *F. longifissa*; five species of herbivorous chitons; the herbivorous crab *Pachygrapsus transversus* and the omnivorous crab *Eriphides hispida*; and the herbivorous urchins *Echinometra vanbrunti* and *Eucidaris thouarsi*. It is common to find the chiton *Tonicia forbesi* in holes created by the urchin *Echinometra*. There are more predatory species in the low zone than in higher zones. The most important and common predators are the gastropods *Thais melones*, *T. triangularis* and *Acanthina brevidentata*, and the crab *Eriphia squamata* (Glynn 1972, Lubchenco et al. 1984).

In the very low zone, the available space is dominated by algal crusts. This zone contains the lowest density of sessile individuals, but the highest species diversity of all zones. The

most abundant sessile organisms are the particle- feeding oyster *Chama echinata*; five species of particle-feeding vermetids; and the particle feeding barnacle *Balanus inexpectatus*. The most abundant mobile herbivores are the mollusks *Siphonaria palmata* and *Fissurella virescens*, the crab *Pachygrapsus transversus*; and the urchin *Echinometra vanbrunti* (Lessios, 1983; Lubchenco et al., 1984). It is common to find the chiton *Tonicia forbesi* and the limpet *Fissurella morrisoni* in holes created by the urchin *Echinometra*. The most abundant predators are the gastropods *Thais melones*, *Acanthina brevidentata*, *Thais triangularis* and *Opeatostoma pseudodon*. Other species of particle-feeding ophiuroids, nudibranchs and sea cucumbers; and the herbivorous urchin *Arbacia stellata* are also common in this zone (Lessios, 1983; Lubchenco et al., 1984).

Fishes forage along the entire gradient during high tides, but there are consistent differences among species along the gradient. The high zone is frequented by the herbivorous chub *Kyphosus elegans* and the predatory porcupine fish *Diodon hystrix*. On the other hand, balistids, holacanthids, *Microspathodon dorsalis*, and *Eupomacentrus flavilatus* rarely forage above the low zone. The most common herbivorous fish is the territorial damselfish *Eupomacentrus acapulcoensis*, the chub *Kyphosus elegans*, the blenny *Ophioblennius steindachneri* and other damselfishes like *Microspathodon bairdii*. The most common predator of intertidal areas is the wrasse *Bodianus diplotaenia*, followed by the angelfishes *Holacanthus passer* and *Pomacanthus zonipectus*. Less abundant are the triggerfishes *Balistes polylepis* and *Pseudobalistes naufragium*, the porcupine fish *Diodon hystrix*, and the puffers *Arothron hispidus* and *Arothrom meleagris* (Lubchenco et al., 1984).

Reproduction, recruitment, migration, red tides, and other phenomena are related to upwelling (Glynn, 1972). However, Lubchenco et al. (1984) found no significant seasonal differences in population densities or zonation.

Density and diversity present little quantitative seasonal or annual change in the high and mid zones. In the low zone, however, several species show large annual fluctuations, but there is no significant diversity change through time (Lubchenco et al. 1984).

There are 78 species of decapod crustacea on Pacific intertidal rocky shores. The most abundant are the hermit crabs *Clibanarius albidigitus* and *Calcinus obscurus*, and the crabs *Xanthodius stenberghii* and *Petrolistes armatus* (Abele, 1972a,b). Figure A.13 shows the trophic chain of tropical intertidal rocky shores.

Conclusions

Pacific rocky shores support a higher species diversity and density of sessile biota that reflect a larger number of microhabitats for a diverse microbiota (Glynn 1972).

Caribbean rocky shores are composed of boulders and exposed shores of fossil coral. A special zonation pattern had been described for this habitat.

On Pacific rocky shores, most available space is dominated by algal crusts in the mid, low, and very low zones and by bare rock in the high zone. Sessile animals are scarce, most species are rare or patchily distributed. Coverage by erect algae is very low, erect algae are short (usually <1 cm), and species diversity is higher in lower zones (Lubchenco et al., 1984).

Sessile animal densities decrease in successively lower zones, while slow-moving animal densities increase (Lubchenco et al., 1984).

The decapod crustacean fauna is quite similar on intertidal rocky shores on both sides of the Isthmus of Panama (67 species on the Caribbean compared to 78 on the Pacific). This is the most diverse crustacean habitat in Panama. Eighteen genera have closely related species pairs (Abele, 1972a).

A.1.3.2 Sandy Beaches

Sandy beaches are dynamic environments where physical habitat structure is determined by the basic elements of sand and water. Sand originates from erosion of land that is transported by rivers, or from biogenic sources in the sea. The most important features of sand particles are their size and porosity (volume of water needed to saturate the sand; Brown & McLachlan, 1990).

Sandy beaches are exposed to two types of waves, tidal and surface gravity. Tidal waves produce an intertidal zone that dries for several hours a day. Surface gravity waves induce secondary currents, shoaling and breaking, that transport sand along the beach (Brown & McLachlan, 1990).

Less complex than other intertidal tropical habitats, sandy beaches exhibit less biological diversity than intertidal rocky shores, mudflats, mangrove roots or coral reefs.

Physical factors that influence sandy beaches are 1) exposure to wave action, 2) organic content of sand, 3) sediment characteristics, 4) temperature, 5) salinity, and 6) tidal exposure (Dexter, 1979; Brown & McLachlan, 1990). Biological factors that influence faunal populations on sandy beaches are: 1) interspecific competition, 2) trophic relations, 3) amensalism, and 4) predation (Dexter, 1979).

Sandy beaches of the Pacific and Caribbean are divided into six horizontal zones, based on tidal level and slope of the beach; that is, on the amount of beach surface exposed to air during low tides. Those zones are 1) supralittoral (from highest spring tide level up), 2)

high tide level, 3) mid tide level, and 4) low tide level (Dexter, 1979; Brown & McLachlan, 1990). Subtidal habitat is divided into the transition zone and the outer turbulent zone (Brown & McLachlan, 1990). Table A.18 presents the most important physical characteristics of each zone.

The benthic flora of sandy substrate consists of microalgae and phytoplankton. Both are often dominated by a single diatom species of the genera *Aulacodiscus*, *Asterionella*, *Chaetoceros* or *Anaulus*; which are associated with autotrophic flagellates and cyanobacteria. They growth in the upper 5 mm of sand, creating associations based on particle size, oxygen content, and light penetration inside the sand (5 mm maximum). They occur principally on sites exposed to high wave energy and are always associated with air bubbles that form a semi-stable foam. The organisms disperse throughout the water column and colonize sediments, producing a mucous coating that allows them to attach to sand grains. A diurnal vertical movement takes place between the sediment and the foam. There are also diurnal offshore and onshore migrations (Brown & McLachlan, 1990).

Surf zooplankton is composed of resident and visiting crustacean species. Resident species include planktonic or bentho-planktonic forms. The former is composed of mysid shrimps and small prawns. Bentho-planktonic species are species that inhabit the sandy bottom and migrate into the plankton to feed at night, returning to the sand during the day. They include aquatic isopods, amphipods and mysids (Brown & McLachlan, 1990).

Visiting species are divided into holoplanktonic and meroplanktonic forms. The holoplankton is divided into 1) micro-zooplankton, such as tintinnid ciliates and copepod nauplii; and, 2) macro-zooplankton, including copepods, cladocerans, chaetognaths and jellyfish. Meroplanktonic forms comprise the larval stages of nonplanktonic animals from other areas, such as larvae of crabs, bivalves, polychaetes, and fishes from nearby estuaries, rocky shores or offshore ecosystems (Brown & McLachlan, 1990).

The intertidal benthic fauna of sandy beaches has been well studied by Dexter (1977), who compares this habitat for both Panamanian coasts. There are a total over 58 species of benthic invertebrates from the Pacific and Caribbean. There are 9 genera and 3 species common to both oceans (Dexter, 1979).

Fishes associated with beach habitats have not been studied in Panama; however, research from other tropical and temperate areas shows sandy beaches to be important nursery areas for 50 to 71 species of fish, of which only about 10% are permanent residents. Most of the fish associated with sandy beaches are juveniles that feed on zooplankton; however, consumers of benthic fauna (mostly flatfishes) are important in controlling populations of benthic organisms. Almost all species are opportunists, feeding on whatever is available (Brown & McLachlan, 1990).

Typical fish residents of sandy beach surf zones include pompanos (*Trachinotus* spp.), croakers (*Umbrina* spp. and *Menticirrhus* spp), anchovies (*Anchoa* spp.), and grounters (*Mugil* spp.), various flatfishes (*Citharichthys* spp., *Cyclopsetta* spp., *Etropus* spp., and *Hipoglossina bollmani*), and the rays *Rhinobatus* sp. and *Myliobatis* sp. Fish densities estimated from harvest data are highly variable, but often quite high (e.g., 10^3 to 10^4 per haul). There is little overall seasonal variation in the abundance of fish associated with beaches, but it may be marked in some individual species (Brown & McLachlan, 1990).

Terrestrial herbivores and piscivores (e.g., shorebirds and wading birds; Table A.39) occur in very small numbers in beach habitats. Most of the bird species are common to both coasts. Sandpipers (*Tringa solitaria*, *Actitis macularia*, *Calidris mauri*, and others) feed on benthic macrofauna (amphipods, isopods, and other invertebrates) that burrow in the sand. The brown pelican (*Pelecanus occidentalis carolinensis*), the neotropic cormorant (*Phalacrocorax olivaceus*), the magnificent frigatebird (*Fregata magnificens*), several species of terns (*Sterna elegans*, *S. maxima*, *S. caspia*, and others) and gulls (*Larus argentatus smithsonianus*, *L. delawarensis*, *L. atricilla*, and others) feed on different species of fishes that frequent sandy beaches, such as anchovies (*Anchoa lamprotaenia* and *A. lyolepis*), pompanos (*Trachinotus kennedy* and *T. paitensis*) and others. Reptiles are represented by the herbivorous black iguana (*Ctenosaura similis*). The most common mammal on sandy beaches is the raccoon (*Procyon* spp.), which feeds on crabs, birds, and other small animals (Brown & McLachlan, 1990).

Several species of seaturtles frequent sandy beaches to deposit eggs. Seaturtles are omnivorous. They feed on seagrasses (*Thalassia testudinum*), algae, small invertebrates, and fishes. On the Caribbean side, the most common are the Atlantic loggerhead turtle (*Caretta caretta*), the Atlantic green seaturtle (*Chelonia mydas mydas*), the Atlantic hawksbill turtle (*Eretmochelys imbricata*), the Atlantic ridley turtle (*Lepidochelys kempii*), and the Atlantic leatherback turtle (*Dermochelys coriacea coriacea*). On the Pacific ocean the most common species are the Pacific green turtle (*Chelonia mydas agassizii*), the Pacific hawksbill turtle (*Eretmochelys imbricata squamata*), the Pacific Ridley turtle (*Lepidochelys olivacea*) and the Pacific leatherback turtle (*Dermochelys coriacea schlegelii*).

Caribbean

Caribbean beaches are composed of calcareous materials, affected by high winds, strong wave action, and irregular tidal cycles during the dry season and part of the rainy season. During the rainy season there is heavier rainfall, greater variations in temperature and salinity, higher water temperature, lower salinity, higher sediment temperature, higher sediment organic content, and higher chlorophyll content (Abele, 1972; Dexter, 1979). This is the most difficult habitat to colonize and survive in all the intertidal tropical marine habitats.

Following the beach slope, sand grain size decreases slightly with decreased exposure to wave action. There is little variation in chlorophyll content along the tidal gradient (Dexter, 1979).

Caribbean sandy beaches are inhabited by approximately 34 invertebrate species (Table A.19). The scavenger crab *Ocypode quadrata* occurs in supralittoral burrows, but scavenges for food along the beach during low tide (Abele, 1972b). The isopod *Excirolana braziliensis* (49.8 ind/m^2) dominates the high tide level. The isopods *Ancinus brasiliensis* (68.9 ind/m^2), *E. braziliensis* (14.6 ind/m^2), and the cumacean *Cyclaspis* sp. B (43.3 ind/m^2) are the most abundant species in the mid-tide level. Cumeaceans *Cyclaspis* sp. B (251.7 ind/m^2) dominate the low tide level, but their relative dominance and density fluctuate over time (Dexter, 1979). Of the eight species of decapod crustacea occurring in this habitat, the most abundant is the omnivorous scavenger mole crab *Hippa testudinata* (= *H. cubensis*) (Abele, 1972a,b). Figure A.14 shows a generalized scheme of trophic relationships found in sandy beaches.

There is a higher faunal density and diversity at high tide level during the rainy season, and a lower density during the dry season, due to an increase in sand grain size (Dexter, 1979).

Pacific

Pacific beaches in Panama are composed of quartz and mud. Large areas are exposed to air twice a day during normal low tides. A major environmental influence affecting these beaches is upwelling of cold water during the dry season. In general, wave action is lower than on Caribbean beaches and tidal cycles are more predictable (Abele, 1972a,b; Dexter, 1979).

Sand-grain size variation along the tidal gradient is minimal. It is slightly higher at the high tide level, an area dominated by silt and clay. Chlorophyll content is higher at low tide level (Dexter, 1979).

Pacific sandy beaches provide habitat for approximately 60 invertebrate species. Table A.20 lists the species associated with Pacific sandy beaches. A marked faunal zonation is observed. The isopod *Excirolana braziliensis* (3,989.4 ind/m^2 at high tide, 1,535.7 ind/m^2 at mid tide, and 864.8 ind/m^2) dominates the entire beach gradient. The second most abundant organism at mid tide level is the isopod *Ancinus panamensis* (90.3 ind/m^2). At low tide level, the isopod *A. panamensis* (283.8 ind/m^2), the cumacean *Cyclaspis* sp. A (222.2 ind/m^2), and the polychaete *Paraonides platybranchia* (71.2 ind/m^2) are also abundant (Dexter, 1979). Of the 17 species of decapod crustaceans found on Pacific beaches, the most abundant is the mole crab *Emerita rathbunae*. However, several burrowing genera are not represented on Caribbean sandy beaches (*Calianassa*, *Pinnixa* and

Ambidexter; Abele, 1972a). Figure A.14 shows a generalized scheme of trophic relationships found in sandy beaches.

The high-tide level contains the lowest species diversity and the highest density of organisms. Mid- and low-tide levels support similar densities. However, low tide levels display the greatest species diversity and marked fluctuations in densities of organisms (Dexter, 1979).

Major changes in distribution, abundance, and species diversity are observed on Pacific sandy beaches during upwelling. Populations of *Ancinus panamensis* increase substantially during the dry season and adults migrate toward the high tide zone at this time of year. Similar migration patterns along the tidal gradient are common for almost all organisms (Dexter, 1979).

Conclusions

Pacific sandy beaches contain approximately 3 times as many species (60), six times the density of individuals ($2462/m^2$) and nine times the biomass ($3.59\ g/m^2$) of Caribbean sandy beaches (Glynn, 1972; Dexter, 1979).

Common genera to Caribbean and Pacific sandy beaches represent only 10% of the overall fauna occurring in these areas (Glynn, 1972).

Pacific beaches present higher decapod crustacean diversity (17 species compared to 8 in the Caribbean). This is explained by greater habitat stability (Abele, 1972a) and higher phytoplankton production (Dexter, 1979).

Caribbean sandy beaches are characterized by low population densities, fewer species, higher diversity and greater fluctuations among faunal dominants (Dexter, 1979).

Two dominant species common to both coasts are *Excirolana brasilensis* and *Cyclaspis* sp. (Dexter, 1979).

A.1.3.3 Mudflats

Whereas sharp boundaries exist between rocky shores and sandy shores, differentiating between muddy and sandy beaches is not as straightforward. Often, it is not possible to distinguish the two beach types. In lower energy sites, beaches become finer grained and accumulate larger amounts of organic matter, thus becoming more muddy. Muddy and sandy beaches are the extremes of a continuum.

The major contrast with open sand beaches is that muddy shores cannot develop in the presence of significant wave action. Sediment grain size is the most important factor

affecting the zonation of mud-dwelling organisms. Since grain size is generally reflected in the type of feeding mechanism employed by an organism, there is a relationship between the size of sediment particles and the species present (Villalaz et al., 1978).

Mudflats are generally encountered in protected/enclosed bays, coves, ports, estuaries and swamp areas where wave action and bottom slope are minimal. Fine grain size and shallow slope do not allow water to drain from the substrate. This water retention, the exchange of interstitial water with the overlying sea water, and the metabolic activities of large bacterial populations commonly result in oxygen depletion in the top few centimeters of sediment. This produces a vertical chemical zonation, with a chemocline of aerobic conditions at the surface and anaerobic sediments below. Three types of coloration are commonly found in the stratification of these sediments: a brownish surface where rusty organic matter prevails (mostly ferric hydroxide [$Fe(OH)_3$]); an intermediate layer containing ferric sulfide (FeS) with deposits from anaerobic decomposition, and; a blackish bottom layer with pyrite, (FeS2) with very little decomposing organic matter (Anderson et al., 1978).

As a rule, mudflats occupy extensive areas of intertidal shoreline. As an example, Bique Beach (Province of Panama, Arraijan, Pacific coast) encompasses a vast exposed section of approximately 1 km in width at low tide (Villalaz et al., 1978). Fauna associated with these beaches also display a transitional gradient in species composition, with invertebrates typical of sandy beaches in the larger grain-size sediment areas, and the typical mudflat fauna in the finer sediments (Table A.21).

The most important factors affecting the establishment of these organisms are the ease of penetration into the substrate, water content, and the availability of oxygen. The distribution of sessile or partially sessile benthic organisms is determined basically by the hardness of the substrate, dividing organisms into those that live in the substrate (infauna) and those that live on it (epifauna).

Few organisms live on the surface of mudflats. Many escape desiccation, extreme temperatures, and the mechanical action of waves by burrowing into the substrate. The majority of the inhabitants are buried in the soft substrate while others inhabit permanent burrows. Numerous infaunal organisms are essentially sessile and vary little in their position in the substrate. In contrast to sandy beaches, the presence of mudflat organisms is obvious from the visible burrow openings, tubes, and fecal mounds.

One of the first adaptations of organisms to muddy bottoms is the ability to dig into the substrate or to form permanent burrows. Another adaptation is the ability to deal with anaerobic conditions that prevail in the substrate. If organisms survive within the substrate, it is because they are physiologically equipped to endure anaerobic conditions or because they possess a mechanism to bring oxygen-rich water to them. Most multi-cellular organisms

cannot survive in the absence of oxygen and therefore obtain oxygenated water and food from overlying waters through burrows, holes and tubes.

Villalaz et al. (1978) studied the ecology of a sand - mud beach in Bique Beach and profiled the beach zonation. The profile contains three zones: an upper zone with large sediments of sand and gravel, an middle zone with intermediate-sized sediments (sand and fine sand), and a lower zone of fine sediments composed of silt and clay.

The size of the organisms in different communities can vary, depending on grain size. In addition to the relationship between feeding type and grain size, there also exists a relationship between the size of the animal and particle size. Though this relationship is not found among detritus feeders or filter feeders, it does hold true for deposit feeders.

Mudflats are distinct from sandy beaches in the frequent development of substantial algal growth. On mudflat surfaces, the most abundant algae are diatoms, which often give a brownish tint to the mud surface. The flora of these beaches consists primarily of benthic microalgae and phytoplankton. Both groups are treated in the description of sandy beaches (see section A.1.3.2).

Mudflats contain great numbers of bacteria which feed on the abundant organic matter. Bacteria are the most numerous organisms found in the anaerobic zone and constitute a significant portion of the biomass. The bacteria inhabiting this zone are capable of utilizing the potential energy from various reduced chemical compounds. Organic matter is produced using the energy released from the oxidation of reduced sulfur compounds.

The great quantity of organic matter within and on the mudflats increases productivity by providing bacteria and plants with nutrients. Levels of organic matter are directly linked to energy conditions (water movement) and to sediment grain size. The large- grained sediments are associated with considerable wave energy. A rich layer of detritus cannot be deposited under these conditions, and therefore excludes detritivorous fauna (Villalaz et al., 1978).

Since organic matter is a major source of energy utilized by heterotrophic bacteria and larger benthic organisms, it is also an important determinant of their distributions. The dominant groups of macrofauna in the mudflats are the same as those found in sandy beaches (see A.1.3.2). In Beach Bique there are polychaetes (bristle worms), ophiuroids (brittle stars), bivalves (clams, cockles), gastropods (snails), amphineurans (chitons), crustaceans (amphipods, cumaceans, tanaids, burrowing shrimp), and cephalochordates. Table A.22 lists the faunal species associated with mudflats.

The two dominant of feeding mechanism types in mudflats are the deposit feeders (detritivores) and the filter feeders (suspension feeders). The deposit feeders are

particularly abundant since there are great quantities of organic matter and bacteria in the sediment. Among the deposit feeders are the polychaetes *Owenia* sp. and *Ctenodrilus* sp., and the brittle stars *Ophiolepis elegans* and *Ophionereis annulata*. The suspension feeders are mostly represented by the bivalves *Protothaca asperrima, P. mcginty, Chione subrugosa*, the polychaete *Sabella* sp. and the ophiuroid *Ophionereis annulata*.

Among the polychaetes, the fanworms (family Sabellidae, genus *Sabella*, is the most abundant. This polychaete is found predominantly in the median-grain sediments of muddy sand. Here it builds burrows with shell and sand fragments. The genera *Owenia* and *Ctenodrilus* show a preference for finer sediments where they build burrows in the mud, cementing them with mucous secretions. The carnivorous *Nothria sp.* is found in intermediate and fine-grain sediments. This polychaete has the ability to leave its galleries to seek food (Barnes, 1969). The family Arabellidae is represented by the genus *Biborin*, a burrowing carnivore that shows a wide tolerance to sediment types, being found in all three zones.

Moisture plays an important role in the distribution of polychaetes. With smaller sediment particle sizes retaining greater quantities of water, tubes and galleries can be constructed in the substrate. Water also provides conditions that allow the sediment to be sufficiently soft and at the same time stable, permitting invertebrates to be buried without destroying their burrows or obstructing their respiratory conduits.

Brittle stars (ophiuroids) do not display as marked a zonation as polychaetes and bivalves. Villalaz et al. (1978) found that these echinoderms are tolerant to numerous sediment types. *Ophiolepis elegans* is exclusively detritivorous, while *Ophionereis annulata* can feed by filtration or on detritus. The ophiuroids have need of an adequate supply of organic matter; their numbers increase when organic matter accumulates.

Seventeen species of bivalves are found at Bique Beach, with four predominant species: *Protothaca (Luekoma) asperrima, Chione (Iliochione) subrugosa, P. (Leukoma) mcginty and P. (Luekoma) metodon*. The distribution of bivalves indicates a relationship between the size of the sediment particles and the organisms observed. Bivalves prevail in areas where sediment grains are intermediate in size -- an adaptation for filtering organisms. Gastropods did not demonstrate a distinct zonation, due to their epifaunal habits and their different feeding modes. Among the most abundant gastropods are *Nassarius (Arcularia) luteostoma, N. (Arcularia) complanatus* and *Thais (Thaisella) kiosquiformis*.

During periods of low tide, various birds come to the mudflats to feed. There is little information of the effects of these birds on the invertebrate communities. Many are carnivorous or omnivorous. A fringe of some 15 km along the Pacific coast near Panama City provides excellent habitat for coastal birds of the western hemisphere. Among the most common are the blue egret *(Egretta caerulea)* and tri-colored egret *(Egretta ruficollis)*,

Endocimus albus, Caladris mauri, Caladris minutilla, Numenius phaeopus hudsonicus and *Larus atricilla*. Figure A.15 shows mudflat trophic relationships.

Conclusions

Mudflats have a minimal slope gradient and little water movement; the flats are not completely drained during low tide periods. This retention creates a depletion of the oxygen in the first few centimeters of sediment, creating aerobic and anaerobic areas. Sediment grain size is the most important factor in the zonation of these beaches.

There is a relationship between the sediment particle size and the species that dwelling in the sediment. Grain size is related to the particular species, reflecting the organism's type of feeding mechanism.

Few organisms live on the surface of the mudflats; the majority of the mud biota belongs to the infauna. These organisms move little if at all from their position in the sediment, remaining virtually sessile. The most important factors in the establishment of these organisms are the ease of burrowing of the substrate, the water content, and the availability of oxygen.

Organic matter is important in the distribution of the benthic organisms, being used as an energy source by heterotrophic bacteria and larger benthic organisms. Mudflats are dominated by detritivores and filter-feeding organisms.

A.1.4 Coral reefs

Coral reefs are the most complex tropical coastal ecosystems and exhibit the highest species diversity and the strongest differences between both oceans. They also present a very high productivity. Several studies have estimate primary productivty of 1,500-3,500 g $C/m^2/yr$ (Nybakken, 1982).

Environmental factors that limit coral growth in the Pacific and the Caribbean are 1) light penetration, 2) water temperature, 3) tidal amplitude, 4) salinity, 5) turbidity, and 6) sedimentation (Glynn 1972, Porter 1972, Von Prahl y Erhardt 1985). Biological factors that influence wildlife populations on coral reefs differ from ocean to ocean, and will be treated separately.

The first requirment for coral growth is light. A diminute algae called zooxanthellae lives inside coral tissue. It fixes organic compounds by photosysthesis, the final products serve as food for the coral. The zooxanthellae also contributes significantly in calcification and coral growth (Nybakken, 1982).

Caribbean corals are more sensitive to sedimentation than Eastern Pacific species. The species that better adapt to sedimentation are those with small branches or larger tentacles (Gonzalez & Polo, 1982).

There are more than 90 hermatypic scleractinians and over 150 ahermatipic scleractinian genera of corals from the entire Eastern Pacific and the Caribbean. Of these, the Caribbean and the Pacific contains only six common hermatipic genera: *Acropora*, *Cladocora*, *Favia*, *Madracis*, and *Porites*, and 20 ahermatipic genera with very few species in common (e.g. *Tubastrea aurea* and *Madracis asperula*; Glynn, 1982).

Caribbean

Most Caribbean reefs are large, well consolidated fringing reefs" that occur continuously over large geographic areas. They occur under a greater range of conditions (e.g. exposed to strong wave action and currents or in protected areas; shallow or deep water) than Eastern Pacific reefs. Reef thickness can reach 33 m and have a rate of frame accumulation of 0.6 to 3.9 m/1000 yrs (Glynn 1982). Their slope extends to 60 m depth, but most profuse coral growth generally occurs at the edges of the reef and the highest diversity occurs between the 5 and 25 m (Porter, 1972; Glynn, 1982).

Reefs are often associated with seagrasses and mangrove communities (Glynn, 1982). Seagrass beds are located between fringing reefs and mangrove forests. There is a constant interchange of nutrients, energy flow and biota between the three communities. For a complete characterization of seagrass beds and/or mangrove communities, see the discussion of Seagrasses and Mangroves.

There are 50 species of hermatypic (Glynn, 1982), 16 ahermatipic, and four Millepora corals in the Caribbean of Panama (Glynn, 1972; Porter, 1972). The number of individuals per species is low to moderately high (Glynn, 1982).

Habitat diversity is high. Goreau and Goreau (1975) identified 11 zones along Jamaican coral reefs. This is considered the general zonation for all Caribbean reefs, including Panama. The 11 Caribbean coral reefs zones are grouped into three regions: 1) the back reef region, 2) the reef crest, and 3) the seaward slope. Table A.23 compares the typical zonation of Caribbean and Eastern Pacific coral reefs.

The reef back region is divided into two zones, the inshore zone and the lagoon zone. The inshore zone is an extremely variable region. Its biotic associations and bottom sediments depend on whether the coast is alluvial, rocky, mangrove, estuarine, etc., and on the degree of exposure to the sea. Depths range 0.1 to 3 m (Goreau & Goreau, 1975). There is a close association with seagrasses and fragile coral species (e.g., *Acropora cervicornis*; Von

Prahl & Erhardt, 1985; Guzmán & Jackson, 1991). This zone is inhabited by 31 species of corals, grouped in 21 genera and 9 families (Goreau & Goreau, 1975).

The lagoon zone is present only on fringing reefs. The bottom is typical of calm environments, composed of soft, silty, or muddy sediments. Its depth ranges from 0.5 to 5 m. The biota is dominated by algae and seagrass beds. It is inhabited by 31 species of corals, in 21 genera and 11 families (Goreau and Goreau 1975).

The reef framework is characterized by intensive coral calcification and high turbulence, and is a "self cleaning" community. It is divided into six zones. The rear zone borders the lagoon side of the reef crest with depths of 0.2 to 3 m. Space is restricted, due to shallowness and the encroachment of muddy substrate. There are 29 coral species in 17 genera and nine families (Goreau & Goreau, 1975).

The reef flat is also known as the *Zoanthus* zone (Goreau & Goreau, 1975). It is the shallowest part of the reef crest (0 to 1 m depth) and is often exposed at low tides. Coral species that inhabit the reef flat, and the associated biota, are adapted to extreme environmental fluctuations and have short life cycles and high egg production (Guzmán & Jackson, 1991). The reef flats contain an emergent algal ridge along the seaward front, composed of crustose coralline algae and vermetid gastropods (Glynn, 1972, 1982; Porter, 1972). There are 22 species of corals in 10 genera and seven families (Goreau & Goreau, 1975).

The surf zone is also called the breaker zone, or *palmata* Zone because it is always exposed to wave action and is dominated by *Acropora palmata* and *Millepora complanata*. Depths range 0 to 5 m. There are 20 species of corals in 10 genera and six families (Goreau & Goreau, 1975).

The barren zone is also known as the moat zone, or Lower *palmata* zone, because *Acropora palmata* is the most common coral species. Its depth ranges from 2 to 8 m. The bottom is strewn with dead, fragmented, and displaced colonies of *Acropora palmata*, broken away from the surf zone by storms. Crustose red algae are present, with *Halimeda* being the most common genus. There are 28 coral species in 17 genera and seven families (Goreau & Goreau, 1975).

The mixed zone ranges from 7 to 15 m depth. It is also known as the *annularis-cervicornis* zone, because *Montastrea annularis* and *Acropora cervicornis* are the two most common coral species. *Porites porites, Dendrogyra cylindricus, Agaricia agaricites, Madrasis mirabilis, Diploria strigosa, Colpophyllia natans, Porites astreoides, Porites furcata*, mussids, and *Millepora* are also abundant. Foraminifera, Halimeda, and other calcareous algae are also very common. There are 39 species of corals in 23 genera and 11 families (Goreau & Goreau, 1975).

When present, the buttress zone is the richest reef habitat. There are 41 species of corals in 23 genera in depths of 2 to 20 m. The zone is bissected by a system of narrow, somewhat meandering, but regularly spaced canyons between the spurs, whose bottoms are a mixture of rubble and sand. Coral growth in these canyons is limited by the movement of sediment and calcareous detritus by gravity and currents from higher, deeper zones. However, coral overgrowth may roof the canyons, forming caverns and narrow passages (Goreau & Goreau, 1975).

The seaward slope region is a variable habitat, depending on topography and substrate (soft or hard). There are marked biotic gradients in species diversity. It is divided in three zones. The fore-reef zone overlaps the deepest end of the buttress or the mixed zones. Its depth ranges from 15 to 40 m. It is composed of promontories or lobes on which coral grows on the rock, forming a terrace with sills that funnel the sediments down slope to deeper waters. The sill is dominated by *Acropora cervicornis, Montastrea annularis, Madracis mirabilis, Porites furcata, Colpophyllia natans, Porites astreoides, Montastrea cavernosa*, and *Eusmilia fastigiata*. The more common coral species occurring on the boulders are *Siderastrea siderea, Colpophyllia natans, Montastrea annularis, Montastrea cavernosa, Acropora cervicornis, Porites astreoides, Porites furcata*, and *Millepora complanata* (above 13 m depth). *Madracis mirabilis* tends to replace *Porites furcata* below 13 m depth (Goreau & Goreau, 1975).

The fore-reef slope is a gradually descending sedimentary slope that ranges from 30 to 65 m depth. It is characterized by extensive accumulations of fine calcareous sediments that can reach 20 m depth in very well developed reefs. Single coral colonies grow individually, the more common species being *Agaricia lamarcki, Helioseris cucullata, Agaricia undata, Agaricia fragilis, Stephanocoenia michelinii, Porites astreoides, Montastrea cavernosa, Montastrea annularis, Mycetophyllia aliciae, Madracis mirabilis, Eusmilia fastigiata, Meandrina meandrites, Siderastrea siderea, Mussa angulosa*, and, rarely, *Porites furcata*. Sandy slopes are covered with algae, mostly *Halophila, Udotea wilsoni, Penicillus dumetosus*, and *Penicillus pyriformis* (Goreau & Goreau, 1975).

The final zone is the deep fore reef, also known as "the final drop-off". It ranges from 60 to 200 m depth. Solitary coral colonies are flatter at this depth, due to high pressure. The most abundant are *Madrasis* sp., *Mycetophyllia reesii*, agaricians, and *Montastrea cavernosa*. Ahermatypes, algae, sponges and gorgonians are also abundant. There are a total of 17 coral species in 10 genera and six families.

Biotic factors are not so important in determining reef structure as in Eastern Pacific reefs. Branching corals are not associated with protective symbiotic crustaceans, but pathogenic blue-green algae and bacteria are reported in reef corals and associated fauna (Glynn, 1982).

Bioerosion is moderate, and corallivores, when abundant (seven invertebrate species and 14 fish species), are relatively unimportant to reef growth (Glynn, 1982). Sea urchins are the most important bioeroders of Caribbean reefs. Six of the eight species of sea urchins found in Caribbean waters inhabit coral reefs. The most common species is *Diadema antillarum*, which also is the most dangerous to man (Lessios 1983). It feeds on *Madracis miriabilis, Acropora palmata, Acropora cervicornis, Agaricia agaricites, Colpophyllia* sp., *Montastrea annularis* and *Millepora* sp. (Glynn, 1982). An extensive die-off was observed during 1983 in the entire Caribbean; populations have not yet recovered (Lessios, 1988a,b). *Astropyga magnifica* and *Arbacia punctulata* are rare species. *Echinometra lucunter* is a very common species on the reef platform, while *Echinometra viridis* is very common in subtidal coral reefs with a high percentage of cover, and is therefore a good indicator of reef health. The seastar *Oreaster reticulatus* feeds on *Acropora cervicornis* and *Montastrea annularis* (Glynn, 1982).

Several other Caribbean invertebrates feed on corals. The fireworm *Hermodice carunculata* feeds on *Porites astreoides, P. porites, Favia fragum, Diploria strigosa, D. clivosa, Montastrea annularis, Millepora complanata, Acropora cervicornis*, and *Porites furcata*. The gastropods *Coralliophila abbreviata, Coralliophilia caribbea*, and *Calliostoma javanicum* feed on *Montastrea annularis, Acropora palmata, A. cervicornis, Agaricia agaricites, Helioceris cucullata, Siderastrea siderea, S. radians, Porites astreoides, P. porites, Favia fragum, Diploria clivosa, D. strigosa, D. labyrinthiformis, Mycetophyllia lamarckana, Colpophyllia natans, Agaricia* spp., and *Mussa angulosa*. The crab *Mythrax sculptus* feeds on *Porites porites* and P. *furcata*.

There are several fish species that feed on corals. Butterfly fishes (*Chaetodipterus faber* and *Chaetodon capistratus*) feed on *Montastrea annularis, Siderastrea siderea* and *Oculina diffusa*. Juvenile damselfishes (*Microspathodon chrysurus, Stegastes planifrons* and *S. dorsopunicans*) feed on *Millepora complanata, Acropora palmata, Porites spp., A. cervicornis, Colpophyllia natans*, and *Montastrea annularis*, while adults (*Eupomacentrus planifrons*) feed on *Siderastrea siderea* and *Millepora complanata*. Parrotfishes (*Scarus coelestinus, S. guacamaia, S. croicensis, S. vetula, S. taeniopterus, Sparisoma viride* and *S. aurofrenatum*) feed on *Siderastrea siderea, Acropora cervicornis, Madracis miriabilis, Agaricia agaricites, Porites astreoides, P. porites, Montastrea annularis, M. cavernosa, Millepora* sp., and *M. alcicornis*. Filefishes (*Alutera scripta, Cantherhines macrocerus*, and *C. pullus*) feed on *Millepora alcicornis*. Three species of surgeon fishes (*Holacanthus* spp.) are sponge specialists, but predation on sponge and motile corallivorous invertebrates is limited compared to Eastern Pacific (Glynn, 1972). Table A.24 list the key species inhabiting Caribbean coral reefs by trophic status and zonation; Table A.39 list the bird species associates to coral reefs trophic chain.

Coral reefs are located at different sites along the Caribbean coast. The most important reefs can be gruped around three big areas. 1) Bocas del Toro islands, 230 Km west of the Panama Canal entrance; 2) Colon reefs, from 20 Km west to 60 Km east of the Panama

Canal entrance; and, 3) San Blas islands, 130 km from the Panama Canal entrance (Glynn, 1972).

Pacific Ocean

Eastern Pacific coral reefs are small subtidal "patch" or "fringing reefs" exposed only during extreme low tides. They occur discontinuously, and are relatively isolated and confined to volcanic islands in environments characterized by sheltered habitats. Reef thickness reaches 12 m and reefs have a rate of frame accumulation of 1.3 to 7.5 m/1000 yrs. Their slope extends to a maximum depth of 15 m (Glynn, 1972, 1982; Porter, 1972).

Dana (1975) has suggested that Eastern Pacific reefs became extinct during Pleistocene glacial events. Current Eastern Pacific reefs are derived from recent colonists from Central Pacific island populations. The age of formation of these reefs confirms this hypothesis (Glynn, 1982).

Coral growth is limited in the Gulf of Panama to the northern and eastern sectors of certain islands due to upwelling. Temperatures lower than 20° C dimish and eventually halt coral growth and coral's feeding capacity (Glynn & Stewart, 1973; Glynn et al., 1972).

Seagrass and mangrove communities are not present near reefs, and crustose coralline algae and other binding organisms are rare. Pathogens have not been reported in Eastern Pacific coral species or associated biota (Glynn, 1982).

Eastern Pacific coral reef ecology is also regulated by El Niño phenomenon. Glynn & D'Croz (1990) have shown that temperatures of 30-32° C (Pacific water temperature during the 1982 El Niño) for ten weeks induced *Pocillopora* to expulse zooxanthela, producing histopathological abnormalities and massive deaths. Individuals from the Gulf of Panama are more sensitive to high temperatures because of their adaptation to the fall in temperature during upwelling.

There are 20 species of hermatypic corals in the Eastern Pacific, the dominant species being *Pocillopora damicornis*, which represents 90% to 95% of the total coral cover. Other genera, like *Porites* and *Pavona* also contribute to reefs development (Glynn, 1972, 1982). The number of individuals per species is generally high (Glynn, 1982).

Glynn (1976) identified four zones along Secas and Uva Island reefs (Gulf of Chiriqui), all of them dominated by *Pocillopora damicornis*. This is considered the general zonation for all Eastern Pacific coral reefs, including the Gulf of Panama. Table A.25 presents the characteristics of the four zones of a typical Eastern Pacific reef. Eastern Pacific reef zones are not grouped into regions as are Caribbean reefs, but for purposes of comparison, the former have been grouped into regions. Table A.23 compares the zonation of typical

Caribbean and Eastern Pacific coral reefs. Habitat diversity is low in these reefs and there is intense competition for space. The number of sedentary associated biota is low (Glynn, 1982).

The reef-flat zone is a platform that is exposed during extreme low tides, which produces severe disturbances in coral populations. The most common coral species are *Pocillopra damicornis, Psammocora stellata, Psammocora* sp., and *Porites panamensis*. The last three species have proved to be highly resistant to desiccation, while pocilloporid species showed high mortality after exposure (Glynn, 1976).

The reef-crest zone is a few centimeters higher than the reef flat, being the shallowest zone of the reef. It is also exposed during extreme low tides. *Pocillopora damicornis* is the only species present in this zone. Breaking waves and constant spray allow *Pocillopora damicornis* to survive in this habitat (Glynn, 1976).

The upper reef slope is inhabited only by fast-growing pocilloporid corals. Colonies grow as a continuous surface cover, which favors the survival of pocilloporid corals. The ahermatypic corals *(Tubastrea* spp.) grow in crevices along this zone. The corallivorous crown of thorns seastar (*Acanthaster plancii*) and several corallivorous fishes avoid this area, maximizing the vertical growth of coral (Glynn, 1976). This live coral wall is responsible for the horizontal reef growth toward the sea.

The dominance of pocilloporid corals in the three shallow reef zones is due to their rapid growth, overtopping nature, and high reproductive potential (Glynn, 1976).

The lower reef slope and the reef base support the highest coral diversity of the reef. Large heads of *Pavona* spp. and *Porites* spp. alternate with pocilloporid corals, *Gardinoseris planulata*, and hydrocorals (Glynn, 1976). The ahermatypic coral *Tubastrea* spp. grow on crevices and in caves along this zone. In front of the reef base, sandy or sand-mud bottoms are common, with patches of pocilloporid corals or solitary heads of *Pavona* spp. and *Porites* spp.

The increase in species diversity in this zone is due to specific physical and biological factors. According to Glynn (1976), four biotic forces that affect coral community structure in the deepest zone of Pacific reefs are 1) competition for space, 2) destruction by corallivores, 3) disruptive effects from bioturbation, and 4) mutualistic interactions involving the defense of particular coral species by their symbionts.

Competition for space is high in the lower parts of Pacific reefs. First, restriction of coral reefs to shallow waters induces overlap in species distribution; second, falling of coral debris from upper zones causes selective mortality of small and loosely attached corals; and third, the growth rate of *Pocillopora damicornis* is reduced with depth (Glynn, 1976).

There are fewer corallivorous species in the Eastern Pacific than in the Caribbean (10 invertebrate species and five fish species). Bioerosion is intense in Eastern Pacific coral reefs, even when predation on mobile corallivore invertebrates is high, because corallivoures are more speciallized and voracious than Caribbean species (Glynn, 1982). No polychaetes feed on Eastern Pacific corals. The gastropods *Jenneria pustulata*, *Muricopsis zeteki*, *Latiaxis hindsii*, *Quoyula madreporarum*, and the nudibranch *Aeolidea* sp. feed on *Porites lobata*, *Pavona clavus*, and pocilloporids. The crabs *Trizopagurus magnificus* and *Aniculus elegans* feed on pocilloporids. The seastar *Acanthaster plancii* feeds on several coral species. The seastars *Pharia pyramidata*, *Nidorellia armata*, and the urchin *Eucidaris thouarsii* feed on pocilloporids and *Pavona clavus*.

Coral fishes prey on both scleractinian hermatype and hydrozoan corals. Parrotfishes (*Scarus ghobban* and *S. perrico*) feed on *Porites panamensis*, *Pavona* spp. and pocilloporids. Puffer fishes (*Diodon holocanthus*, *D. hystrix*, *Arothron hispidus*, *A. meleagris*, and *Canthigaster amboinensis*) feed on the terminal branches of pocilloporids, *Psammocora stellata*, *Pavona* sp., and *Porites californicus*. Triggerfishes (*Balistes polylepis*, *Melichthys niger*, *Pseudobalistes naufragium*, and *Sufflamen verres*) break off different coral species in search of algae and sponge. Finally, damselfishes (*Stegastes flavilatus*, *S. acapulcoensis*, and *Microspathodon dorsalis*) cultivate algae over massive coral heads like *Porites* spp. and *Pavona* spp., soffocating them. Several species feed on sponges (asteroids and fishes; Glynn, 1982).

There are seven sea urchin species that feed on algae associated with Pacific reefs. *Diadema mexicanum*, *Tripneustes depressus* and *Astropyga pulvinata* are most abundant. *Toxopneustes roseus* produces serious injuries and intoxication-like symptoms in humans. *Toxopneustes* does not exist in the Caribbean. *Lytechinus panamensis* is an extremely rare species. Two species of sea urchins associated with intertidal rocky shores, *Arbacia stellata* and *Echinometra vanbrunti*, might also be found in coral reefs (Lessios, 1983).

The crown-of-thorns starfish *Acanthaster plancii* feeds preferentially on Porites spp., Pavona spp. and pocilloporids, but also preys upon *Millepora* spp. (Glynn, 1973; Glynn 1976). It forages actively during the day and night and can consume 18% to 47% of the live cover of a 20 ha reef in four months (Glynn, 1973). Its predator in the Eastern Pacific is the shrimp *Hymenocera picta* (Glynn, 1972, 1976, 1982).

There are 55 species of decapod crustacean associated with *Pocillopora* spp. on Pacific coral reefs. The most abundant species are *Petrolisthes haigae*, *Pagurus* sp., *Trapezia cymodoce ferruginea*, *Harpiliopsis depresus*, *Heteractaea lunata*, and *Alpheus lottini*. *Trapezia cymodoce ferruginea* is an ectoparasite on the coral; 18 species are obligate commensals (Abele, 1972a). Two of these symbiont crustaceans (the crab *Trapezia ferruginea* and the shrimp *Alpheus lottini*) protect *Pocillopora* spp. from *Acanthaster*. They feed on coral mucus (Glynn, 1976).

Trapezia crabs are more abundant on the Reef Flat than in other reef zones. *Alpheus* shrimp abundance is constant throughout all zones. Both symbionts are more resistant to air exposure than their host coral (crabs can move into the moister areas of the colonies during extreme low tides). However, the massive die-off of *Pocillopora* after exposure produces a massive die-off of symbionts due to starvation. This phenomena is followed by a massive recruitment from the Reef Crest zone after pocilloporids recover. Even during this period of low symbiont numbers in the Reef Crest Zone, when pocilloporids are more vulnerable, *Acanthaster* does not colonize this area. The dense cover of live pocilloporids on the upper forereef limits *Acanthaster* to deep reef areas. This is evidence of the effectiveness of symbionts on protecting pocilloporids from their major predator. The association between branching corals and their symbiotic crustaceans maintains a trophic equilibrium (Glynn 1976). Table A.26 list the species inhabiting Eastern Pacific coral reefs by trophic status and zonation; Table A.39 list the bird species associates to coral reefs trophic chain.

Iguana Island (Province of Los Santos) has the biggest coral reef (16 Ha) reported inside the Gulf of Panama. Other important reefs inside the Gulf of Panama are located at Contadora (15.6 ha), Bolaño (14.7 ha), Mogo Mogo (12.0 ha), Chapera (6.3 ha), Pacheca (5.7 ha), Saboga 5.2 ha), Bajo Boyarena (3.3 ha), and Pedro Gonzales (0.6 ha) islands in the Archipielago Las Perlas. Other smallest coral communities are found in Taboga and Taboguilla islands. The biggest and oldest coral reefs of the Panamanian Eastern Pacific are located in the Gulf of Chiriqui. Coiba island has the biggest coral reef of the Eastern Pacific. There are also big reefs in Secas and Contreras islands (Glynn & Stewart, 1973; Glynn et al., 1972; Guzmán et al., 1991).

Conclusions

Environmental factors that limit coral growth are: light penetration, sedimentation, tidal amplitude, salinity, turbidity and water temperature (Glynn, 1972; Porter, 1972).

Pacific coral reefs, compared to Caribbean reefs, are characterized by (Table A.27; Glynn 1982):

- shallower (15m vs. 60m), discontinuous, and less complex reefs that grow in much lower energy habitats;
- less consolidated;
- higher rate of frame accumulation (1.3-7.5 m/1000 yrs vs. 0.6-3.9 m/1000 yrs);
- lower coral diversity but higher coral cover;
- higher number of individuals;
- lesser thickness (12 m vs 33 m);
- lesser habitat diversity (4 vs. 11 vertical zones);
- lesser amount of coralline algae;

- lesser competition for space;
- much higher sponge predation;
- association of branching species with protective symbiotic crustaceans;
- no pathogens present; and,
- bioerosion is much more intense with important corallivorous species.

Biotic factors are more important on reef structure in the Eastern Pacific than in the Caribbean. There is more grazing pressure and coral predation by invertebrates and fishes in the Pacific. *Acanthaster* is the major coral predator in the Pacific while *Diadema antillarum* is the most important corallivore in the Caribbean (Glynn, 1972, 1976, 1982).

Pocilloporid symbionts play a crucial role in maintaining the equilibrium of the system between *Acanthaster* and its coral prey. Even when there are coral symbionts in the Caribbean, this kind of association is unknown on this side of the Isthmus.

Caribbean coral reefs occur in association with seagrass beds and mangrove communities. Seagrasses exist in the Pacific, but they do not form patches near reefs (Glynn 1972).

There is very little similarity between Caribbean and Pacific coral decapod crustacea. This is explained because most of the species are obligate commensals on individual coral species.

A.1.5 Seagrasses

Seagrasses are characteristic of shallow coastal waters in temperate and tropical zones. There are approximately 60 seagrass species classified within 12 genera. These are distinguished from algae by the presence of roots, a vascular system, and the capacity to bloom (Fonseca, 1987). In tropical zones, they are distributed along the Gulf of Mexico and the Caribbean Sea, where there are vast seagrass beds associated with various species of algae (Moore, 1963; Hartog, 1970). In Panama, their distribution is mainly on the Atlantic Coast. Important meadows of these grasses are generally found associated with coral reefs and mangrove forests in the area of Bay Las Minas (to the east of Colon) and in the San Blas region. These seagrass communities can stretch out along extensive shoreline, occasionally being broken up by coral reefs or sand channels. They often occur behind well-developed reef flats. These reef structures absorb wave energy and create protected areas that are conducive to the establishment of seagrass beds.

Although Panamanian Pacific coasts have a greater diversity of seagrasses than the Caribbean (Earle 1972), seagrass beds are rarely encountered in the Panamanian Pacific (Glynn, 1972). For Panamanian coasts, there are nine known seagrass species: five in the Pacific and four in the Caribbean (Earle, 1972) (Table A.28).

Thalassia testudinum (turtlegrass) is the most common of the tropical seagrasses and forms continuous beds called ceibadales that extend from the tidal zone to depths of 10 m (Glynn, 1972). The principal physical factors influencing seagrass flats are substrate type, wave action, turbidity, temperature, sedimentation and salinity. Among the most important biological factors that affect them are: trophic relationships, predation and interspecies competition.

The importance of seagrass beds has been proven by various authors (Murina et al., 1969; Wood, E.J.F. et al., 1969; Diaz - Piferrer, 1972; Rodriguez, 1972), who describe their ecological significance in providing food and refuge to a great number of organisms and serving as the base of a complex trophic chain. Their root system helps prevent erosion of soft bottoms, preserves the microflora that inhabit the sediments, and participates in the exchange of nutrients among sediment and water. Seagrass beds export matter to other systems such as coral reefs and mangrove swamps and maintain active nutrient cycles (Fonseca, 1987; Thayer et al., 1975).

Seagrass communities have intimate contact with other nearby communities, such as coral reefs and mangroves. The importance of this link is particularly relevant in the nutrient-poor waters of the Caribbean Sea.

The proximity of the seagrass provides an available and rapid source of energy. In contrast with the characteristic cycle of coral reefs, the seagrass flats have an open system with many organisms visiting from the adjacent communities. Tropical coastal waters are characterized by an abundance of coral-inhabiting herbivorous organisms (surgeon fish, parrot fish and sea urchins) that pass through their juvenile stages in adjacent seagrasses.

The amount of matter exported from the blades of *Thalassia* varies depending on season, wave action and storm activity. *Thalassia* blades have been found floating in the open sea and over abyssal depths (Menzies et al., 1967). It is certain they provide some level of energy to distant communities.

Heck (1977) performed studies in the seagrass flats of the Caribbean coast of Panama, finding different species dominant (in biomass) such as the marine angiosperms *Thalassia testudinum* and *Syringodium filiforme*. Associated with these are the green calcareous algae *Halimeda opuntia, H. incrassatra, Penicillus capitatus,* and *Udotea flabellum;* the green filamentous alga *Cladophora jamaicensis;* and periodically the brown alga *Dictyota divaricata*. Also found with the seagrasses are various groups of microalgae that grow as epiphytes on the blades of marine angiosperms and macroalgae. These microalgae include diatoms, coralline algae and numerous other groups (Humm, 1964).

The fauna of seagrass meadows can be split into three principal groups: 1) those which use the meadows as refuge and are part of it, 2) the organisms that pass part of their life cycle

in the seagrasses, and 3) the organisms that occasionally visit the beds, seeking food and/or protection (See Table A.29). It is estimated that a great percentage of the production of the blades of *Thalassia* enters the food chain as detritus (Wood et al., 1969).

There are two principal pathways in this chain. The first is where the plants are decomposed by bacteria and fungi which possess the capacity to digest the cellulose. The second is the consumption of blades by herbivores that, due to the lack of digestive enzymes to break down the cellulose, digest only the epiphytes on the blades.

Dense populations of bacteria are associated with seagrass beds (Burkholder et al., 1959). These bacteria are the major food source of detritus feeders that live within the sediments (Fenchel, 1970). Among the detritivores are large numbers of polychaetes, crustaceans, bivalves and gastropods (O'Gower and Wacasey, 1967; Orth, 1971; Brook, 1975). These consumers strip the bacteria from the detritus; fecal wastes are then subsequently reinvaded by bacteria (Fenchel, 1970).

Probably the most important predators of epibenthic invertebrates living on or at the base of seagrasses are: snappers *Lutjanus analis, L. synagris, L. griseus* and *Ocyurus chrysurus;* two scorpionfish species, *Scorpaena grandicornis* and *S. brasiliensis;* two species of mojarras, *Eucinostomus argenteus* and *E. gula;* the tamborils *Sphoeroides spengleri* and *S. testudineus;* and the groupers *Epinephelus afer* and *E. striatus.*

Another important group of predators seek shelter in coral habitat, but graze in seagrass meadows during evening hours. This group includes the grunts *Haemulon plumieri, H. sciurus* and *H. bonairensis;* the snapper *Lutjanus apodus;* and *Gymnothorax funebris* (Heck, 1977). Among the principal herbivorous fish is the parrot fish *Sparisoma radians,* which selects epiphytes growing on seagrass blades (Lobel et al., unpubl.). Other fish that are important seagrass consumers are the surgeon fishes (Acanthuridae), particularly *Acanthurus bahianus* and *A. chirurgus.*

Food selection in relation to its availability or seasonal variation of fishes has not been well studied in seagrass beds. Randall (1965) indicated that the movements of foraging fish originating from the reefs toward the seagrass meadows were responsible for the "halos" around reef patches. These halos are areas lacking vegetation.

Sea urchins are the most important seagrass consumers. Among the most common species are *Eucidaris tribuloides, Diadema antillarum, Echinometra lucunter, Lytechinus variegatus,* and *Tripneustes ventricosus.* Some seagrass species are preferred, others are taken at random, and others are avoided. *Tripneustes ventricosus* feeds exclusively on epiphytes. *D. antillarum* and *E. lucunter* do not inhabit the meadows of *Thalassia,* but 60% of their stomach contents consisted of seagrasses (Ogden et al., 1974).

D. antillarum and *T. ventricosus* are active during the night and move between the reefs and seagrass flats. Sessile epifauna living in seagrass beds includes massive corals (*Manicina* sp., *Porites* sp., *Siderastrea* sp. and *Cladocora* sp.), sponges, tunicates and anemones. In these flats, there are about 90 invertebrate species (Table A.30), of which 68% are decapod crustaceans. The most abundant is the shrimp *Tozeuma carolinense* (Heck, 1977). In addition, there are the gastropods *Cerithium eburneum, C. litteratum* and *Modulus;* the shrimp *Penaeus dourorum notialis;* the crab *Microphrys bicornutus;* the hermit crabs *Pagurus bonairensis* and *Paguristes limonensis;* the donkey dung sea cucumber *Holothuria mexicana* and the polychaetes *Onuphis sp., Nereis riseii, Arabella mutans* and *Malaceros indicus* (Heck, 1977). Marshall (1991) lists some 19 species of epiphytic invertebrates and 44 species inhabiting the seagrass-associated sediments. Many have not yet been identified (Table A.30).

Seagrass meadows on the Panamanian coast are important breeding grounds for some commercial species such as the shrimp *Penaeus dourorum notialis,* the lobster *Panulirus argus,* and the gastropod *Strombus gigas.* In shallow reef-flat areas where *Thalassia* is present, one can find a variety of birds. These birds feed on small invertebrates. There is little information on the relationship of these birds with seagrass communities. Among the most common we are pelicans, gulls and blue herons.

Conclusions

The seagrass meadows in the Caribbean are dominated by turtlegrass (*Thalassia testudinum*). The high productivity of these seagrass beds is channeled toward detritus, in which a complex fauna, in and on the sediments exploits this resource. Primary productivity of seagrasses, based on carbon fixation, reaches 600 g/m2/year (Williams, 1988; Thayer et al., 1975). A small quantity of this energy goes toward the macroconsumers that are generally common species of commercial importance. Their direct consumption of the seagrasses is small.

The productivity of the seagrasses is in the blades and the associated epiphytes. The most important macroconsumers are sea urchins, fish, and gastropods. These herbivores inhabit several portions of the seagrass communities, but few are exclusive inhabitants of the meadows.

The movement of fish from the coral reefs into the seagrass flats forms an important link between these two communities. The close association of the three tropical communities, coral reefs, mangroves and seagrass flats, is an important example of the interrelationships and migration of organisms

A.1.6 Mangroves

Mangrove forest, mangrove swamp, and mangal are general terms used to describe a variety of tropical inshore communities dominated by several species of trees or shrubs that have the ability to grow in saltwater. Mangroves make up the most conspicuous vegetation on Central American tropical coasts and are possibly of greatest ecological importance in coastal communities. Approximately 1,750 hectares of mangroves occur in the study area.

Mangroves collectively refer to trees and shrubs of 12 genera in 8 families and comprise all flowering terrestrial plants that have re-invaded the fringes of the sea. The leaves are tough and succulent and have internal water storage tissue and elevated salt concentrations. Mangrove trees have either shallow roots that spread widely or prop roots extending from the trunk or branches. These trees often send up extensions (called pneumatophores) from their shallow roots to the surface of the substrate. The pneumatophores allow the roots to receive oxygen in the otherwise anoxic mud in which the trees grow. Prop roots are often so numerous that they form an impenetrable tangle between the surface of the mud and the surface of the water, further decreasing water movement. The result is that the very finest particles settle out around the roots, creating ever- accumulating layers of sediment, ultimately leading to accretion of new coastal land and the zonation observed in mangrove forests (Nybakken, 1982). Newly created soils are fine-grained, low in oxygen, and have high salt and high organic content. The forested coast also acts as a protective barrier or wind break for adjacent agricultural land, impeding or minimizing the erosive action of winds, tides, and wave action.

All mangrove ecosystems are estuarine or open systems, subjected to periodic flooding by seawater and freshwater. They are able to grow only on shores that are sheltered from wave action, frequently along the lee sides of islands and on land masses behind protecting offshore coral reefs. Mangroves can establish themselves only where there is no significant wave action and where water motion is minimal. Slow water movement allows fine sediment particles to settle out and accumulate on the bottom, resulting in an accumulation of mud and the development of anoxic conditions. Tropical estuaries are locations where mangrove forests reach their greatest areal extent.

External factors believed to be the most important to mangrove function are tidal flushing, soil salinity, availability of freshwater and nutrients, and climate (Cintrón et al., 1978). High salinity tends to kill off mangroves. Full development of mangrove forests is thus found in areas of high rainfall or in areas where rivers furnish enough freshwater to preclude the development of hypersaline conditions. Mangroves are strongly influenced by tides, and trees develop only in intertidal areas and shallow water. The periodicity of forest inundation is determined by the tide and its vertical range. It is this periodicity that determines what kinds of mangrove associations develop and the different types of zonation observed (Nybakken, 1982; Rabinowitz, 1975). Wherever the tidal range is small, the intertidal zone

and consequently the mangroves are restricted. The most extensive forests are developed on shores that have a substantial vertical tidal range.

In general, mangroves have a net import of nutrients, freshwater, and sediments from terrestrial environments and a net outflow of organic matter and water to marine or estuarine waters. Mangroves also exchange salts with the sea, and organisms with estuarine and marine waters and with adjacent terrestrial ecosystems. Mangroves are therefore naturally stressed ecosystems. Natural stressors include high soil salinity which increases the cost of obtaining freshwater; tidal flows which remove stored potential energy in the form of litter and dissolved organics; overland runoff, storm tides, and waves which may cause excessive siltation and erosion; and periodic hurricane or storm winds which disrupt the structure of the system. All these factors contribute to strong environmental gradients that act as selective forces which, in turn, determine the distribution and density of species and individuals along the gradients. Vegetation zones of varying widths have evolved as a result of species tolerance and the breadth of the environmental gradients (Lugo, 1980).

While these properties are common to all mangrove stands, each stand may differ in complexity and diversity, the composition and stature of its vegetation, associated animal populations, and the rate at which ecological processes occur (Cintrón et al., 1985). Mangrove ecosystems may not support a diverse flora, but their low floristic richness does not imply low ecological value. Primary production in Caribbean mangrove ecosystems totals approximately 7.6 metric tons/hectare/year, two-thirds of which is leaves (Duke and Pinzón, 1991). One third of the coastal production in the Gulf of Panama is from mangroves. Major trophic pathways in tropical mangrove forests are illustrated in Figure A.16.

Each species dominates a specific sector of the forest and is differentiated by the shape of its leaves, fruit, and root system. In all, seven to eight species of mangroves occur in Panama (see Table A.31).

Since *Mora oleifera* ("brown mangrove") and *Montrichardia aborescens* ("cork mangrove") are associated with mangrove forests, some authors refer to these two species as mangroves. However, they are commonly encountered in freshwater habitats with no marine influence and cannot be considered true mangroves.

Mangrove species are normally vertically stratified within a mangrove forest. Other species are also found in lesser numbers at this level. Physiological differences of each species, frequency of tides, salinity, soil quality and permeability, rainfall, runoff volume from lakes and rivers, evaporation, and transpiration are the major factors determining where each species of mangrove occurs. *Rhizophora* normally predominates in the lower zone, with roots that are always submerged. The root system of this species induces sedimentation, raising the level of the land, facilitating the immigration of species from higher strata.

Avicennia, with the associated *Montrichardia* and *Mora*, occur in the next higher stratum, where their roots are covered only during high tides. These species also dominate the more brackish water communities which develop along a salinity gradient in the rivers and estuaries in eastern Panama (Golley, 1975). *Laguncularia* dominates the next stratum, with its roots covered only during the highest tides of the year.

The lianas *Phryganocidia phellosperma* and *Rhabdadenia biflora*, the woody vine *Dalbergia brownei*, and the Malvaceae *Hibiscus tiliaceaus* and *Pavonia spicata* are present in most of the large mangrove forests in rainy climates. *Pavonia rhizophorae* is found only in Panamanian mangroves. The shrubs *Clerodendrum pitterii* and *Tabebuia palustris* are also abundant in many mangrove forests of the region. The first is restricted to dry seasonal climates on elevated saline soils, while the latter occurs in rainy regions on elevated brackish soils, usually near stands of *Muellera frutescens*. In these areas of the isthmus, one can also find large, monospecific stands of *Mora oleifera*.

Mangrove forests have few, if any, herbaceous components, but on low-salinity soils *Hymmenocalis littoralis*, *H. pedalis*, and *Crinum erubescens* may be found, as well as large ferns (*Acrostichum* spp.). Approximately 40 additional herbaceous species grow in association with Pacific mangrove forests, but their occurrence is not entirely restricted to mangrove environments (Jiménez, 1992).

Mangrove forests can be divided into three distinct communities (Garrity and Levings, 1991):

Fringe (open coast) communities, which contain high salinity levels (oceanic). These communities occur mostly on a substrate of sand and mollusc shell fragments. Fringes usually have a strong horizontal gradient in topography, as well as a gradient in turbulence and tidal amplitude with no temperature stratification. Tidal and wave energy dissipates rapidly with distance from shore. Energy is thus delivered to the forest along a frontal area. This inland reduction of flushing results in a salinity gradient, with higher salinity prevailing inland.

Estuarine channel and lagoon communities, characterized by sheet flows over large areas of small topographic relief, are affected by tidal invasion, resulting in daily fluctuations in salinity and a vertical salinity gradient in the water column. These forests receive substantial freshwater and nutrients during the wet season; in the dry season, salinity increases as saltwater intrudes. In the Caribbean, these communities occur on a substrate of peat, coral rubble, and organic and inorganic mud.

Riverine communities develop along the edges of rivers as far as the inland toe of saline intrusion. They are subjected to variable salinity levels (which decrease to less than 15% during rainy seasons, when river flows increase). Water flows are

moderate to high, with high nutrient input, leading to the development of luxuriant stands. These communities grow on a substrate of fine-grained mud and peat.

Before 1960, Panamanian mangrove swamps and forests covered more than 300,00 hectares. The National Geographic Institute of Panama ("Tommy Guardia") estimated a coverage of 170,601 hectares of mangroves in Panama in 1988, more than any other Central American country (Anguizola et al., 1988; INRENARE, 1991). Ninety-seven percent of these are on the Pacific coast. In 1992, Jiménez estimated a total of 164,968 hectares of mangrove swamps and forests remaining in Panama. Loss of mangroves comes from a variety of human-related causes. Mangroves are cut for timber and to extract tannins from the plants for use in tanning leathers; mangroves are also cleared to create land used for agriculture (e.g., rice), mariculture, salt evaporation ponds, and cattle ranching (Table A.32).

Cubit et al. (1984) list 34 animal and plant species of commercial importance which are currently taken from the mangrove swamps on the coast of Colón.

Numerous marine organisms pass through their juvenile stages either in coastal fringe mangroves, estuaries or lagoons. Mangroves offer abundant food, guaranteeing rapid growth, and vital protection from predators. Organisms associated with the roots of mangrove trees can be categorized as:

1) those using roots as substrate,
2) species using roots as a refuge (i.e., fish),
3) species visiting roots searching for food (stomatopods, crabs, birds, fish),
4) algal species associated with the roots and nearby/adjoining mud (such as the green algae *Caulerpa verticillata*, *Halimeda opuntia*, and *Udotea flabellum*, and
5) species living among the algae associated with the roots (isopods, amphipods) (Batista, 1980).

The dominant fauna in this habitat include bivalve mollusks (oysters and mussels), crustaceans (crabs and shrimps), and small fishes. Crabs and shrimp excavate burrows in the soft substrate and are highly specialized feeders on detrital particles in the mud. The burrows function as breeding places, refuges from predators, and aids to feeding. They also allow oxygen to enter more deeply into the substrate.

An important flow of energy occurs between mangroves and adjacent marine communities, principally in the form of organic detritus from leaf decomposition. Yearly leaf production in a mangrove swamp can reach 1500 gm/m2/yr. The lignin and cellulose in the leaves, at first make them indigestible for most marine animals. Bacterial action and fungi in the water however, convert the coarse plant material into an abundant source of protein. A large amount of the mangrove litter-fall is also washed out into the open subtidal zone, where it degrades and becomes food for amphipods, mysids, caridean and penaeid shrimp,

and detritivorous fish such as anchovies, poeciliids, and mullet. In turn, these same organisms are food for other omnivorous and carnivorous fishes (croakers, snappers, snook, corvina, drums, and weakfish). A direct correlation exists between the amount of coastline bordered by mangroves and fishery production (D'Croz & Kwiecinski, 1980).

A series of blood-sucking insects breed and are common in mangroves. Among these are the mosquitos that breed inside crab burrows: *Deinocerites pseudes* and *D. spanius*, in the Pacific mangroves; together with *D. melanophylum* and *D. atlanticus* in the Caribbean mangroves. Other mosquitos include *Haemagogus chalcospilans*, which breeds in the cavities of trees. Additional important pests to man include *Aedes scapularis* and *A. taeniorhyncus*, together with the no-see-ums *Culicoides insignis* and *C. furens*.

Caribbean Mangroves

Approximately 1,680 hectares of mangrove forest occur between Point Toro (the western outlet of the Panama Canal into the Caribbean) and María Chiquita (19 km east of the Canal entrance) (Biological Inventory, 1992). This is considered the most extensive system of mangrove forest on the Atlantic coast of Panama (Cubit et al., 1984). Eighty to ninety percent of these mangrove communities are found within the study area. The largest mangrove swamps extend along an area west of the Caribbean Canal entrance, between Coco Solo and Punta Muerto. A large portion of the coral reefs near Colón have reached the water surface, forming extensive platforms invaded by the mangrove forest. Between the reefs and the mangrove forests, where the wind and the tide have formed sandy beaches, numerous coconut trees occur.

To the east of Colón, the mangrove forests occur in estuarine-fringe communities behind coral-reef lagoons, toward the mouth of estuaries along major tidal channels and in more riverine channels. These forests are dominated by the short-growing form of the red mangrove *Rhizophora mangle* toward the outer edge of the fringe and the periphery of riverine communities, where greater energy prevails. The less abundant but taller *Laguncularia racemosa* becomes dominant in less flushed parts of the fringe forest and in the inner riverine forest, where natural energies are diluted. *Avicennia germinans* (also known as *A. nitida*) also occurs here, but is less common in all habitats. *Laguncularia racemosa* and *A. germinans* are usually dominant in lagoon communities, although where sheet flows converge into channels, the banks are lined with *Rhizophora*. *Pelliciera rhizophorae* is uncommon and only in riverine habitats. An additional species of palm tree (*Nypa fruticans*) associated only with mangrove and previously unknown in the neotropics, was also recently discovered in this area.

In general, lagoon mangrove communities support more species than riverine communities which, in turn, support more species than fringe communities. Fringe forests develop in more constant conditions of salinity and nutrients and are exposed to higher energy regimes,

which ultimately selects for dominance of one or a few species. In lagoon and riverine forests, nutrients and salinity oscillate widely and the energy of water flows is lower. The relatively short hydroperiod of lagoon communities in combination with a more favorable nutrient balance may account for a higher species richness in these forests. Tree densities are highest in fringe communities, followed by riverine and lagoon forests, but riverine communities generally contain taller and larger diameter trees than the other two communities (Cintrón et al., 1985).

Mangrove Root Communities

The intertidal habitats resulting from the structure of *Rhizophora mangle* roots form a topographically heterogeneous region. The tree roots in each of the three major mangrove zones (open coast, lagoon/channel, and riverine) support a distinct epibiotic community. Although patchy in distribution, mangrove marine assemblages near Punta Galeta are species-rich, with the greatest diversity evident in the open-coast community. The only in-depth information for mangrove marine habitats comes from studies of post-oil spill successional communities.

Fringe/open coast community

One habitat is formed by the aerial prop roots which support a typical association of algae: *Bostrychia binderi*, *Catenella repens*, *Caloglossa leprieurii* and *Murrayella periclados*. These grow as dense masses with each plant attached to others by holdfasts. This *Bostrychia-Catenella* association of diverse foliose and crustose algae dominates root surfaces (42 to 62% cover). Sessile filter-feeding invertebrates are secondary space-occupiers (13 to 22%). Several species of amphipods and some xanthid and oxypodid crabs are usually found associated with the epiphytic algae of the prop roots. There are some epizoic barnacles and a few polychaete worms which build tubes in cracks and galleries.

A more developed succesional community can have 170 species of fouling and encrusting marine organisms, 75% of which are fauna and 25% algae (Table A.33; Batista, 1980). Again, the red alga *Bostrychia* sp. can be the most abundant species, representing 35% of the algal biomass. A sponge ("species A") makes up 45% of the mean faunal weight and the polychaete *Spirorbis* sp. represents 54% of the faunal count. A moderate amount of bare space is available, but no single species dominates space (Duke et al., in Keller and Jackson, 1991).

When the mangrove root fouling community is divided into 10-cm vertical sections, a zonation of organisms is apparent (Table A.34). The level 10 to 20 cm below mean low water (MLW) has the greatest diversity of species, both flora and fauna. The greatest algal density by weight is at +10-20 cm MLW and the greatest density

by weight for fauna at -10-20 cm MLW. The highest faunal density (counts) occurred at +0-10 cm MLW. In this mangrove root assemblage, invertebrate species are more diverse, but algae possess higher biomass values (Batista, 1980).

Recruitment onto roots is initiated by diatoms and followed by foliose algae (including mixed algal turf). The mixed algal turf consists of <3 mm-high turf composed of fine filaments of red, brown and green algal species. Other genera of algae that are regularly found include *Dictyota*, *Galaxaura*, *Acanthophora*, *Ceramium*, *Derbesia*, *Jania* and *Polysiphonia* (Table A.35). Subsequent colonizers are sponges, tunicates, hydroids, mixed arborescent bryozoans, and crustose coralline algae.

Another mangrove habitat is the ground between the prop roots which consists of fine sand, mud, and/or coral fragments (fragments washed in from nearby reef) and is usually covered by a dense mat of algae (Table A.36). Large numbers of mollusks such as *Batillaria minima* and hermit crabs of the genus *Clibanarius* move around on this algal mat. In the sand or mud underneath there are a few polychaetes, some sipunculans of the genus *Golfingia*, and some crustaceans.

Channels and lagoon community

Channels and lagoons have two major space-occupiers in the edible oyster *Crassostrea rhizophorae* (10 to 54%) and the barnacle *Balanus improvisus*. This oyster is also used as an indicator organism for petroleum contamination in coastal waters (Cubit et al., 1991). Four other bivalves also relatively common are *Brachidontes ?exustus*, *Crassostrea* sp. 2, *Isognomon ?alatus*, and *Mytilopsis sallei*.

Riverine/drainage stream community

Roots in drainage streams (riverine habitat) are mainly occupied by the mussel *Mytilopsis sallei* (59 to 64% cover). Barnacles, algae, and diatoms are also abundant.

There is limited overlap in species occurrence among the three habitats. The exceptions are mixed species groups (e.g., diatoms, mixed algal turfs) and bare space. Where taxa did occur in more than one habitat, their abundance on roots tends to be quite different (e.g., *Balanus improvisus* at all sites, *Crassostrea rhizophorae* in streams and channels).

Fisheries

The abundant refugia among the dense tangle of mangrove prop roots are the natural nurseries and principal habitats for many of the commercially important

species of fish (Table A.37), crustaceans, and mollusks. Mangroves are one of the principal areas for fishing on the Caribbean coast in Panama (Cubit et al., 1984).

In shallow water at the edge of the mangroves, fishermen obtain mullet (*Mugil curema*), snapper (*Lutjanus* spp.), mojarras (*Gerres cinerus*), snook (*Centropomus robalito*), shad (*Megalops atlanticus*), sharks, anchovies (*Anchoa* sp.), and sardines (*Atherinomorus stipes*). The small fish such as mullet, anchovies, sardines and others are trapped using fishnets that the fishermen make. These fish are used directly as food or as bait for fishing in the open sea. Almost all the fish and crustacean bait used for fishing the open sea are obtained in the mangroves and nearby estuaries. The pink shrimp (*Penaeus duorarum*) that inhabits the small bays and canals of the mangroves, is also taken with fishnets and used directly as food or bait.

In the marginal areas of Colón, the native fisherman has few jobs or work opportunities within his reach; he catches fish and shellfish to feed his family and sells the rest. For these people the mangrove forest is a vital resource: when work becomes scarce, subsistence fishing still provides food and some monetary income (Cubit et al., 1984).

Tropical estuaries are typically bordered by mangroves and are also habitats frequented by fish for purposes of feeding, migration, and refuge. In the estuaries of Rio Guanche and Rio Piedra, the most abundant fish species are juveniles of *Ulaema lefroyi* and the mullet *Mugil trichodon*. Only 26 species were collected by D'Croz and Averza (1978) who attributed the low diversity to the instability of the environment (periods of flooding).

Pacific Mangroves

These are among the ecosystems under the greatest pressure in Panama. Extensive deforestation has occurred in these areas for agriculture, cattle ranching, urban development, and mariculture. The largest extensions of mangrove swamps in the Gulf of Panama are in Parita, Chame, Tocumen, Bayano and Darién Bays. In 1979, mangrove swamps bordered most of the coast between Matías Hernández and Tocumen rivers, just east of Panama city. Today, most of these forests have been cut; elsewhere in the study area, about 65 hectares of mangroves are found in the Chame sector, in small areas in Veracruz and Venado (west of the Pacific Canal entrance).

The Juan Díaz mangroves, along the shores of Panama City, exhibit a characteristic pattern of zonation. *Rhizophora harrisonni* (red mangrove) dominates the zone of permanent contact with the sea (fringe community). These trees are among the tallest mangroves in the world (30-40 m.). Pure stands of this species develop along the open coast and rivers. Where tides fluctuate daily, a dense network of prop roots rises two to three meters or more

above the soil surface. Organic debris is continually trapped in this network of roots and is added to the organically rich soil. This system is almost monospecific, dominated by tall, slender, widely spaced trees and is practically devoid of understory vegetation. The up-curving branching pattern of the trees and their wide spacing create a relatively open canopy with only 50% of the surface covered by tree leaves and branches. Although vines and epiphytes are rare, some are present in the upper canopy. Tree bark usually supports a thin layer of nonvascular plants, and dense mats of algae cover the prop roots below the high-tide water line.

Behind the red mangrove, and in the supralittoral zone, is a band of *Avicennia germinans* (black mangrove) followed by *Laguncularia racemosa* (white mangrove). These two species also occur in some areas as co-dominants. *Pelliciera rhizophora*, locally known as "pie de santo" (saint's foot), generally dominates along the edges of lagoons.

Fisheries

It is generally recognized that there is a direct correlation between the quantity of coasts bordered by mangroves and fishery production. Mangrove forests have an integral role in the Gulf of Panama fisheries as sites for primary production and juvenile nurseries for key commercial shrimp and fish species.

The Panamanian shrimp fishery is the most extensive and productive south of Mexican coasts. Eight shrimp species of commercial importance are found among Gulf of Panama mangroves. The most abundant are "white shrimp" (*Penaeus occidentalis*, *P. stylirostris*, and *P. vannamei*). These species arrive at the mangroves as postlarvae and remain in the mangroves and nearby estuaries for a period of four to five months, after which they migrate to greater depths. Spawning of these shrimp occurs throughout the year, so that the presence of juveniles in the mangroves and estuaries is year-round. Other shrimp species observed in mangroves include the brown shrimp (*P. californiensis*), red shrimp (*P. brevirostris*), and carabalí shrimp (*Trachypenaeus byrdi* and *T. faoea*). Two species of camaroncillo or tití shrimp (*Xiphopenaeus riveti* and *Protrachypene precipus*) are found associated with marine waters in front of the mangrove forests. The other commercial species, the Fidel shrimp (*Solenocera* sp.), is completely dissociated from mangroves and estuaries and comprises <6% of the total catch of Panamanian shrimp. Ninety four percent of the shrimp yield/harvest depends on the shelter and feeding capacity of estuaries and mangroves.

There are no less than 30 fish species that utilize the Juan Díaz mangroves, many of commercial interest. The white mullet (*Mugil curema*) is the most abundant species in the mangroves, mostly during August and September, even though it is

found year-round. In the western region of the Gulf of Panama, the greatest abundance of mullet occurs between January and March.

The mojarra (*Eucinostomus californiensis*), in its juvenile forms, is another common fish in estuaries and mangrove forests of Juan Díaz. Four species of snook are also associated with the mangroves: *Centropomus armatus* (armed snook, robalo corcovado) is the most abundant, *C. nigrescens* (black snook), *C. robalito* (yellowfin snook), and *C. unionensis* (union snook). Also, there are juvenile stages of two species of snapper: *Lutjanus aratus* (mullet snapper) and *L. argentiventris* (amarillo snapper). The latter is found in mangroves of San Carlos (west of Juan Díaz), but is probably present in Juan Díaz, too.

Other juvenile fish observed associated with mangroves are the golden croaker *Micropogon altipinnis*, the Panama anchovy *Anchoa panamensis*, the Jordan sea catfish *Galeichthys jordani*, sardines (Clupeidae), and flatfish (Bothidae). Juveniles of the Pacific anchoveta *Cetengraulis mysticetus* (the species used in manufacture of fish meal) are pelagic and are found in deeper waters in January to March. In April, when they are considered adults, they are found near the coast, principally over muddy bottoms and depths less than 10 m. According to the Fishery Statistics of the Ministry of Commerce and Industries, the fishing area of the anchoveta coincides with Gulf of Panama coasts that have mostly estuaries and mangroves; the largest catches are in those areas where there are found large estuary and mangrove systems like those of the Bay of Chame, the mouth of the Bayano River, and the mouth of the Tuira River.

The nutritional contribution of estuaries and mangroves could be of importance in the feeding of these fish during their adult life. Bayliff (1963) has indicated that adults remove mud from the bottom and ingest it to obtain detritus and small benthic organisms. This adult diet indicates implies an important relationship between the contribution of detritus from the coastal zone mangroves and the abundance of anchovy. Another important aspect is that the spawning of anchoveta occurs in great measure directly in front of the coasts of mangroves of Juan Díaz (Table A.4; Smayda, 1966).

Not less than 60% of the shrimp fishery is from the eastern region of the Gulf of Panama which has approximately 600 km of coastline boardered by mangroves. Every kilometer of mangrove coastline in this region should produce about $26,350 annually. For Juan Díaz mangroves, a conservative estimate of shrimp production is about $316,200 annually; the anchoveta fishery yields an annual total of $781,972. The artesanal fishery of the Juan Díaz mangroves is valued at $37, 378 (or, $3,114/km.). The total fishery value of the Juan Díaz mangroves comes to $1,135,550, or $94,629/km of mangrove coastline (D'Croz & Kwiecinski, 1979).

Terrestrial Fauna

Mangrove communities are unique in that terrestrial organisms can occupy the upper levels, while marine and/or freshwater aquatic animals occupy the lower levels of this habitat.

Insects and other arthropods dominate the arboreal habitat of mangrove swamps. Among the most conspicuous groups are gnats (Ceratopogonidae) and mosquitos (Culicidae). These flies and their larvae are important food resources for a diversity of other fauna including shorebirds, flycatchers, and bats. Among the mosquitos is the highly specialized genus *Deinocertires*, whose larvae develop in the burrows of terrestrial crabs. Mosquitos found in mangroves are important as vectors of human illnesses (see Section 5.2.1.4). Other common mangrove dwellers include ants and beetles (scarabs - Scarabaeidae, and weevils - Curculionidae, and borers - Buprestidae).

Several species of *Pseudomyrmex* ants are commonly associated with *Rhizophora*, while *Azteca* ant species are associated with *Pelliciera* mangroves. Ants of many other species are found on both of these mangrove species, while *Avicennia* and *Laguncularia* harbor fewer colonies. Other prominent mangrove ants include species of *Crematogaster*, *Camponotus*, *Paracryptocerus*, *Tapinoma*, *Xenomyrmex*, and *Monomorium*. Almost all colonies are found in hollow twigs, with larger species restricted to the larger of such twigs.

More woodboring and herbivorous arthropods are found on *Rhizophora* than on the other mangroves, in spite of *Rhizophora*'s high tannin content. Leaves are eaten primarily by macrolepidopteran caterpillars, fruits are bored by the host-specific scolytid beetle *Poecilips rhizophorae*, shoots are bored by moth caterpillars, roots are bored by both *Poecilips* and caterpillars (including branching, as isopods do below the water), and twigs are bored by anobiid, buprestid, and cerambycid beetle larvae. Myriad other insects (thrips, crickets, termites, bugs) abound and there are also abundant spiders, millipedes, centipedes, mites, scorpions, and pseudoscorpions. Small *Rhizophora* islands have subsets of the species pool found in larger mangrove swamps; the smaller or more isolated the island, the fewer the species. As there is no eulittoral ground in a mangrove swamp, all resident species must lead some form of arboreal life (Janzen, 1983).

A recent study of the vertical and horizontal distribution of vertebrate fauna in mangroves provides a detailed account of the mangrove fauna (Farrugia and Ponce, 1988). These authors found 117 vertebrate species (46 families) associated with the Juan Díaz mangroves on the eastern edge of Panama city (Table A.38). Thirty percent of all species observed used the prop roots, 50% used mangrove trunks, 54% branches, 45% leaves, and 18% used the canopy.

Birds represented the richest faunal element - about 100 species. Mangrove swamps typically contain far fewer species of birds than do other tropical forests, and with few

species that are ecologically limited to mangroves. Notwithstanding, mangroves have unique terrestrial elements in addition to their well-documented aquatic wealth. Seabirds, herons, and egrets often roost here, at times in such densities that the guano produced increases the mangroves' growth rates, in spite of daily tidal flushing (Janzen, 1983). While not yet recorded in our area, elsewhere mangroves provide nest sites for herons, egrets, and other colonially nesting wading birds. Characteristic 'mangrove' birds include northern scrub-flycatchers (*Sublegatus arenarum*), straight-billed woodcreepers (*Xiphorhynchus picus*), mangrove warbler (*Dendroica petechia erithachorides*), and two rare species, the spot-breasted woodpecker (*Colaptes punctigula*) and rufous-necked wood-rail (*Aramides axillaris*). Several North American migrants are fairly common in the mangroves, including prothonotary warbler (*Protonotaria citrea*) and American Redstart (*Setophaga ruticilla*).

Diversity of other vertebrates is low in mangrove forests. Amphibians are notably absent; having skin which is highly water-permeable, they cannot tolerate the saline conditions. None of the sampling points were in mangroves, but species to be expected include 13 species from 9 families (Table A.49); most of these species occur on tierra firme. The more common species include black iguanas (*Ctenosaura similis*), basilisks (*Basiliscus basilicus*), a gecko (*Gonatodes albogularis*) and anoles (*Anolis limifrons*). Also, hawksbill sea turtles (*Eretmochelys imbricata*) have been recorded near mangroves on the Atlantic entrance to the Canal, as have been leatherback turtles (*Dermochelys coriacea*). Mammals are limited to a few, notably crab-eating raccoons (*Procyon cancrivorus*) and several bats, among them the fishing bats (*Noctilio leporinus, N. albiventris*).

A.1.7 Lakes and Rivers

In Central America the dominant lacustrine environments are not in discrete lake basins, but are rather those poorly defined lakes which are part of rivers. The Gatun Lake/Chagres River basin illustrates a dominant form of lacustrine water body which typifies the lowlands of tropical America (Zaret, 1984).

Lying in an area of relatively low topography, the Chagres River flows from headwaters in the continental divide, 160 m above sea level, meandering downward and occupying the basin before it enters the Caribbean west of the Gatun Locks. By controlling the release of Chagres River water from Madden Dam, the maximum yearly fluctuation in Gatun Lake is limited to 2 m. In the areas below Madden Dam to Gamboa, where the river enters Gatun Lake, one can still witness the dramatic seasonal changes, the widening of the river during the rainy season, the increase in concentrations of suspended and dissolved substances, and the rafts of floating water hyacinth (*Eichhornia crassipes*) and other vegetation which harbor a diverse fauna beneath their roots.

The degree of constancy of air temperatures is reflected in lake water-temperature values (approximately 27 to 30° C). The rainfall pattern, though, is anything but constant and

includes a dry season from mid-December through April and a wet season beginning in May and lasting through November. The heaviest precipitation begins in October and lasts into the first half of December.

There is a rapid renewal rate of approximately 1.0 year (Gliwicz, 1976a) due to the locks at each end of the Canal. A strong seasonal component is produced by rains and the sediment carried into the basin. Even in areas of old forest (over 200 years old) such as the forest preserve of the Smithsonian Tropical Research Institute on Barro Colorado Island, a heavy rain fills the small, clear forest streams with rich tan sediment, a result of the easily eroded tropical latosols. In most respects, Gatun Lake can be considered as a buffered Chagres River.

The maximum lake elevation is 26 m above sea level. The surface area is 431 km^2, with a maximum for the entire drainage basin of 2313 km^2. The maximum depth of the lake is 29 m and the mean depth is 12.7 m. This is a lake with a long, convoluted, intricate shoreline (1750 km), and whose maximum volume is 5.48 km^3. There are two important influents other than the major Chagres River, namely the Trinidad River and the Ciri River which are located in the southwest section called the Trinidad Arm.

Although the maximum temperatures reached in tropical lakes are high, the maximum density differences across the thermocline are quite low. For tropical lakes near the Equator, the effect of the Coriolis force is significantly reduced. This results in the increased mixing potential of a given tropical wind. These two effects oppose the formation of stable thermoclines in the tropics. When evening cooling results in some surficial heat loss with destabilizing convection for the daily thermocline, any winds will rapidly mix the water column, preventing the establishment of a stable thermocline. Tropical lakes such as Gatun Lake are characterized by an almost daily wind, often of considerable velocities. As a result, in Gatun Lake there is almost never any detectable long-lasting thermocline. Instead, multiple-layered and temporary thermoclines are found, accompanied by destratification during the year.

Significant differences in dissolved oxygen between surface and bottom depths (29 m maximum) never last longer than three weeks (Gliwicz, 1976b). In shallower lake areas with a maximum depth of 16 m, temperature differences of 0.1° C or less are common. Although winds are the most important source of mixing force, rapid mixing can occur from rainstorms.

The combination of regular daily mixing plus the rapid turnover of the lake militate against significant vertical or seasonal differences in water chemistry (see 5.1.3). In shallow lakes such as Gatun Lake, regenerated nutrients are constantly recycled, giving a more even distribution throughout the year. It is true that during the wet season sediment is carried

into the Lake from stream run-off, but even great amounts of eroded materials from these nutrient-poor tropical soils provide only low levels of nutrient addition.

The lower limit of the photosynthetic zone is between 13 and 15 m; there is a uniform vertical distribution of chlorophyll *a* within this part of the water column. This results in a depth profile of photosynthesis per unit volume identical to the depth profiles of photosynthetic rate per unit of algal population. The lower region of the euphotic zone is not due to ambient light intensity, but rather to the value of vertical light extinction. The maximum value of photosynthesis is 1.08 mg O_2/m^2 /hr. (Gliwicz, 1976a).

Since there is no correlation between light intensity and maximum photosynthesis in Gatun Lake, light is not thought to limit primary production. Instead, total standing crop, percentage of different dominant algal size classes, and the effects of grazers appear to be the prime determinants of maximum photosynthesis. This is true throughout the year since neither total solar illumination nor temperature varies greatly (Gliwicz, 1976a).

Water clarity, from Secchi disk values, has a maximum of 7 m in mid-summer and a minimum of 3.25 m during the end of the wet season and the beginning of the dry season. There are several sources of the seasonal variation in the depth of light penetration. First, in the dry season there is an increase in the colonial blue-green *Microcystis*, which affects values for light scattering. Second, the increased turbulence as a result of daily and constant mixing during the heavy winds of the dry season may also result in decreased light penetration. Finally, as the Chagres River is carrying appreciable quantities of suspended sediments, these also have at least some effect which continues into January and the dry season.

Aquatic macrophytes

All of the aquatic macrophytes in Table A.40 were probably present in the region historically, with the important exception of *Hydrilla verticillata*, an exotic from India that probably arrived from someone's fish aquarium. This plant can now be considered one of the dominating lake macrophytes; it encircles the lake from within 1 m of the shoreline out to a depth of 5 m or more. The recent stabilization of Gatun Lake level from the construction of Madden Dam may have resulted in a more favorable habitat for *Hydrilla*. This is supported by the fact that in Lake Alajuela, where there is a lake level fluctuation of as much as 15 m per year, *Hydrilla* is absent. It is also less dominant in the Chagres River compared to the Lake. Fauna associated with the dense stands of *Hydrilla verticillata* include gastropods (*Melanoides* sp. and Planorbidae) and the monoplacophorans (Ancylidae) (Lamela & Hamilton, 1989).

The other major macrophyte is the water hyacinth, *Eichhornia crassipes*, locally known for clogging waterways. *Pistia stratiotes* (water lettuce), *Salvinia* sp., *Ludwigia* sp., Ciperaceae,

and *Typha* sp. are also common aquatic macrophytes. At depths from 5 m to about 8 m, the bottom of Lake Gatun is commonly covered by one of the *Chara* species (*C. haitensis*, *C. hydropitys*, *C. kenoyeri*, and *C. martiana*). Also, species of *Cabomba*, *Ceratophyllum*, and *Utricularia* are present (Pasco, 1975; Zaret, 1984; UNIPAN-ANCON, 1992).

Phytoplankton

The algal population from the open-water areas of Gatun Lake consists of nearly 180 species, contained in four groups: the Chlorophyta (green algae including desmids), Bacillariophyta (including diatoms), Cyanophyta (blue-green algae) and Pyrrophyta (including dinoflagellates). Numerically, the most important groups of phytoplankton are those in the small-size category, 1 to 10 μm in size, which constitute an average of 92% of the total algal cells throughout the year (Weers & Zaret, 1975). Expressed as chlorophyll *a*, the <50 μm fraction of the nannophytoplankton is always 40% or more of the total biomass. Cell densities indicate a range of 3.1 to 11.2 x 10^6 cells per liter, with a seasonal maximum during January and a minimum during July. Of the four major algal groups, the numerical dominants are the small blue-green algae (<10 μm), but the majority of the biomass is concentrated in the net phytoplankton species ($\geq$50 μm). Two trends dominate the size distribution of phytoplankton cells in Gatun Lake: (1) the majority of biomass is found in the net phytoplankton, and (2) as much as 70% of the smaller-sized, apparently edible cells, pass through the gut of the zooplankton without being digested (Weers & Zaret, 1975). Table A.41 presents the most common phytoplankton genera in Gatun Lake.

Gatun Lake does not have phytoplankton blooms characteristic of temperate zone lakes. Algal densities normally fluctuate within one order of magnitude, and most species are present year-round (Lewis, 1973). In January, at the beginning of the dry season, *Microcystis* may appear in unusually large densities, but this surge is not comparable to those found in temperate zone lakes.

Zooplankton

Table A.42 presents a list of the zooplankton in Gatun Lake. *Ceriodaphnia lacustris* has appeared only since the introduction of the cichlid *Cichla ocellaris* in 1967, which has had major effects on the Gatun Lake community (see later). Also of note are the two forms of the cladoceran *Ceriodaphnia cornuta*, a polymorphism which is known to be balanced by predation by the planktivorous atherinid fish *Melaniris chagresi* (Zaret, 1969, 1972). Total adult crustacean density is low, normally around 10/liter; inclusion of copepodids and nauplii would double this value. There is a seasonal trend in zooplankton abundance with lowest densities during the late dry season, a maximum during the late summer period, and a peak in March. At the beginning of the year, other seasonal members of the plankton include larval forms of the many freshwater prawns (Paleomonidae) which are found in the Lake.

The numerical dominant of the open-water zooplankton is the copepod *Diaptomus gatunensis* which, in terms of numbers and total biomass (including nauplii), represents more than 90% of the total within the lake. This herbivore is rarely fed upon by *Melaniris*, due to the vertical migration patterns of *Diaptomus* which make it unavailable to the fish (Zaret & Suffern, 1976). Predatory crustaceans are absent in the Lake; even the cyclopoid *Eucyclops agilis* is an herbivorous species.

The rotifers of Gatun Lake (Table A.43) include about 37 open-water species. These consist of a number of predatory forms such as *Synchaeta*, *Trichocerca*, and especially *Asplanchna*, of which there are at least two species. The seasonal trend in abundance of rotifers shows a nadir during the months when the crustacean fraction of the zooplankton is dominant, and an increase during the late dry season. The most common forms are *Collotheca*, *Conochiloides*, *Conochilus*, *Keratella cochlearis*, *K. americana* and *Ptygura*.

A lack of distinct blooms is also characteristic for zooplankton populations. The densities of total Gatun Lake zooplankton over a 12-month period range from 20 to 200/liter.

Benthos

The sediments of the lake bottom are moderately homogeneous, consisting of combinations of silt, fine sand, and clay, with varying quantities of leaf litter. Benthic populations are principally represented by snails, clams, oligochaete worms, crabs, and prawns. Mollusk bivalves (*Corbicula* sp., *Sphaerium stratium*, *Musulium* sp.) are frequently the most abundant, followed by gastropods (*Melanoides tuberculata*, *Pyroophorus coronatus*, *Potamopyrgus* sp., *Lyogirus* sp., *Gyraulus* sp.). Oligochaetes (*Branchiura sowerbyi*, Naididae) are ubiquitous and leeches (Hirudinea) are found in large numbers in the south central portion of the Lake (Zaret, 1975; UNIPAN-ANCON, 1992).

A total of twelve species of decapod crustaceans, including the freshwater prawns *Atya innocous*, *A. scabra*, *Macrobrachium carcinum*, *M. crenulatum*, *M. heterochirum*, *Micratya poeyi*, *Palaemon pandaliformis*, *Potimirim glabra* and *P. mexicana*, and three crabs, *Potamocarcinus richmondi*, *Pseudothelphusa* sp. and *Sesarma americanum* are listed for the Lake region (Abele, 1975). The aquatic larval forms of several of these, especially *Atya* and *Macrobrachium*, are seasonally abundant in the waters of Lake Gatun.

The dominant forms of mollusks within the entire lake and adjoining streams include bivalves and several gastropods: *Mytilopsis leucophaetus*, *Melanoides tuberculata*, *Neritina meleagris*, *N. piratica*, *N. reclivata*, and *Pomacea* sp. (Greenberg, 1975).

Fishes

Table A.43 contains fish species present in Gatun Lake, the canal locks, rivers, and drainage streams. Although most of these species are still present in the Chagres River-Gatun Lake system, a great number of them are no longer present in the Lake proper, owing to the introduction of 60 fingerlings in 1967 of the predatory South American cichlid *Cichla ocellaris*. This cichlid spread quickly throughout the Lake and caused the local extermination of most of the formerly native fishes, becoming the key dominant species responsible for the restructuring of the Lake Gatun community (Zaret, 1972.). Only in the Chagres River, where *Cichla* was initially introduced, is the original native fish fauna intact.

Common diurnal species encountered in the Lake are *Megalops atlanticus*, *Gobiomorus dormitor*, *Melaniris chagresi*, *Poecilia mexicana*, *Cichlosoma maculicauda*, *Cichla ocellaris*, and *Astyanax ruberrimus*. The Chinese grass carp, *Ctenopharyngodon*, has been introduced to alleviate the problems associated with dense stands of the exotic macrophyte, *Hydrilla verticillata*.

In Gatun Lake fish feed intensively on zooplankton for twelve months of the year. The most abundant planktivore was formerly the atherinid *Melaniris chagresi*, a highly efficient predator of zooplankton. The small size distribution of zooplankters is a consequence of intense natural selection occurring between fish and prey throughout the year.

Subsistence and sport fisheries are centered on the peacock bass (*Cichla ocellaris*) and sábalo (*Brycon* spp.), with other fish species taken incidentally. There is also some local harvest of freshwater prawns (*Macrobrachium* spp.) for personal consumption. Numerous bony fish species that are marine in origin are found in the Canal (Table A.43). Sharks have also been reported in Canal waters, having passed through the Pedro Miguel Locks.

Lake and River Mammals

Mammals found in wetland areas are discussed under the wetland section (5.2.1.8). In the study area only two mammals depend on river and lake systems: the manatee (*Trichechus manatus*) and the tropical otter (*Lutra longicaudis*). The manatee was re-introduced into Lake Gatun some years ago and a small population still survives, presumably from the initial introduction. Multiple sightings by reliable observers, including Dr. N. Smythe of the Smithsonian Tropical Research Institute, confirm the continued presence of manatees in the lake, in spite of popular beliefs to the contrary (manatees are very inconspicuous).

Manatees are one of the rarest and most endangered species in the study area and are protected by Panamanian and international laws (CITES); hunting is the greatest threat to the species, with injury by boats a lesser problem. The tropical otter occurs in small numbers in Lake Gatun and in rivers and streams throughout the study area. An infrequent

visitor is the Gulf of Panama spotted dolphin (*Stenella graffmani*), which has been seen passing through Miraflores and Pedro Miguel Locks and into Lake Gatun (N. Smythe, pers. comm.).

Five other mammals are closely associated with aquatic habitats. Two fishing bats (*Noctilio albiventris, N. leporinis*) feed by scooping up fish and invertebrates from the surface of open waters. The water opossum (*Chironectes minimus*) captures fish and invertebrates at the water's edge, especially along clear, flowing streams; water rats (*Nectomys alfari*) are adapted for swimming, and are almost always found near water. Capybaras (*Hydrochaeris*) are also closely associated with water, living near water and feeding on aquatic vegetation and littoral grasses; in spite of hunting, the species persists widely in the study area.

Lake and River Avifauna

Certain species of birds are strictly associated with aquatic habitats, rarely venturing onto land, while others use both habitats, or, more commonly, exist primarily at the water-land ecotone. For the purpose of this discussion, species are included which occur primarily at land-river and/or land-lake edges, such as herons, egrets and rails. Excluded are many species typical of generic forest edge habitats, and which occur along river and lake margins simply because forest edge habitats are present there.

Table A.44 lists 42 bird species from 18 families which were judged to depend on the aquatic element. Important families include the waders - herons and egrets (Ardeidae, nine species) and kingfishers (five species). Most herons feed by stalking aquatic fish and larger invertebrates in shallow water; kingfishers feed by diving into water from waterside perches to capture small fish. Populations of three kingfishers (*Ceryle torquata, Chloroceryle americana, C. amazona*) have declined dramatically around Lake Gatun, likely due to the disappearance of prey species resulting from the introduction of peacock bass in 1967; other piscivorous species may also have been affected, but there are no supporting data. Ducks are relatively uncommon in the study area, with the exception of blue-winged teal (*Anas discors*) as a winter visitor; a total of seven duck species occur on lakes and rivers of the area. An interesting effect of the canal's presence is the increasing use of it by brown pelicans (*Pelicanus occidentalis*). Usually limited to ocean waters, these pelicans fish in Lake Gatun and around the locks, and in recent years a small nesting colony has been observed on the west margin of Miraflores Lake (N. Smythe, pers. comm.).

Reptiles and Amphibians

Many of the reptiles and amphibians discussed for freshwater marshes (Section 5.2.1.8) also occur in lakes, rivers, and streams. Many frogs (families Centrolenidae, Bufonidae, Ranidae, and most Hylidae) depend on free-standing water for reproduction and larval development. Among reptiles, four turtles are primarily aquatic (*Rhinoclemmys funerea, Chelydra serpentina, Kinosternon leucostomum, Trachemys scripta*), as are the spectacled caiman (*Caiman crocodilus*) and american crocodile (*Crocodylus acutus*). The caiman inhabits swamps and slow rivers and streams, while the crocodile is found in coastal waters and in lakes and larger rivers..

As discussed elsewhere (Section 5.2.1.8), crocodilians populations have recently increased in some areas, due to decreased demand for their skins. Basilisk lizards (*Basiliscus basiliscus*) and green iguanas (*Iguana iguana*) also occur primarily in freshwater littoral areas where they feed on vegetation (both species) and vertebrates and crustaceans (basilisks). Basilisks are often very common and are remarkable in their ability to run across water; iguanas can be quite common, but hunting for eggs and meat has reduced populations in most areas. Rand and Myer (1990) report a gathering of 200 female iguanas to nest on an islet off Barro Colorado Island.

A.1.8 Freshwater Wetlands

Freshwater wetlands represent the transition from terrestrial to aquatic habitats, and occur most extensively in the study area where streams enter Lake Gatun, and around the shore of Lake Gatun. They are normally characterized by hydromorphic soils, but a variety of water regimes are encountered. Most of the wetland areas experience periodic inundation, but free-draining levees and permanently wet marshes also occur. Soil fertility is variable, depending on local sediment characteristics. Although complex vegetation patterns may exist within wetlands, individual wetland formations frequently display similar physiognomy and composition over large areas. Periodically flooded, herbaceous wetlands are scattered along freshwater streams and lakes in the study area.

Herbaceous wetlands occur along the edges of freshwater lakes and waterways and in places where underground waters, springs, rivers, and floodwaters produce frequent enough inundation to maintain a more or less permanent shallow water cover (Table 45). Marshes around lake margins can extend from littoral to deeper limnetic zones, where insufficient light penetrates to allow vegetative growth. Wave action and seasonal depth variation influence the type of marsh vegetation in a given area.

Marshes can function to control floodwaters, protect against storms, and affect water quality by regulating the quantity of nutrients and sediments entering a lake. Many wetlands also serve as sources of fresh water for human consumption, animal breeding, and agricultural

and industrial uses. Table A.45 lists a number of the functions and values of wetlands. Not all characteristics are present in each wetland, nor do all functions occur in the same manner in each wetland.

Marsh vegetation can stabilize a shoreline by reducing the energy in waves and currents that cause erosion. At the same time, plant roots trap sediments and anchor them to the substrate. The accumulation of too much sediment can alter a wetland's functions, however, especially when toxic substances that adhere to suspended sediments are retained along with them. The concentration and retention of sediments in wetland surface waters can maintain higher water quality in rivers and lakes, lessening the need for removal of sediments from weirs, dikes, locks, and other similar structures.

Wetland vegetation can also absorb nutrients, principally nitrogen and phosphorus that accumulates in the subsurface. This improves water quality and helps to prevent eutrophication. These nutrients in turn, augment wetland production. Wetlands can function as nutrient sources when they export these materials into adjacent waters. A common function of wetlands during the growth season is the accumulation of nutrients when waters are slow-moving. Later, when waters are faster moving, these nutrients serve as food sources to support the production of fish, wildlife, and agricultural products derived from wetlands. This cycle has important implications in the growth of algae, production of fish, and water quality during seasons when excess nutrients lead to eutrophic conditions. Hydrologic, nutrient, and material transport cycles, in combination with the pattern of energy flow in wetlands, can also serve to regulate local microclimates, which affects the stability of wetland ecosystems.
The abundant flora and fauna of wetlands can also provide a source of commercial products, including forest products such as firewood, construction materials, bark, resins, and medicinal compounds. Many wetlands have been converted to intensive agricultural zones which, when managed properly, can benefit local rural communities, and some wetlands support areas valuable to grazing livestock. Many wetlands provide habitats rich in nutrients, that fish use for spawning or breeding. One third of all fish consumed depend on wetlands during some stage of their life cycle. Many wetlands are also rich in wildlife, thus providing an important recreational resource and commercial products, such as meats, pelts, and bird or reptile eggs.

Wetlands are a source of high endemic plant and animal diversity and attract species, that although not exclusive to wetlands, depend on the refuge that they provide. These areas can also be important as genetic reserves for certain plant species. The diversity of waterfowl and shorebirds that depend on wetlands has been an important consideration in conservation efforts worldwide.

Finally, wetlands are commonly associated with vectors of disease organisms, such as malaria and encephalitis. While this serves as an argument for the draining wetlands, the true

benefits and costs of wetland modification should be thoroughly considered; wetland modification might even benefit the insect vectors of those diseases (see section 5.2.1.4). Irrigation systems, for example, can favor the dispersal of malarial vectors by providing areas of reproduction for mosquitos.

Wetland habitats in the study area occur along rivers and around the margins of Lake Gatun, which covers a surface area of 32,000 hectares, and has a maximum depth of 60 m. This large, freshwater lake was created during the construction of the Panama Canal in 1912-1914, and is fed by the Chagres and Alajuela rivers and numerous smaller drainages. The salinity of the lake varies between 0-7 ppm, and its water level is controlled by the system of locks that discharge water to both the Pacific and Caribbean. Because the lake level fluctuates seasonally 1-2 m, much of the lake shore is rather barren, particularly near the ship channel, due to erosion by ship-generated waves. The lake shoreline is complex, with many small inlets, which provide quiet backwaters where small patches (e.g. 0.01-0.1 ha) of marshes with emergent vegetation occur; these backwaters are used by fish, waterbirds, and other wildlife. More extensive wetlands occur where larger rivers meet Lake Gatun, such as Rio Gatun in the northeast, and the Trinidad, Pescado, and Ciri rivers in the south; at least 800 hectares of wetlands occur in these areas, based on data from aerial photos and topographic maps (Table A.45).

Many wetlands support large populations of fish and wildlife that live and feed in the nutrient-rich waters or on the abundant vegetation. While these resources are commonly abundant, they vary with water quality. The primary productivity of rivers in the study area is fairly low, with the food chain mainly dependent on supplies from terrestrial sources. Productivity improves however, at the mouths of rivers and in open water lakes.

Aquatic vegetation in shallow areas of Gatun Lake and other bodies of water includes a diversity of plant forms. Emergent species include *Vallesneria, Typha angustifolia* (cattail), *Panicum repens, Panicum purpurescens*, and *Sagittaria lanciofolia* (arrow-weed). Floating plants such as *Eichornia* (water hyacinth), *Nymphaea* (water lily) and *Pistia* (water lettuce) are also found primarily in open fresh waters (see Section 5.2.1.7). Other plants include *Salvinia* (fern), and *Nymphaea* (water lily). *Hydrilla* establishes large, dense, rooted mats in waters as deep as 6 m, becoming navigation hazards, which are controlled by application of copper sulfate.

In shallower water and drier portions of wetland communities one finds *Leersia, Echinochloa, Thalia, Heliconia, Eleocharis* (rushes), and sedges (*Cyperus* spp.)

Wetland Mammals

Nine mammal species, representing 8 families can be found in wetlands in the study area. These include the aquatic marsupial *Chironectes minimus*, two bats which capture fish and

invertebrates from open water surfaces (*Noctilio albiventris*, *N. leporinus*), the frog-eating bat *Vampyrum spectrum*, the heteromyid rodent *Heteromys desmarestianus*, the murid rodent *Nectomys alfari*, and the rodent *Hydrochaeris hydrochaeris* (capybara). Larger carnivores, such as the crab-eating raccoon *Procyon cancrivorous* and otter *Lutra longicaudis* also occur here.

Wetland Birds

About eighty species of birds occur in wetlands in the study area (Ridgely 1989), 49 of these, from 16 families, were recorded in study area wetlands (Biological Inventory, Karr 1990; Table A.44). Wetlands are important habitat for many resident and migrant waterbirds, notably waterfowl and shorebirds (Ardeidae - herons and egrets, 9 species; Anatidae - ducks, 11 species); 15 species are North American migrants. Other important bird families in wetlands are Rallidae - rails, 7 species; Laridae - gulls and terns, 2 species; and Alcedinidae - kingfishers, 6 species. Of these, the 11 duck species are protected as game; one of these, the Black-bellied Whistling-duck *Dendrocygna autumnalis*, is listed as endangered in the IUCN Red Data Book.

Reptiles and Amphibians

Species from three families of amphibians and seven families of reptiles are normally associated with wetland habitats in the study area (see Table A.46). Species typical of wetlands include the basilisk lizards *(Basiliscus basiliscus*), as well as the turtle *(Trachemys scripta),* an herbivorous turtle usually found in permanent lowland waters, especially larger rivers. People eat the eggs and meat of *Trachemys scripta*. American crocodiles (*Crocodylus acutus*) and boas (*Boa constrictor*) are either currently extinct or nearing extinction in these areas and the frog *Agalychnis callidryas* is threatened due to loss of or severe modification to its habitat. Crocodiles are hunted for their skins, and iguanas for meat and eggs; when not hunted, iguanas are can be abundant along forested waterways.

Fishes

In general, fish are most plentiful along river banks and in small streams, where allochthonous plant debris and insects provide a supply of food. Favorable conditions for fish also exist in and around lakes, where in-flowing rivers decant their sediment and mix with runoff from the adjacent lands. Plankton, macrophytes, and organic detritus support a complex food chain in these fertile habitats, which sustain many fish species.

Invertebrates

Freshwater wetlands are a productive environment, supporting a rich insect fauna. Dominant groups include dipterans (e.g. mosquitos - Culicidae; gnats - Psychodidae,

Ceratopogonidae), aquatic and phytophagous hemipterans (e.g. Nepidae, Belostomatidae, Reduviidae, Lygaeidae), and bees and ants. Characteristic species include mosquitos (*Mansonia* spp., *Coquillettidia* spp., *Culex ningripalpus, Anopheles albimanus, A. triangulatus, A. strodei*, and the tabanid fly *Lepiselaga crassipes*. Several orders have aquatic larvae which are often important parts of aquatic food webs: Odonata - dragonflies; Plecoptera - stoneflies; Trichoptera - caddisflies; Ephemeroptera - mayflies. An abundance of members from the latter 3 orders is an indication of a well-functioning wetland ecosystem.

A.1.9 Tropical Forest Ecosystems

The majority of the forests in the study area fall within the tropical Moist Forest life zone (Holdridge, 1967), with small areas of Premontane Wet Forest and Premontane Moist Forest in the northwest corner of the study area, and Tropical Dry Forest on the islands of Taboga and Uraba, and in limited areas near the Pacific coast mainland. As the Biological Inventory sampled the tropical moist forest life zone almost exclusively, the following discussion applies specifically to those forests, although many of the characteristics also apply to premontane and dry forests.

The free-draining soils of the majority of the study area commonly support semi-evergreen forests where annual rainfall typically ranges between 1,800 and 2,600 mm; Barro Colorado Island (BCI) in Lake Gatun receives 2,600 mm, and the wettest areas, such as parts of Parque Nacional Soberanía, receiving up to 3,600 mm.

Within forests of the region, young successional forests and older successional/mature forest differ substantially in species diversity and composition, and so are treated separately (except for the herpetofauna, for reasons given in that section). While the transition from young forest to older forest is a continuous process, distinct structural and floristic changes occur in the first few decades of succession (summarized in Table A.47). These changes form the basis for separating the two forest types.

Older forests occur extensively in the Parque Soberanía, Barro Colorado Nature Monument, and near Fort Sherman. Elsewhere in the study area it occurs mostly as disjunct forest fragments, due to a long history of deforestation. Where it exists, it forms a species-rich community. Tree crowns in this forest type form a continuous canopy, with occasional emergent trees extending well above the canopy. Tree trunks are straight and quite large (diameters recorded to 1.5+ m in Biological Inventory) and tall with smooth, thin bark, large bases. Epiphytes and lianas may be present in abundance, particularly in older forests and where the dry season is short. Many trees have large-seed, fleshy fruits which depend on vertebrates for seed dispersal.

Younger successional forest occurs widely in the study area, wherever cleared areas are left undisturbed for several or more years. Compared to older forest, tree diversity in young

successional forest is low, and most trees are 'pioneer' or colonizing species, such as *Cecropia*, which require direct sun, grow rapidly, and are short-lived. The canopy is typically broken and less than 10 m in height. Lianas and epiphytes are rare in young forest, as are trees with large, vertebrate-dispersed seeds.

A.1.9.1 Mature and Old Successional Forests

Mature and old successional forests are tall and dense, with a large phytomass and heterogenous composition. Most trees are evergreen, although some deciduous species occur. The canopy of mature and old successional forests is continuous and commonly reaches 25-35 m in height, with emergent trees rising to 45 m or more. These forests are dense, frequently containing 160-170 trees/ha with a circumference of 60 cm or more (Foster and Brokaw, 1982). Although the forest margin, like the canopy above, has a luxuriant and impenetrable aspect, the interior of a mature or old successional forest is relatively devoid of understory. Straight trunks ascend, often covered with lianas, but there is limited growth in the shaded conditions at ground level. The ground surface is covered by a layer of leaf litter and other debris, and root systems are mainly superficial, with many fine roots extending into the litter layer, absorbing nutrients directly from leaf litter or through symbiotic mycorrizhal fungi.

Flora

The flora of the moist tropical forest is characterized by a high diversity of species, and a low density of individuals of any one species. For example, on Barro Colorado Island, one of the most studied neotropical forests, the native flora includes 1207 species, 633 genera, and 120 families in an area of 16 km^2 (Foster and Hubbell, 1990).

While a few tree species may make up a significant proportion of the tree population in some places, individual species dominance is not characteristic. The forest is quite heterogeneous, due to small scale variation in soil characters, random processes, and historic processes, including large scale perturbation by humans since pre-Columbian times (Hubbell and Foster, 1990). Treefalls in the forest provide small gaps where sunlight reaches the forest floor. Such gaps provide habitat for shade-intolerant species, and are critical for seedling establishment for many forest tree species. It is thought that gap dynamics are a major factor contributing to the diversity of types and species of plants in tropical forests (Denslow, 1980).

Mature and older successional forests are diverse both on a small scale and regionally, typically containing 55-60 tree species over 60 cm circumference per hectare; regionally, Parque Nacional Soberanía contains 400+ tree and shrub species in 220 km^2, and over 230 trees occur on BCI (16 km^2), with 112 species on 5 ha of BCI forest (Foster and Hubbell, 1990, Thorington et al., 1982).

Few data are available on the phytomass (total mass of living plants) of the region's forests, but high values generally prevail; two moist tropical forests in the Darien of eastern Panama contained 276 and 378 metric tons of phytomass per hectare (Golley et al., 1975). Although phytomass data are not available for the study area, supplementary information is available in the form of commercial estimates of standing timber volume. Volume estimates from six sites in the Biological Inventory averaged 225 metric tons (equivalent to cubic meters) per hectare, with a range of 84 to 425 tons. Most sites included early successional stages in sampling transects, so the volume average is probably lower than typical of older forests.

No precise data are available on forest productivity in the study area, but net productivity of humid tropical forests is typically about 25-50 (75-150 gross) metric tons/ha/yr. (Hartshorn, 1983). Wood and leaf production is governed more by climate than soil nutrients, contrary to some popular impressions; on poorer soils, nutrient cycling networks efficiently recycle limited nutrients such as calcium and phosphorus (Vitousek and Sanford, 1986). Soil richness does appear to have a strong positive influence on fruit production and animal abundance, however (Janzen, 1974 cited in Leigh and Windsor, 1982). Data from Barro Colorado Island show soils there to be relatively rich in phosphorus and other nutrients, in contrast to many tropical forests in Africa, Asia, and Amazonia, where soils are low in nutrients other than nitrogen (Leigh and Windsor, 1982).

Forests of this type contain several strata: an upper tree stratum dominated by species including *Terminalia amazonica*, *Spondias* spp., *Cavanillesia platanifolia*, *Bombacopsis quinatum*, *Tabebuia rosea*, *Anacardium excelsum*, *Trichilia tuberculata*, and *Ficus* spp.; a lower tree stratum with palms (e.g. *Oenocarpus panamensis*, *Scheelea* spp. and *Socratea durissima*) and other trees such as *Faramea occidentalis* and *Inga* spp. Giant emergent trees include *Ceiba pentandra*, *Dipteryx panamensis*, and *Cavanillesia platanifolia*. As little light penetrates to the ground, shrubs and herbaceous plants are often scarce (*Piper*, *Heliconia*, *Miconia* and Rubiaceae are common taxa) except in sunlit patches where these taxa and typical early successional species flourish.

Flora within the tropical forest varied within and between sites. On a local scale, flora varies between ridges and valley bottoms due to differences of soil drainage and moisture. For example, figs (*Ficus* spp.) tend to occur on well-drained, rich soils. The Biological Inventory found species abundances to vary between sample sites. The history of human disturbance, soil and moisture characteristics, and random processes are likely to be important influences on local flora in the study area. While species composition and abundance varies between areas, many of the same genera occur widely, and forest structure remains similar. To illustrate this, the Panamanian forest on BCI and a forest 2,500 km away in the Peruvian Amazon shared 82% of woody plant genera (Gentry, 1990). Finally, rainfall strongly influences flora composition and diversity, with species diversity increasing with rainfall (Gentry, 1982). In the study area, Pacific dry forests have the lowest diversity,

and deciduous and drought tolerant species such as *Bursera simarouba* and various Bombacaceae are more common here, than in the moister forests.

Epiphytes are abundant in mature and old successional forests, both in the number of individuals and in the diversity of species that grow on the trunks and branches of the larger trees. Data indicate that over 200 epiphyte species occur in forests of this type within the study area. Dominant taxa are ferns, Orchidaceae, Araceae and Bromeliaceae. On BCI, orchids alone formed a third of the epiphyte species.

The forests of the study area contain many species of trees of commercial value. Mahogany (*Swietenia macrophylla*) and cedro (*Cedrela odorata*) are among the most valuable timber trees, and were selectively logged from many areas decades ago. Commercially valuable species less affected by logging include *Anacardium excelsum* (espave), *Bombacopsis quinatum*, *Terminalia amazonica*, *Guarea glabra*, *Tabebuia* spp., *Cordia alliodora*, and *Platymiscium* spp. As wood sources dwindle worldwide, other tropical trees will no doubt gain value for lumber and pulp. The sites sampled in the inventory were judged to have little current timber value, due to disturbance and previous logging. The more valuable timber occurs mostly in protected areas, especially the northern part of Soberanía Park, and possibly in the area traversed by the northern end of the proposed sea-level route.

Little information exists about the population status of most plant species, but three forest species listed as threatened and endangered are valuable timber trees which have been heavily logged for years: mahogany (*Swietenia macrophylla*), laurel (*Cordia alliodora*) and cedro espino (*Bombacopsis quinatum*).

Tropical forest food webs are extremely complex with many interconnections between species, and for this reason it is difficult to identify singularly important floral taxa. Nonetheless, studies in Panamá and other Neotropical forests (Terborgh, 1986) have identified certain plant groups as 'keystone species', which are critical to many consumer species. Notable are plants which provide food during periods of minimum fruit production. These include palm nuts (*Astrocaryum*, *Scheelea*, *Iriartea*), figs (*Ficus* spp.), and some nectar sources. Figs stand out as a key food source for many bird and mammal species. Large hollow trees provide critical shelter for numerous vertebrates, including many species of bats; Janzen (1976) suggests that hollow trees may benefit from nutrients brought in by animal occupants.

The flora and fauna of riverside forests are typically quite similar to other forests in the area. Gallery forests in the study area occur as remnant forest strips along rivers in otherwise deforested areas. As such, these strips may form reservoirs of species for recolonization of adjacent cleared areas, or perhaps as corridors for movements of forest species. Due to the hilly topography of central Panamá, regular seasonal flooding is not the important influence on flora which is in low-lying tropical basins such as the Amazon and

parts of eastern Panamá, where distinctive gallery forest communities exist. Small areas of seasonally flooded forest may exist in the study area, but data on these forests do not exist; such forest in the Darién is characterized by the canopy dominant *Prioria copaifera* (cativo), which otherwise exists at low density in older forests (Golley et al., 1975).

Fauna

The faunal diversity of forested habitats is generally high, although directly correlated with the amount of disturbance in a specific location. Data on spatial patterns of faunal abundance are limited for the study area. Most of the forest animal biomass consists of soil and leaf litter arthropods, including ants and termites, with the balance made up of other insects, mammals, and other vertebrates. Large vertebrates are rare in most tropical forests in the study area, and hunting has clearly depleted mammal populations even more (Glanz, 1991).

Among the larger forest animals, there is considerable diversity of species, but individual species density is highly variable. Some animals such as primates and white-lipped peccary *Tajacu pecari* occur in groups, but many others are solitary and exist at very low densities. Among the more abundant mammals are herbivores such as sloths, and the large rodents *Dasyprocta* and *Hydrochaeris* (capybaras), while most carnivores occur at lower densities; for example, the small cats (*Felis pardalis, F. wiedii, F. yagouaroundi*) have home ranges of 10-30 square km (Konecny, 1989). Because of low densities, many species require large areas of forest to maintain effective breeding populations.

The inventory recorded 30 families and 88 species of mammals in mature/old successional older forest--by far the richest habitat sampled. Bats stand out as a rich assemblage of species, comprising 37 species. Tropical forest bats have diverse habits, including 13 species which are primarily frugivorous, 17 insectivorous species, pollen and nectar feeding bats (3 species), 1 blood-feeder, and 3 species that take mostly small vertebrates. The true bat diversity is doubtlessly greater than indicated by the data, as bats are notoriously hard to detect by available sampling techniques. At least 102 species of bats occur in the republic of Panama, of which at least 58 have been recorded in the study area (Handley, 1966, Fleming et al., 1972).

The carnivore order is very diverse taxonomically (15 species, 4 families), and ecologically. Some species are strict flesh-eaters (5 cat species), while others are omnivorous (raccoons - *Procyon* spp., tayras - *Eira barbara*), and kinkajous *Potus flavus* are largely frugivorous. The forest is rich in edentates (5-7 species), a distinctive feature of the forest fauna. Two of these species, the giant anteater *Myrmecophaga* and armadillo *Cabassous* were not recorded in the census, but have been recorded in years past, and may still occur in the area.

Species characteristic of older forest include several arboreal mammal species, which require a continuous canopy; these include spider monkeys (*Ateles geoffroyi*), howler monkeys (*Alouatta palliata*), kinkajous (*Potus flavus*), and the silky anteater (*Cyclopes didactylus*). Other typical forest species include 2 species of sloths, and several rodents, one of which (*Proechimys semispinosus*) is one of the most abundant animals, and is important as food for many predators, including ocelots and the bushmaster snake (Emmons, 1990). The white-lipped peccary *Tayassu pecari* is also a deep-forest species, which travels in large bands (50-300 animals, where not hunted) which require large tracts of intact forest. This species has been extirpated from the study area by hunters, as have been pumas *Felis concolor*.

Twenty-nine forest mammals are protected as endangered species by Panamanian law (Table A.48); most of these species are hunted for meat or skins. White-lipped peccary and pumas are protected species which no longer occur in the area, although populations survive nearby to the east in the upper Chagres drainage. All primate species are listed, but spider monkeys (*Ateles geoffroyi*) are particularly threatened in the study area, due to hunting. This species and howler monkeys receive the highest level of protection from the CITES treaty (see Section A.2).

Several protected mammals which are quite rare in Panama occur in the study area. A few jaguars survive in the northern portion of Soberania National Park, but jaguars have large home ranges, and they are persecuted widely as cattle predators. An other extremely rare carnivore is the bush dog *Speothos venaticus*, a social canid about which almost nothing is known. There have been two reliable sightings in the study area in the last 2 years (along Pipeline Road and near Summit Gardens). Baird's tapir *Tapirus bairdii* today occurs in the study area only on Barro Colorado Island, where they have been reintroduced. Suitable habitat occurs in much of the study area, but hunting has extirpated the species. Manatees *Trichechus manatus* were native to the area, extirpated, then reintroduced into Gatun Lake, where a small population has become established. This strictly aquatic mammal is easily overlooked, as it spends much time submerged, and is inconspicuous when it surfaces.

Populations of other protected mammals have been substantially reduced by hunting in many of the forested areas: collared peccaries (*Tayassu tajacu*), pacas (*Agouti paca*), and brocket deer (*Mazama americana*) (Glanz, 1991). The presence of these and spider monkeys indicates minimal hunting in an area.

Mammals are important seed dispersal agents for many forest plants, and certain mammals, notably primates and agoutis (*Dasyprocta punctata*), play a particularly important role (Smythe, 1978). In the absence of these animals, substantial changes occur in floral composition of forests (see Section A). Agoutis can withstand light hunting pressure, but suffer when hunting is heavy, and where habitat fragmentation creates small, vulnerable populations.

The avifauna of Neotropical forests, such as those of central Panamá, are the most species-rich of the world. Using data from the Biological Inventory and the extensive work of Karr (1971, 1990a,b), approximately 270 bird species from 34 families have been recorded in the study area. Families represented by many species included: Embirizidae passerines (tanagers, wood warblers, embirizine finches), which formed 21% of the avifauna (55 spp.); Tyrannidae flycatchers (38 spp., 14%); Accipitridae hawks (25 spp., 9%); and Formicariidae (antbirds, 21 spp., 8%).

Correlated with high species diversity is a high frequency of species with specialized feeding habits. Specialized feeding often requires large home ranges to support an individual. As a result, forest systems can support only low population densities of these species. In order to maintain viable populations of such species, large tracts of forest are required. Work on Barro Colorado and in Amazonia (Willis and Oniki, 1973, Lovejoy et al., 1986) demonstrate loss of avian species when habitat is fragmented. Twenty-six avian species have been identified as dependent on conditions found only in the interior or canopy of intact forest. These species are likely to among the forest species to suffer from forest fragmentation.

One distinct feature of the forest avifauna is the diversity of frugivorous species, including mannakins (Pipridae), contingas (Contingidae), parrots (Psittacidae), trogons (Trogonidae), pigeons and doves (Columbidae), toucans (Ramphastidae). The high diversity of antbirds is also distinctive. As the name implies, many antbirds specialize on taking insects flushed by advancing swarms of army ants (*Eciton burchelli*).

Another characteristic of the avifauna is the presence of many migratory species, which breed in temperate North America and spent 4-6 months in the tropics. Forty species (7 families) of Neotropical migrants were recorded in forests; most of these migrants were Tyrannidae flycatchers and wood warblers (Embirizidae). Many species of Neotropical migrants have declined in numbers in recent decades, leading to much interest in their conservation (Terborgh, 1989).

Seven endangered bird species were recorded in the inventory of forests, or have been recorded by others: 2 tinamous (*Crypturellus soui, Tinamus major*), 3 species of fowl-like cracids (*Ortalis cinereiceps, Crax rubra, Penelope purpurascens*), and 2 pigeons (*Columba cayennensis, C. nigrirostris*). The cracids and tinamous are species heavily hunted, as are the pigeons to a lesser extent. The endangered Harpy Eagle *Harpia harpyja*, a former resident of the region, was not recorded in the inventory. Ridgely's (1989) report of recent sightings along the Pipeline Road could represent either transient individuals or a resident pair or two.

Seven threatened species have been recorded from the area's forests in recent years. Four are raptors: *Leucopternis plumbea, Morphnus guianensis, Spizastur melanoleucus, Daptrius americanus*; two cuckoos: *Coccyzus minor, Neomorphus geoffroyi*; and a flycatcher:

Pachyramphus rufus. All these species are threatened primarily by habitat destruction, although raptors are also suffer from indiscriminate shooting. In addition to these species, psittacines as a group are heavily impacted by illegal pet trade, and four species of macaws have disappeared from the region in recent decades: *Ara ambigua, A. macao, A. chloroptera, A. severa*. A single bird is endemic to the area's woodlands, the Yellow-green Tyrannulet (*Phylloscartes flavovirens*).

The data on forest reptiles and amphibians are too limited to permit a clear differentiation between old and younger forest, although more species (78 versus 66 spp.) occur in the older forest than in early successional forest. These counts include 13 species not recorded in the inventory, but which should occur (Table A.49). The following discussion is applicable to both habitat types, except where noted otherwise.

A total of 43 species of reptiles and 41 amphibians were identified as occurring in forest habitats. Leptodactylid, centrolenellid (glass) and dendrobatid (poison dart) frogs were represented by many species; all three families reach their greatest abundance in forest habitats. Salamander diversity was low, as is typical of neotropical lowland forests. Families which dominated the reptile fauna include 2 lizard families (Iguanidae, Teidae), and 2 snake families (Colubridae, Viperidae).

Species normally associated with older forest include: *Oscaecilia ochrocephala* (a caecilian); *Colostethus talamancae, Agalychnis calidryas, Hyla rufitela, H. palmeri, Eleuthrodactylus cerasinus, E. gaigeae, E. gollmeri, Bufo coniferus* (frogs and toads); *Corythophanes cristatus, Ptychoglossus festae*, (lizards); *Bothrops schlegelii, Lachesis muta* (snakes). On Barro Colorado Island, *Bufo typhonius* and *Colestethus flotator* were characteristic of older forest (Toft *et al.*, 1982). The bushmaster (*Lachesis muta*) is closely associated with older forest, perhaps because its requires constant humidity and temperature for egg development. Many of the frog species listed above are closely associated with undisturbed moist forest, where their specialized breeding sites occur (discussed below). While no reptile species have been identified as being associated strictly with young forest, the frog *Centrolenella fleishmanni* was typical of early successional forests.

A distinctive characteristic of neotropical amphibian fauna is diversity of reproductive modes (Scott and Limerick, 1983). The typical temperate amphibian pattern of aquatic eggs and larvae is not the rule in the tropics. Centrolenellid and some hylid frogs lay eggs on vegetation over streams or ponds, with the larvae dropping into the water to develop. Leptodactylid frogs lay eggs in leaf litter, where they develop in the egg directly into small adults, while poison dart frogs (Dendrobatidae) lay eggs on land, and transport larvae to water. Lastly, caecilians are viviparous, where the young are born as small adults, having developed in the female's oviduct. Among species with aquatic eggs and larvae (Hylidae), laying sites vary from streams and ponds to arboreal water sources in tree cavities and

bromeliad bases. The dependence of forest amphibians on highly specific breeding sites illustrates the importance of microhabitats within the forest ecosystem.

Thirty-two species of amphibians and 68 of reptiles have been recorded on BCI in 47 years of collecting (Myers and Rand, 1969). The greater number of reptiles recorded at BCI compared to the Biological Inventory (43 spp.) reflects the difficulty in sampling tropical forest snakes, many of which are both rare and arboreal; the work based on the inventory recorded 20 snake species, while Myers and Rand listed 39 species.

Three reptile species are listed as endangered: *Caiman crocodilus, Boa constrictor, Iguana iguana.* Threats to these species are trade in skins for leather (all 3 species) and for food (iguana, hunted for meat and eggs). Boas are also killed because it is a predator of chickens and other domestic animals. Since the closure of a Panamanian tannery which handled reptile skins, caiman and crocodiles have become more common in the study area (N. Smythe, pers. comm.). The tropical snapping turtle *Chelydra serpentina* is also endangered; this little-known species is reported by local residents to occurs in fresh waters of the study area (Biological Inventory, 2nd quarterly report). Sixteen reptiles (9 snakes, 7 lizards) are considered threatened (Table A.49); the common threat to these 16 species is the destruction of their forest habitat.

Thirteen threatened amphibians were recorded: 11 anurans, 1 salamander, 1 caecilian. Forest destruction and alteration is the main threat. The threat to frog populations is compounded by sharply declining frog populations, the cause of which remains a mystery. Only the Golden Frog is legally protected in the study area.

In recent years, dendrobatid frogs (*Dendrobates, Colostethus, Minyobates*) have been collected for their skins, which are exported for use in research into medical uses for alkaloids occurring in their skins. The venom of pit vipers (*Bothrops asper, B. nasuta, B. schlegelii, Lachesis muta*) is collected from live snakes, also for medical research; the venom of bushmasters is reported to bring $500 per gram.

Invertebrates are by far the most numerous animal group found in tropical forests, both in species and numbers of individuals. Arthropods occur everywhere throughout the forest, and form many important links in trophic webs, such as detritivores, herbivores, predators, pollinators, seed dispersal agents, and as food for many birds, lizards, and amphibians. Relationships between insects and plants are particularly rich and specialized, encompassing the all roles mentioned, as well as complex mutualistic symbioses in which insects defend plants against herbivores.

The insect fauna of forests is extremely rich in species, some orders are more abundant. These include Coleoptera, Hymenoptera, Diptera, Lepidoptera, Hemiptera, and Homoptera. Among the most obvious forest insects are the butterflies (e.g. *Morpho, Heliconius, Eurema*

and *Papilio*) and cicadas, whose persistent loud calls are unmistakable. Many species complete their entire life in strata far above the forest floor; this includes species which live in the canopy, in tree cavities, in epiphytes such as bromeliads. Some canopy-dwelling mosquitos (*Haemagogus, Sabethes, Aedes, Trichoprosopon, Wyeomyia*) feed on arboreal mammals such as primates, and can be vectors for zoonoses (Section A.1.4). Other bloodfeeding insects of the canopy include psychodid midges (*Lutzomyia*) and reduvid bugs (*Panstrongylus, Tiratoma*); the reduvid *Rhodnius prolixus* is closely associated with the palm *Scheela zoneneis*.

Additional blood-sucking insects are found in the forest canopy. These include the mosquitos of the genera *Haemagogus, Sabethes, Aedes, Anopheles, Trichoprosopon* and *Wyeomyia*. Other important blood-sucking insects of the Diptera include the Psycodidae family, Lutzomya, and the triatominic bugs of the Hemiptera,
Soil fauna is substantial in forested habitats, and play a vital role as detrital feeders in the system once initial litter decomposition by fungi has occurred. Arthropods are an important component in the recycling of detrital nutrients, with dominant detritivore groups including amphipods, isopods, millipedes, and the larvae of holometabolous insects (e.g. beetles, diptera) (Levings and Windsor, 1982).

Both numerically and from an ecological perspective, ants and termites are important components of the invertebrate fauna; for virtually any type of available food, there are ants that will eat it (Wilson, 1971, in Levings and Windsor). Leaf-cutter ants (*Atta* spp.) are important as consumers of living leaf mass, and along with termites are recyclers of nutrients (Stevens, 1983, Longman and Jenik, 1987). Army ants (*Eciton burchelli* and others) are important predators, as well as creating a food supply for numerous fly and bird species, which specialize on catching prey flushed by advancing ant swarms (Willis and Oniki, 1978, Franks and Bossert, 1983). *As Eciton burchelli* populations require large areas of forest to survive, their presence indicates a large, healthy forest system.

Flying insects such as *Trigona* and Euglossine bees are critical as pollinators in tropical systems, and mutualistic relationships between single plant and pollinator species are common. Other groups of insects that are often common in forests include the orders Coleoptera (beetles), Orthoptera (roaches, katydids, crickets), Homoptera (cicadas, leafhoppers), and Lepidoptera (moths and butterflies). Insect abundance fluctuates considerably, depending in part upon seasonal climate changes; abundance of phytophagous insects on BCI tends to peak early in the rainy season, while litter arthropods peak in the dry season (Smythe, 1982; Wolda, 1978; Toft, 1980).

A.1.9.2 Young Successional Forest

Following the disturbance of the vegetation, a successional process begins which typically results, after many decades, in a complex, mature forest. While the vegetation that replaces

the original forest depends to some extent on the nature of the perturbation, in most cases a successional sequence occurs which is typical throughout Neotropical moist forests (Table A.47).

Flora

In a typical successional sequence, heliophytic pioneer species, such as *Cecropia* spp., *Trema micrantha, Ochroma pyramidale, Didymopanax morototoni*, and *Cochlospermum vittifolium* rapidly become dominant, with closed stands of *Cecropia* reaching 10 m in height over a period of two to three years. The rapid growth of pioneer tree species reflects the ready availability of their seeds, which tend to be small, and readily dispersed. The seeds of many pioneer species can lay dormant in the soil for years, germinating in response to increased solar radiation at ground level. Early successional forests support a dense understory of weedy, herbaceous species (e.g. *Piper* spp.) as a result of the large amount of sunlight that reaches the ground surface. As the forest matures, the less competitive pioneer species gradually give way to slower growing but longer-lived shade intolerant species (e.g. *Luehea seemannii, Spondias mombin, Cavanillesia platanifolia*), and to shade tolerant trees (e.g. *Tabebuia rosea, Cedrela* spp., *Apeiba* spp., *Cordia alliodora*, and *Inga* spp.); these shade tolerant species can germinate in the shade of the pioneers, which they eventually replace. With time, the slower-growing species will form secondary forest with fairly continuous canopy forming in 50 years or less. On Barro Colorado Island, forest 60-100 years old resembled older forest (>200 yrs) in most respects. Changes which continue to occur after the first 50-100 years include an increase in tree species with large, animal-dispersed seeds, more epiphytes, and a greater abundance and thickness of lianas. A good indicator of old forest is the presence of thick lianas (Hartshorn, 1980).

Where soil structure and fertility are degraded by repeated disturbance, forest re-establishment may be greatly retarded.
An alternate successional sequence sometimes occurs in the study area, resulting in the rapid establishment of *Saccharum spontaneum*, a tall (1-2 m) introduced grass which forms dense stands supporting few species of plants or animals. When this occurs, the normal successional sequence halts or is dramatically slowed. This grass is common in abandoned cattle pastures, as found around the western portion of Lake Gatun (N. Smythe, pers comm).

When disturbance occurs on a large scale, with thousands of hectares cleared in single blocks, the regenerative capacity of the forest is impaired. Weedy shrubs and woody pioneer species readily re-establish themselves, but restoration of mature forest cover is less assured. This results from lack of seed input from forest tree species, whose seeds tend to be large, rather short-lived, and dependent on animal dispersal. It may even be that mature forest species are incapable of recolonizing large areas opened to intensive and extensive

agriculture. While the secondary forest may still re-establish itself, the process may take longer and it is likely to remain impoverished, in comparison to the original climax forest.

Forest regeneration also varies somewhat in relation to local habitat conditions. Forest regeneration on more infertile soils tends to be very slow. In areas of lower and more seasonal rainfall, forest regeneration is also slower, and there is always the possibility of deflecting succession to grassland or savanna as a result of burning or grazing (Deshmukh, 1986).

Fauna

Twenty-five species of mammals from 15 families were recorded in this habitat, dramatically less than in older forest. Because secondary forests by nature are concentrated near populated areas, "missing" species include those hunted for food or skins, such as peccaries, deer, pacas, and carnivores (e.g. spotted cats). The canopy-dependent species mentioned for mature forest are also absent. Another reason for low mammalian diversity may be insufficient food supplies for diet specialists; many of the species occurring in early secondary forest are diet generalists (such as opossums and raccoons - *Procyon* spp.), and herbivores (deer and sloths). Also conspicuously absent are many frugivorous mammals. As discussed previously, the pioneer species of early forests are largely wind/gravity dispersed, so there is much less fruit available to obligate frugivorous. The low bat diversity in these forests is due in part to the low numbers of frugivorous and other feeding specialists, e.g. species which eat large insects, carnivores, and nectar-feeders. Many canopy trees provide nectar for bats, which serve as pollinators.

Over 115 bird species from 25 families were recorded from early successional forest, based on the Biological Inventory plus the works cited for mature forest. Three families with more than 10% of all species observed were: Tyrannidae (28 species, 25%), Embirizidae (17 species, 15%), and Trochilidae (hummingbirds, 16 species, 14%). These families include insectivores, nectarivores, and seedeaters. Compared to older forest, ovenbirds (Furnariidae), antbirds, and woodcreepers (Dendrocolaptidae) are represented by few species. Many missing species forage in specific microhabitats common in older forests, but rare in young forests. For example, woodcreepers probe for insects around epiphytes, lianas, and in nooks and crannies of complex bark surfaces; antbirds forage on the forest floor, often near army ant swarms; and many ovenbirds feed in leaf litter, among epiphytes or in dry leaf clusters. Few fruit specialists were recorded from young forest, reflecting low abundance and diversity of plants with fleshy fruits. Thirteen species of neotropical migrants were recorded in this habitat. This number is low compared to the diversity of Neotropical migrants observed in old and young successional forests of the study area and nearby (Hespenheide, 1980; Blake and Loiselle, 1992). Among forest habitats, Blake and Loiselle found migrant diversity to decrease with forest age, with the greatest diversity (31 species) in young secondary forest in northeastern Costa Rica.

The invertebrate fauna are typified by insects from the orders Diptera, Coleoptera, Hemiptera, and Homoptera. Among the dipterans are a number of species which are vectors of zoonotic diseases (detailed in Section A.1.4); important vectors include biting flies in genus *Lutzomyia* (family Psychodidae), and beetles are abundant in this habitat, as in older forests. Important coleopteran families include Coccinellidae, Curculionidae, Elateridae, Chrysomelidae, Pselaphidae and Scarabaeidae. Hompoterans are also numerous (Membracidae, Cicadidae, Cicadellidae, Dictyopharidae). Phytophagous insects are notably abundant in this habitat, especially homopterans (Membracidae) and beetles (Chrysomelidae).

The abundance of phytophagous insects supports a community of predators. Among arthropods, spiders are the abundant predators; the genus *Nephila* is an important predator of orthopterans and lepidopterans. The arthropod fauna also supports the many insectivorous birds, bats, reptiles and amphibians of the young successional forests.

A.1.10 Open Areas (Grasslands & Pastures)

These habitats are characterized as open, grassy areas. These areas are found most extensively on the Pacific slope, but in recent years, large grassy areas are being created by forest clearing on the Caribbean slope as well.

While some areas may have a long history as grasslands, this association usually occurs after an area is disturbed, either by forest clearing, tilling or cultivating the soil (Sarmiento and Monasterio, 1975). Under natural conditions, this type of vegetation (if present at all) is usually transitory, being replaced by early successional forest. With the addition of cattle grazing and non-native grasses, succession is slowed, and in some cases, e.g. if the soil has been seriously degraded, grasslands may persist for a longer period of time.

Fires are frequent in many grasslands, with most anthropogenic fires started to improve pasture quality by removing dead stems and stimulating new growth; it is not unusual for pastures to burn every year or two. Fires have a profound influence on the ecology of an area, by removing grasses and woody plants which cannot tolerate fires. Thus, repeated burning can maintain this community by inhibiting succession.

Flora

The vegetation is structurally simple, with a single ground layer often dominated by one or a few grasses. Typical species include introduced grasses such as *Hyparrenia rufa* (faragua), a dominant cultivated pasture grass which withstands abuse, overgrazing and fires better than most grasses. This species is also very fire-resistant. Within this habitat, seedlings of pioneer forest trees such as *Cecropia* and *Cordia alliodora* may occur, as may *Bursera* spp. Characteristic trees found in pastures throughout the Neotropics along fence lines,

watercourses, and habitations, or for shade for cattle include: *Byrsonima crassifolia*, *Curatella americana*, *Carludovica palmata* (Panamá), and the palm *Acromia vinifera*. These species have in common their resistance to fire and herbivory. Well-defended shrubs such as *Acacia farnesiana*, *Mimosa pigra*, and ant-acacias occur in overgrazed areas. A variety of other shrubby species, often with clumped distributions, are also occasionally found, as well as shade trees such as *Enterolobium cyclocarpum* and *Pithecellobium saman*. Because many introduced "weed" species are adapted for dispersal and colonization, introduced plants are more abundant in this habitat than in later successional stages (Kellman 1980). On some sites, a near-monoculture of the introduced grass *Saccharum spontaneum* may become established and persist for years, forming a tall, dense cover suitable for neither cattle nor many native animals.

What processes occur which result in such changes are not clearly understood. A particular subject of controversy in recent years has been the effect of year-round use of wet lowland pastures on soil structure, nutrient status, and mycorrhizal populations, and the implications of this for long-term yields.

Many medicinal plants used by local people occur in this habitat. *Chapatalia nutans* is used to treat liver and dental problems, *Bidens pilosa* to treat the common cold, and *Erythrina* spp. to treat appendicitis. In addition to medicinal value, this habitat contains the seedlings of forest species which if left undisturbed will transform the scrub into successional forest.

Fauna

The fauna is also quite simple, being low in species diversity compared to forest areas. While little biological research has been devoted to these and other disturbed habitats in Panama or elsewhere in the Neotropics, several aspects of appear to contribute to the low species diversity. Many factors believed to contribute to high diversity in forests are absent here. Vegetation is simple, both structurally and taxonomically, and many feeding opportunities available in forests are missing. Missing are all feeding niches associated with trees and leaf litter, and most fruit resources. Also, shelter from predators and environmental stresses is limited, for example tree cavities and treetop roosts do not exist. Furthermore, because of the simple vegetation cover, temperature and humidity fluctuates much more than in forests, which places a restriction on species which can survive here.

Twelve mammalian species, representing 8 families, were associated with grassland communities. Rodents are abundant both in species (4) and in numbers. Only three bats are listed for the habitat. Undoubtedly other insectivorous bat species forage in this habitat, but the relatively low diversity of food types and lack of suitable roost sites limits bat diversity. No mammals are strictly limited to this habitat, but cottontail rabbits *(Sylvilagus brasiliensis)*, cotton rats *(Sigmodon hispidus)*, opossum *(Didelphis marsupialis)* and mice *(Zygodontomys microtinus*, *Orozomys fulvescens)* can be fairly abundant here. All of these

species except rabbits are omnivorous. This may contribute to their success, as individuals are not reliant on specialized food types.

The Biological Inventory recorded 71 bird species from 21 families. As to be expected, bird families with the most species were those typical of the open country. There was a high diversity of shorebirds (5 species in Charadriidae, 11 in Scolopacidae); most shorebirds species are winter visitors from North America, and so grasslands (especially if flooded) appears to be important to migrants. Birds feeding on aerial insects were quite common (nightjars, Caprimulgidae, 3 spp.; tyrannid flycatchers, 6 species), as were seed-eating birds, and birds of prey (8 species). Characteristic species include smooth-billed anis (*Crotophaga ani*), nighthawks (*Chordeiles* spp.), and the Blue-black Grassquit (*Volatinia jacarina*).

In a separate study in pasture areas of central Panama, Karr (1971) recorded 21 common resident bird species from 11 families, plus an additional 30 uncommon or migratory species. Common bird species include ground doves (*Columbigallina minuta*), meadowlarks (*Sturnella magna*), slaty spinetail (*Synallaxis brachyura*), red-breasted blackbirds (*Sturnella militaris*), seedeaters and grassquits (*Sporophila* spp., *Volatinia jacarina*), and yellowish pipits (*Anthus lutescens*). Cattle egrets (*Bulbulcus ibis*) feed in association with cattle, which flush insects for them. Raptors typical of open fields and pastures can be fairly common: savannah hawks (*Buteogallus meridionalis*), white-tailed kites (*Elanurus leucurus*), and crested caracaras (*Polyborus plancus*).

The herpetofauna of grassland vegetation includes 18 amphibians (all frogs or toads) and 21 reptile species (8 snakes, 10 lizards, 2 turtles and a crocodile. Species typical of these open, disturbed habitats include the lizards (*Anolis auratus, A. tropidogaster, Ameiva ameiva*), several frogs (e.g. *Hyla ebraccata, Rana vaillanti*), and the toad *Bufo marinus*. Litter-dependent species such as caecilians and *Eleutherodactylus* frogs are notably absent, as are dendrobatid and glass frogs (*Centrolenella* spp.). Caiman and iguana occur in this habitat, near water, but are rare due to hunting for skins (caiman), or meat and eggs (iguana); people also eat the eggs and meat of the turtles *Trachemys scripta* and *Kinosternon leucostomum*.

Because of the constant disturbance associated with grazing, the diversity is low, with 4 families of amphibians and 6 of reptiles. Dominant species include *Bufo marinus, Ameiva,* and *Bothrops asper*, the fer-de-lance. Species such as *Bufo haematiticus, Hyla phlebodes*, and *Physalaemus pustulosus* are also found, *Rana vaillanti* occurs widely, and *Trachemys scripta* and *Basiliscus* are found along waterways.

Tropical grasslands support a relatively simple arthropod community, with species richness less than one-third that found in secondary forests; beetles are relatively uncommon, and hemipterans fairly common (Janzen 1973). Dominant insect taxa include Danaid butterflies (feeding on grasses); homopterans (leafhoppers - Cicadellidae, and Cixiidae nymphs) feed

on grasses and weedy herbs; scarabaeid beetles eat a variety of plants, and crickets (Gryllidae) feed on green grasses. Earwigs (Forficulidae) feed on pollen of crops and weeds. Other common insect taxa include:

Insect Order	Insect family
Coleoptera	Nitulidae, Coccinellidae, Curculionidae
Hymenoptera	Formicidae, Chrysididae
Diptera	Chironomidae, Dolichopodidae, Agromyzidae
Orthoptera	Tetrigidae, Acrididae
Homoptera	Aphididae, Membracidae
Isoptera	Rhinotermitidae
Thysanoptera	Tubullifera

Weedy components of grazed and ungrazed grasslands can support many predatory insects, which benefits adjacent croplands. These include tachinid, asilid and syrphid flies, lygaeid bugs, vespid wasps, staphylinid beetles, mantids, and parasitoids (e.g. Diapriidae, Eulophidae, Braconidae). Of medical interest are mosquitoes: *Aedes angustivittatus*, *Anopheles albimanus*, which occur where canals and small creeks provide semi-permanent water and dense vegetation for refuge. Various culicoides (biting midges, no-see-ums) also thrive in areas with the hat-palm (*Carludovica*) and *Cecropia* trees. Finally, many of the flies, crickets, katydids, and butterfly larva are important food sources for other insects and for insectivorous vertebrates, especially birds.

Sensitive species such as caimans, iguanas, and capybaras occur in this habitat, particularly at the grassland-water ecotone. All of these species are protected by Panamanian law (Section A.1). The endangered Swainson's hawk *(Buteo swainsoni)* is a common transient en route to wintering grounds in South America, and some individuals linger in open areas in the study area. A threatened bird species found here is the hummingbird (*Amazilia tzacatl*). Lastly, the nine-banded armadillo (*Dasypus novemcinctus*) can be fairly common in grassland areas. Although this species is hunted for its meat, it has survived in much of the study area, where other hunted species have not.

A.1.11 Agricultural Ecosystems

Small Farms

Most agricultural holdings in the study area consist of small farms (5-10 hectares). The food items produced on these farms are diverse, as the farmers frequently produce a significant percentage of the food they consume. A typical small farm includes a variety of crops. Among the most important cultivated crops in the study area are rice, maize, and starch-rich root crops, notably yuca (cassava: *Manihot esculenta*) and sweet potatoes (*Ipomoea* spp.);

small patches of pineapple and vegetables are also grown. Subsistence farmers typically have planted fruit trees, including banana, plantain, papaya, mangos, pejibaye palms (*Bactris gasipaes*), and perhaps a few citrus trees, breadfruit trees or manzana de agua.

Natural forested ecosystems in tropical areas are characterized by a relatively balanced cyclic flow of nutrients, which are added to the soil mainly from leaf and branch fall and immediately picked up near the soil surface by plant roots, or farther down, by deep tree roots. Small amounts are lost to the system altogether through erosion and leaching, but the loss is on the whole balanced by the inflow from N_2 fixation by microbes and movement of animals into the system. Conversion of these forests to agricultural uses directly removes a large amount of nutrients from the system in the form of food harvest, and in simplifying the agricultural environment (which often means removing trees), increases losses of nutrients to erosion and leaching. These changes result in a large net nutrient outflow.

A large amount of nutrients is released into the soil by slash-and-burn agriculture, and crops can be grown on the land cleared in this manner for several years, until nutrient levels fall. In permanently cultivated areas, fallow times are short and problems associated with fertilizing and weeding arise. With a short fallow period there is not sufficient time for natural replenishment of soil nutrients and other mechanisms must be found to reestablish soil fertility. Weeds also become more of a problem and plowing becomes necessary to insure that weed roots are not left intact in subsurface soils.

Agriculture in tropical areas with distinct dry seasons normally follows the practice of vegeculture (cultivation of starch-rich cultigens with enlarged tubers or stems, such as manioc, sweet potato, taro, and yams) as opposed to seed culture (grains such as corn, rice, and wheat). The ecology of vegeculture differs from seed culture in several ways:

(1) Traditional vegeculture is characterized by more species-rich and structured polycultures than is seed culture. Typically, ground-covering vine crops, small shrubs, and taller crops (like manioc) all are grown in the same plot, which usually results in less soil erosion and weed invasion.

(2) Vegeculture is less energy-draining than seed culture, since it mostly removes carbohydrates rather than protein-rich seeds. In addition, swidden areas in vegeculture are usually burned less intensively than those subjected to seed cultivation, and thus have more organic material in the soil.

(3) Vegeculture must coexist with protein hunting or gathering, and thus restricts this kind of agriculture to areas that provide predictable animal protein sources. Since this requires a "spatially fixed" protein source, it is not a very mobile type of agriculture.

There are few areas where this type of agriculture is exclusively practiced, and most small farmers engage in complex mixtures of seed culture and vegeculture and frequently interplant the two kinds of plants. The use of polycultures has a number of important of ecological implications, including:

(1) Less soil erosion and fewer weed problems;

(2) More complete use of the total amount of light reaching one area, especially in complex, vertically structured polycultures, in which shade-tolerant crops are grown beneath less shade-tolerant crops;

(3) Better use of the entire spectrum of available soil nutrients; and

(4) Decreased problems with insect pests.

Plantations

The plantation agro-ecosystem occurs in the study area primarily in the coastal are between the Rio Indio and Rio Lagarto, where African oil palms (*Elaeis guineensis*) are grown. The plantation ecosystem frequently require a great deal of pesticide to keep them producing, presumably in accord with the well-known speculations about monoculture susceptibility in the tropics. Since most plantations are monocultures, they usually have a relatively uniform physical environment in their understory, which may favor certain pest species.

Fauna of Agricultural Zones

The fauna associated with agricultural areas is a collection of native and introduced species which are characteristic of disturbed habitats. Since the presence of humans and agriculture in the neotropics is relatively recent on an evolutionary time-scale, species have not evolved which specialize on agricultural systems. Instead, fauna consists of species characteristic of naturally disturbed and open habitats. As a result, many vertebrate species occur also early successional stages and around forest edges. The faunal diversity of an area tends to increase with the complexity of the habitat: the presence of scattered trees, living fences and hedge rows provides habitat for more species than does a monoculture such as oil palm plantations or treeless pasture.

In the simplest agricultural systems, e.g. in crop monocultures or oil palm plantations, mammalian diversity is very low, besides the dominant *Homo sapiens*. While most mammals do poorly in simple agricultural habitats, the opossum *Didelphis marsupialis* tolerates humans, thriving in areas with agriculture and human dwellings, feeding on garbage and other human artifacts. In some parts of the study area The introduced house mice (*Mus musculus*) and rats (*Rattus rattus*) have colonized some parts of the study area, and *Artibeus*

jamaicensis (fruit bat) is ubiquitous where fruit trees (especially figs) occur. Bats were not sampled in strictly agricultural areas, and other species undoubtedly occur here as well.

In much of the study area the agricultural landscape is fairly complex, with small patches of a variety of tree and annual crops, interspersed with scattered trees. In such areas, mammalian diversity can be much higher. Bats, particularly frugivorous ones (10 spp.), are fairly abundant where roost sites and a variety of foods are available. Other mammals to be expected in complex agricultural areas include the cottontail rabbit (*Sylvilagus brasiliensis*), raccoons (*Procyon lotor*), and generalist rodents (*Sigmodon hispidus, Orozomys capito*).

Information on avian fauna of agricultural areas is also very limited, but is likely to share many species recorded by Karr (1971) in pasture areas (see Section A.1.10). Common bird species include ground doves (*Columbigallina minuta*), slaty spinetail (*Synallaxis brachyura*), and seedeaters and grassquits (*Sporophila* spp., *Volatinia jacarina*). The variable seedeater (*Sporophila americana*) is particularly abundant in agricultural and other semi-open areas. Among raptors, barn owls (*Tyto alba*) do well around dwellings and help control rodent populations.

Agricultural areas with vegetation more complex than in pastures offer shelter, nest sites, and feeding opportunities to a greater diversity of birds. These include nectar-feeding hummingbirds (Trochilidae), tyrannid flycatchers (flying insects), and embirizine finches (seed and insects).

Reptiles and amphibians in agricultural areas exist mostly where forest fragments or other vegetation offers complexity and shelter. Because of the constant disturbance associated with farms, the diversity is low, with 7 amphibian species (4 families) and 13 reptiles (6 families). *Bufo marinus* and *Ameiva* lizards are among the few species which do well here. *Bothrops asper* (fer-de-lance) occurs, as does *Physalaemus pustulosus*, a frog which lays its eggs in conspicuous white foamy nests in temporary ponds. Basilisk lizards (*Basiliscus basiliscus*) occur along waterways.

Information on invertebrate fauna in the study area is limited, but a study in Costa Rican agricultural fields shows insect diversity to be very low compared to nearby forests (e.g. 65 vs. 455 beetle species; Janzen, 1973). Overlap between forest and cropland insect faunas was very low. The insect fauna of agricultural areas probably includes species from two main sources: introduced plant pest species; and native 'fugitive' or ruderal species which originally occurred as fragmented populations in small patches of early successional stages in forest areas.

Because of their economic importance, more is known about insects which damage fruits and crops. Carpophagous insects are associated with fruit, legume, and grain crops (maize,

rice). These include many dipterans, including tephritid and drosophilid fruit flies (*Anastrepha* spp. and *Drosophila ananase*), and flies in Otitidae, Lonchaeidae, and Richardiidae families. Lepidopteran pests are important: cutworm larvae (*Spodoptera*) can severely damage young maize plants, *Heliothis* larvae damage developing corn ears and tomato plants, *Diatraea* feeds on sugar cane, and Gelechidae are important pests of fruits. Phloem-feeders are often abundant plant pests, and as vectors of plant plagues: Hemiptera (Miridae, Coreidae, and Lygaeidae); and Homoptera (Membracidae and Aphididae). Beetles are not nearly as diverse as in forests, but weevils (Curculionidae) are often seed pests, and *Andrector salvini* is a common agricultural pest. Finally, ants can be pests of crops, including leaf-cutting ants (*Atta*), which can entirely defoliate crop plants and fruit trees. Other dominant groups include earwigs (Forficulidae), crickets (Gryllidae), katydids (Tettigoniidae), and lacewings (Chrysopidae).

Among beneficial insects are parasitoid wasps are often important biological controls on populations of insect pest. These include Braconidae, Diapriidae, Tiphiidae, Scoliidae, Scelionidae, and Chalidoideae.

No native species depend primarily upon these habitats; the principal value of agricultural lands is as habitat for humans. This is not to discount the ability of agricultural lands to support wildlife, but simply reflects the brief history of anthropogenic habitats, and the fact that species using such areas have available an ever-increasing amount of habitat. Species such as the cotton rat (*Sigmodon hispidus*) and leaf-cutter ants can be a pest of crops; while others, such as insectivorous lizards, amphibians and birds help reduce insect pests. One endangered species is the boa (*Boa constrictor*) which eats rodents. Some rural families recognize their value and protect boas around the house, while others persecute them.

Table A.1. Major plankton categories by size, taxonomy, and trophic position (Smetacek, 1988).

SIZE GROUPS COMPARTMENTS	PICOPL. 0.2-2.0 μm	NANOPL. 2.0-20μm	MICROPL. 20-200 μm	MESO-PL. 0.2-20 mm	MACROPL. 2-20 cm	MEGAPL. 20-200 cm
Bacterioplankton						
Phytoplankton						
Protozooplankton						
Metazooplankton						

Legend:

PICOPL.= Picoplankton; NANOPL.= Nanoplankton; MESOPL.= Mesoplankton; MACROPL.= Macroplankton; MEGAPL.= Megaplankton.

Table A.2. Catálogo de especies de phytoplancton del Golfo de Panamá (Smayda, 1966).

DIATOMEAS	FORMAS CONCENTRICAS (cont...)	FORMAS CONCENTRICAS (Cont...)
	C. a. dichaeta	*C. a. l. stellarus*
FORMAS CONCENTRICAS	*C. a. didymus*	*C. a. l. thorii*
	C. a. var. anglica	*C. a. l. wailseii*
Actinoptychus undulatus	*C. a. var. protuberans*	*Cyclotella caspia*
A. u. var. catenata	*C. a. difficilis*	*C. c. striata*
Asterolampra marylandica	*C. a..diversus*	*Dactyliosolen antarcticus var. laevis*
Asteromphalus flabellatus	*C. a. eibenii*	*D. a. mediterraneus*
A. f. heptactis	*C. a. gracilis*	*Ditylum brightwelli*
Bacteriastrum delicatulum	*C. a. holsaticus*	*D. b. sol*
B. d. elegans	*C. a. laciniosus*	*Eucampia cornuta*
B. d. Hylinum	*C. a. laevis*	*E. c. zoodicus*
B. d. var. princeps	*C. a..lauderi*	*Guinardia cf. blavyana*
B. d. mediterraneum	*C. a. lorenzianus*	*G. b flaccida*
B. d. varians	*C. a. cf. messanensis*	*Hemiaulus hauckii*
Bellerochea malleus	*C. a. pelagicus*	*H. h. sinensis*
Biddulphia alternans	*C. a. cf.pendulus*	*H. h. cuneiformis*
B. a. dubia	*C. a. perpusillus*	*Lauderia annulata*
B. a. longicruris	*C. a. peruvianus*	*Leptocylindrus cf. adriaticus*
B. a. mobiliensis	*C. a. pseudocrinitus*	*L. a. danicus*
B. a. pulchella	*C. a. rostratus*	*L. a. maximus n. sp.*
B. a. sinensis	*C. a. seiracanthus*	*L. a. minimus*
Brenneckella	*C. a. simplex var. calcitrans*	*Lithodesmium undulatum*
Cerataulina bergoni	*C. a. socialis*	*Planktoniella sol*
C. b. compacta	*C. a. subsecundus*	*Rhizosolenia acumidata*
Chatoceros aequatorialis	*C. a. subtilis*	*R. a. alata f. genuina*
C. a. affinis	*C. a. teres*	*R. a . a. f. gracillina*
C. a. var. circinalis	*C. a. tetrastichon*	*R. a a. f. indica*
C. a. var. willei	*C. a. tortissimus*	*R. a. bergonii*
C. a. anastomosans	*C. a. van heurckii*	*R. a. calcar avis*
C. a. apendiculatus	*C. a. vixvisibilis*	*R. a. c. a var. cochlea*
C. a. atlanticus	*Climacodium fraguenfeldianum*	*R. a. cylindrus*
C. a. f. audax	*Corethrom hystrix*	*R. a. delicatula*
C. a. var. neapolitan	*C. h. pelagicum*	*R. a. fragilissima*
C. a. var. skeleton	*Coscinodiscus anguste-lineatus*	*R. a. robusta*
C. a. atlantidae	*C. a. l. cf. argus*	*R. a. setigera*
C. a. brevis	*C. a. l. centralis*	*R. a. stolterfothii*
C. a. coarctatus	*C. a. l. concinnus*	*R. a. styliformis*
C. a. compressus	*C. a. l. excentricus*	*R. a. s. var. latissima*
C. a. constrictus	*C. a. l. cf. gigas*	*R. a. s. var. longispina*
C. a. convolutus	*C. a. l. grani*	*Schroederella delicatula*
C. a. costatus	*C. a. l. cf. lacustris*	*Skeletonema costatum*
C. a. curvisetus	*C. a. l. liniatus*	*S. c. f. tropicum n.f.*
C. a. dadayi	*C. a. l. marginatus*	*Stephanopyxs palmeriana*
C. a. danicus	*C. a. l. perforatus*	*S. p. turris*
C. a. debilis	*C. a. l. p.var. pavillardi*	*Streptotheca thamensis*
C. a. decipiens	*C. a. l. radiatus*	*Thalassiosira subtilis*
C. a. densus	*C. a. l. rothii*	*T. s. aestivalis*

Cuadro A.2. Cont...

PENNADAS FORMAS	DINOFLAGELADOS (Cont...)	DINOFLAGELADOS (Cont...)
	C. d. massiliense	*P. b. f. inflatum*
Asterionella japonica	*C. d. m. f. macroceroides*	*P. b. claudicans*
A. j. f. tropicum n.f.	*C. d. m. f. protuberans*	*P. b. conicum*
Fragilaria cf. nana	*C. d. minutum*	*P. b. crassipes*
Fragilaria norma n. sp.	*C. d. pentagonum*	*P. b. depressum*
Isthmia nervosa	*C. d. p. var. subrobustum*	*P. b. diabolus*
Navicula membranacea	*C. d. setaceum*	*P. b. divergens*
Nitzschia closterium	*C. d. symmetricum*	*P. b. excentricum*
N. c. delicatissima	*C. d. trichoceros*	*P. b. globulus*
N. c. kolaizeckii	*C. d. tripos*	*P. b. g. var. ovatum*
N. c. longissima	*C. d. t. f. semipulchellum*	*P. b. g. var. quarnerense f. spirale*
N. c. lorenziana var. incurva	*Ceratocorys horrida*	*P. b. grande*
N. c. pacifica	*Dinophysis caudata*	*P. b. granii*
N. c. pungens var. atlantica	*D. c. fortii*	*P. b. g. f. mite*
N. c. sigma var. indica	*D. c. hastata*	*P. b.heterospinum*
Opephora pacifica	*D. c. tripos*	*P. b. leonis*
Pseudoeunotia doliolus	*D. c. t. f. semipulchellum*	*P. b. l. f. matzenauri*
Thalassionema nitzschioides	*Exuviaella cf. apora*	*P. b. longispinum*
Thalassiothrix delicatula	*E. a. baltica*	*P.b.minusculum*
T. d. frauenfeldii	*E. a. compressa*	*P. b. minutum*
T. d. f. var. panama n. var.	*E. a. marina*	*P.b.nipponicum*
T. d. longissima	*E. a. vaginula*	*P. b. oceanicum*
T. d. mediterranea	*Glenodinium lenticula f. minor*	*P. b. o. var. oblongum*
T. d. m. var. pacifica	*Goniaulax catenata*	*P. b. ovum*
Tropidoneis antarctica	*G. c. digitales*	*P.b.pellucidum*
T. a. var. polyplasta	*G. c. cf. gracilis*	*P.b.pentagonum*
T. a. lepidoptora	*G. c. minima*	*P.b. p. var. latissimum*
	G. c. monocantha	*P. b. pyriforme*
	G. c. polyedra	*P. b. sinaicum*
DINOFLAGELADOS	*G. c. polygramma*	*P. b. steinii*
	G. c. scrippsa	*P. b. subinerme*
Amphidinium cf. acutissimum	*G. c. spinifera*	*P. b. tenuissimum*
A. a. minutissima	*G. c. tamarensis var. excavatum*	*P. b. trochoideum*
A. a. cf. oceanicum	*G. c. lohmanni*	*Phalacroma doryphorum*
Blepharocysta splendor-maris	*Ornithocercus magnificus*	*Podolampas bipes*
Ceratium declinatum	*O. m. quadratus f. intermedia*	*P. b. spinifera*
C. d. deflexum	*O. m. steinii*	*Prorocentrum gracile*
C. d. extensum	*Oxytuxum caudatum*	*P. g. hentscheli*
C. d. furca	*O. c. curvatum*	*P. g. maximum*
C. d. f. f. belonoides	*O. c. gracilis*	*P. g. obtusidens*
C. d. f. f. eugrammun	*O. c. scolopax*	*P. g. rostratum*
C. d. fusus	*Parahistoneis karsteni*	*P. g. schilleri*
C. d. humile	*Peridinium bipes*	*Protoceratium cf. reticulatum*
C. d. inflatum	*P. b. breve*	*Pseudophalacroma nasutum*
C. d. incisum	*P. b. brevipes*	*Pyrophacus horologicum*
C. d. kofoidii	*P. b. brochi*	

Cuadro A.2. Cont...

COCCOLITHOPHOROS	CYANOPHYTA
Acanthoica cf. monospina	*Anabaena sp.*
A. lithostratus	*Katagnymene spiralis*
Anoplosolenia brasiliensis	*Oscillatoria cf. bonnemaisonii*
Anthosphaera quadricornu	*O. cf. niger*
Braarudosphaera sp.	*O. cf. nigro-viridis*
Calciosolenia cf. murrayi	*Trichodesmium cf. contortum*
C. sinuosa	*T. thiebautii*
Coccolithus huxleyi	
C. leptoporus	
C. pelagicus	**MISCELANEOS**
C. sibogae	
Discosphaera tubifer	*Chilomonas marina*
Gephyrocapsa oceanica	*Euglenaceae*
Halopappus adiraticus	*Halosphaera sp.*
Michaelsarsia elegans	*Lohmaniella evifromis*
Pontosphaera maximus	*Phaecystis*
Syracosphaera mediterranea	*Strombidium conica*
S. nodosa	*S. emergens*
Tergestiella adriatica	*S. (Laboea) crassula*
	S. (L.) strobila
SILICOFLAGELADOS	
Dictyofibula fibula	
D. f. var. aspera	
D. f. var. messanensis	
Distephanus crux	
D. speculum var. octogonum	
D. s. var. polyactis	
Ebria tripartita	
Mesocena polymorpha	
M. p. var. binonaria	
M. p. var. octonaria	

Table A.3. Major taxa of marine zooplankton collected from the Gulf of Panama (from Battelle, 1970; Arellano, 1974; Chang & Solis, 1982; Marra et al., 1987; UNIPAN-ANCON, 1992-93).

Foraminiferans	Decapods (larvae)
Radiolarians	*Squilla parva* (larvae)
Acantharians	*S. panamensis* (larvae)
Tintinnids	Echinoderms (larvae)
Medusae	Appendicularians
Ctenophores	Siphonophores
Polychaetes (larvae)	Doliolids
Gastropods (larvae)	Chaetognaths
Pteropods	Engraulidae (eggs, larvae)
Lamellibranchs (larvae)	Clupeidae (eggs, larvae)
Cladocerans	Gerreidae (eggs, larvae)
Copepods	Carangidae (eggs, larvae)
Ostracods	Sciaenidae (eggs, larvae)
Amphipods	Mugilidae (larvae)
Cirripedes (larvae)	Fish (larvae)

Table A-4. Spawning periods, spawning sites, and egg types for marine fish species of commercial importance in the Gulf of Panama (from Simpson, 1959; Smayda, 1966; Aprieto, 1974; Fish and Wildlife Service, 1978; Thresher, 1984; Angulo, 1985; Pacheco, 1989; Ramirez et. al., 1989; Scott, 1992).

FAMILY	SPECIES	COMMON NAME	SPAWNING PERIOD	SPAWNING SITE	EGG TYPE
CLUPEIDAE	*Clupea harengus*	Pacific herring	Nov. - Apr.	Ocean	Demersal
	Opisthonema oglinum	Herring	Apr. - July	Sea	Pelagic
	Etrumeus teres	Round herring	Apr. - July	Sea	Pelagic
	Sardinella spp.	Sardinella		Littoral zone and deep water	Pelagic, non-adhesive
ENGRAULIDAE	*Cetengraulis mysticetus*	Pacific anchoveta	Oct. - Jan.	Shallow coastal waters in front of mangroves (i.e., Juan Díaz)	Pelagic
CARANGIDAE	*Elagatis bipinnulatus*	Rainbow runner	Entire year, with peak in Mar.		Pelagic
	Oligoplites saurus	Pacific leatherjack	May - Oct.	Shallow continental waters	Pelagic
	Decapterus spp.	Scad			Pelagic
	Chloroscombrus orqueta	Pacific bumper	May - Oct.	Subsurface waters	
LUTJANIDAE	*Lutjanus peru*	Pacific red snapper	Oct. and Feb.	Insular zones	Demersal and pelagic, non-adhesive
SCIAENIDAE	*Cynoscion albus*	Whitefin weakfish	May - Oct.	Coastal fringe	Pelagic
OTHIDAE	*Bothus* spp.	Flounder	Feb. - July (peak in May)	Coastal zones	Pelagic

Table A.5. Fish species collected in the Pacific during the Biological Inventory by habitat and sensitivity (UNIPAN-ANCON, 1992-1993).

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TYP
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
GINGLYMOSTOMATIDAE																	
*Ginglymostoma cirratum**	Tiburón gata	Nurse shark													B de Pt - E	A	
TRIAKIDAE																	
*Mustelus dorsalis**	Tiburón marrón	Sharptooth smoothhound													B de Pt	A	
*Mustelus henlei**	Tiburón marrón	Brown smoothhound													B de Pt	A	
*Mustelus lunulatus**	Tiburón marrón	Sicklefin smoothhound													B de Pt	A	
CARCHARHINIDAE																	
*Carcharinus limbatus**	Tiburón puntinegro	Blacktip shark													Plg (Ct y Oc) - E	A	
*Carcharinus porosus**	Cazón	Smalltail shark													B de Pt - Plg Ct - E	A	
*Carcharinus sp**	Tiburón, toyo, cazón	Shark													B de Pt - Plg Ct - E	A	
*Galeocerdo cuvieri**	Tiburón tigre, tintorera	Tiger shark													B de Pt - Plg(Ct y Oc) - E	A	
SPHYRNIDAE																	
*Sphyrna corona**	Tiburón martillo	Hammerhead													B de Pt - Plg Ct	A	
*Sphyrna sp**	Tiburón martillo	Bannethead shark													B de Pt - Plg Ct - E	A	
*Sphyrna tiburo**	Tiburón martillo	Bannethead													B de Pt - Plg Ct - E	A	
Sphyrna media	Tiburón martillo	Hammerhead												1	B de Pt y Plg Ct	C	4
Sphyrnatiburo vespertina	Tiburón martillo	Hammerhead										1		1	B de Pt, Plg Ct - E	B	4
RHINOBATIDAE																	
Rhinobatos leucorhynchus	Pez guitarra	Whitesnout guitarfish											1		B(Fb) de Pt	C	4
DASYATIDAE																	
Dasyatis brevis	Raya	Whiptail stingray				1				1	1	1	1	1	B(Fb) de Pt	C	6
Dasyatis longus	Raya	Longtail stingray						1	1	1	1			1	B(Fb) de Pt	B	4
ALBULIDAE																	
Albula vulpes	Macabí	Bananafish				1				1				1	B(Fb) de Pt - E	A	3
CLUPEIDAE																	
Lile stolifera	Sardina	Pacific piquitinga	1	1	1			1	1		1				B(Fb) de Pt y Plg Ct	B	4
*Odontognathus panamensis**	Machete	Panama longfin herring													B de Pt	A	3
Opisthonema libertate	Arena	Deepbody thread herring						1	1	1	1	1	1	1	B(Fb) de Pt - Plg Ct	A	3
*Opisthonema mediarastre**	Arenque de hebra	Middling thread herring													Plg Ct	A	3
Opisthopterus dovii	Sinsangre	Pacific longfin herring								1	1	1	1	1	B(Fb) de Pt - E	A	3
ENGRAULIDAE																	
Anchoa exigua	Anchoa	Thin anchovy		1									1	1	B de Pt, Plg Ct - E	B	4

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TYPE
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
Anchoa ischana	Sardina plateada	Slender anchovy					1		1	1		1	1	1	B de Pt, Plg Ct - E	B	4
Anchoa lucida	Anchoa	Bright anchovy		1		1				1			1		B de Pt, Plg Ct - E	B	4
Anchoa panamensis	Anchoveta	Panama anchovy	1	1	1	1		1		1			1		B de Pt, Plg Ct - E	B	4
Anchovia arenicola	Anchoa	Silverstripe anchovy	1	1	1	1	1								B(Fa) de Pt - Plg Ct - E	B	4
Anchovia spp.	Anchoa	Anchovy		1											B(Fa) de Pt - Plg Ct - E	B	4
Cetengraulis mysticetus	Anchoveta	Pacific anchoveta				1				1			1		Plg Ct	A	3
Lycengraulis poeyi	Anchoveta	Pacific toothed anchovy								1					B(Fb) de Pt - E	A	3
MURAENESOCIDAE																	
*Muraenesox coniceps**	Zafiro	Pike congers													B(Fa) de Pt	A	3
ARIIDAE																	
*Arius kessleri**	Cominate, bagre	Bronze sea catfish													B(Fa) de Pt	A	3
*Arius platypogon**	Cominate, bagre	Cominate sea catfish													B(Fa) de Pt	A	3
Arius seemani	Bagre	Jordan sea catfish								1	1	1	1	1	B(Fb) de Pt - E - R	C	4
*Bagre pinnimaculatus**	Barbudo, alguacil	Read sea catfish													B de Pt - E	A	3
*Bagre panamensis**	Barbudo	Chihuil sea catfish													B(Fa) de Pt - E	A	3
Felichthys panamensis							1	1	1	1	1	1	1	1	B(Fb) de Pt - E - R	B	3
*Galeichtyes guatemalensis**	Congo	Sea catfish													B(Fa) de Pt - E - R	A	3
Selenaspis dowi												1	1	1	B(Fb) de Pt - E - R	C	4
SYNODONTIDAE																	
Synodus scituliceps	Pez lagarto	Shorthead lizardfish						1	1	1	1	1	1	1	B(Fb) de Pt	C	4
BELONIDAE																	
*Tylosorus fodiator**	Aguja	Hound needfish													Plg(Ct y Oc)	A	3
FISTULARIIDAE																	
Fistularia corneta	Aguja	Pacific cornetfish						1							B(Fb) de Pt	C	4
POECILIIDAE																	
Poeciliopsis elongata						1									B(Fb) de Pt - E - R	C	6
SERRANIDAE																	
Diplectrum euryplectrum	Sandfish (Panama)	Widespur seabass						1	1	1	1	1	1	1	B(Fb) de Pt	C	4
*Epinephelus acanthistius**	Ambulu, cherna	Gulfconey seabass													B(Fr) de Pt	A	3
Ephinephelus analogus	Merete	Spotted cabrilla grouper						1		1					B(Fr) de Pt	B	4
*Epinephelus guaza**	Mero	Grouper													B(Fr) de Pt	A	3
Epinephelus labriformis	Mereto del Golfo	Flag cabrilla grouper							1	1					B(Fr) de Pt	A	3
Epinephelus multiguttatus	Cherna	Red hind								1					B(Fr) de Pt	A	3

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TY
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
*Epinephelus panamensis**	Cherna	Panama greisby grouper													B(Fr) de Pt	A	
*Mycteroperca xenarcha**	Cherna	Broomtail grouper													B(Fr) de Pt – Tld – Mg	A	
GRAMMISTIDAE																	
Rypticus nigripinnis	Jaboncillo	Black scapfish						1		1					B(Fr) de Pt	C	
CARANGIDAE																	
Alectes ciliaris	Caballito	African pompano							1	1					B de Pt, Plg Ct y Oc	C	
*Carangoides vinctus**	Cojinua chata	Golden jack													Plg(Ct y Oc)	A	
*Carangoides ortrynter**	Cojinua chata	Threadfin jack													Plg(Ct y Oc)	A	
*Caranx caballus**	Cojinua	Green jack													B de Pt – Plg(Ct y Oc) – E	A	
Caranx hippos	Jurel	Crevalle jack								1				1	Plg(Ct y Oc) – B de Pt – E	A	
Caranx marginatus	Jurel	Sixband jack		1											Plg(Ct y Oc)	B	
*Decapterus macrosoma**	Jurel chato–cojinua chata	Shortfin scad													Plg(Ct y Oc) – E – Mg	A	
*Elegatis bipinnulatus**	Salmon	Rainbow runner													Plg(Ct y Oc)	A	
Chloroscombrus orqueta	Anchoveta	Pacific bumper						1	1	1	1	1	1		B de Pt – Mg – E – Plg Oc	B	
Hemicaranx atrimanus	Jurelito	Pacific bluntnose jack												1	B de Pt – E – Plg Ct	A	
*Hemicaranx leucurus**	Jurelito														B de Pt – E – Plg Ct	A	
Hemicaranx zelotes	Cojinua chata	Chumbo bluntrose jack												1	B de Pt – E – Plg Ct	A	
*Hemicaranx spp**	Cojinua chata														B de Pt – E – Plg Ct	A	
*Gnathanodon speciosus**	Boquipenda	Kingyellow jack													Plg(Ct y Oc)	A	
Oligoplites mundus	Páramo	Bigjaw leatherjacket		1	1	1	1								B de Pt – E – Plg Ct	B	
*Oligoplites refulgens**	Longino	Bright leatherjacket													B(Fa) de Pt – E	A	
*Oligoplites spp**															B(Fa) de Pt	A	
Selar crumenophthalmus	Cojinua	Bigeye scad									1				Plg Ct	A	
Selene brevoortii	Adolfito, caballito	Hairfin lookdown		1				1	1	1	1		1	1	B(Fb) de Pt – Plg Ct	A	
Selene oerstedii	Caballito	Pacific lockdown									1		1	1	B(Fa) de Pt – Plg Ct	A	
*Selene peruvianus**	Caballito	Peruvian moonfish													B de Pt – Plg Ct	A	
*Seriola peruvianus**	Bojala	Fortune jack													B de Pt	A	
*Trachinotus kennedy**	Pámpano	Silver pompano													B de Pt – Plg Ct	A	
*Trachinotus paitensis**	Gitano	Paloma pompano													B de Pt – Plg Ct – E	A	
Vomer declivifrons	Pez luna	Pacific moonfish						1	1	1	1	1	1	1	B(Fa) de Pt – Plg Ct	A	
NEMATISTIIDAE																	

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TYPE
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
*Nematistius pectoralis**	Pez gallo	Roosterfish													B(Fa) de Pt – Plg Ct	A	3
CORYPHAENIDAE																	
*Coryphaena hippurus**	Dorado	Common dolphinfish													Plg(Ct y Oc)	A	3
UTJANIDAE																	
*Holopagrus guntheri**	Pargo rosquero	Barred pargo													B(Fr) de Pt	A	3
*Lutjanus argentiventris**	Pargo amarillo	Amarillo snapper													B(Fb,Fr) de Pt– Mg – E – R	A	3
*Lutjanus auratus**	Pargo julguera	Mullet snapper													B(Fa) de Pt – E	A	3
Lutjanus guttatus	Pargo de la mancha	Spotted rose snapper						1	1	1		1			B(Fr y Fb) de Pt	A	3
*Lutjanus jordani**	Pargo seda	Jordan snapper													B de Pt	A	3
OBOTIDAE																	
*Lobotes pacifici**	Berrugate o Pargo negro	Pacific tripletail													B de Pt – Plg Ct – E	A	3
*Lobotes surinamensis**	Berrugate	Tripletail													B de Pt – Plg Ct – E	A	3
GERREIDAE																	
Diapterus peruvianus	Mojarra	Peruvian mojarra	1	1				1	1	1	1	1	1	1	B(Fb) de Pt – E	B	4
Eucinostomus californiensis	Mojarra	Mojarra	1	1	1			1	1	1	1	1	1	1	B(Fb) de Pt – E	C	4
E. californiensis elongatus	Mojarra	Mojarra		1						1			1	1	B(Fb) de Pt – E	C	4
Gerres cinereus	Mojarra	Yellowfin mojarra						1	1	1	1		1		B(Fb) de Pt – E	C	4
POMADASYIDAE																	
*Anisostremus dovii**	Puerca	Spotted head sargo													B(Fr) de Pt	A	3
Anisostremus pacifici	Puerca	Currucu sargo												1	B(Fr) de Pt	A	3
Haemulon sexfasciatum	Roncador	Greybar grunt					1								B(Fr) de Pt	B	4
*Haemulon steindachneri**	Roncador	Chere chere–grunt													B(Fr) de Pt – E	A	3
Orthopristis chalceus	Brin	Brassy grunt							1						B de Pt	A	3
Orthopristis spp.	Roncador	Grunt								1	1				B(Fb) de Pt		
*Pomadasys axillaris**	Roncador	Grunt													B(Fr) de Pt	A	3
Pomadasys leuciscus	Roncador	Grunt						1	1	1	1	1		1	B de Pt	A	3
Pomadasys macracanthus	Pargo blanco	Longspine grunt			1	1	1							1	B de Pt – E	B	4
Pomadasys panamensis	Pargo blanco	Panama grunt		1	1	1	1	1	1	1	1	1		1	B de Pt	A	3
SCIAENIDAE																	
Bairdiella chrysoleuca	Corvineta	Weakfish						1			1	1	1	1	B(Fb, Fr) de Pt	A	3
Cynoscion phoxocephalus	Corvina blanca	Cachima weakfish						1	1	1	1	1	1	1	B(Fb) de Pt	B	3
*Cynoscion praedatorius**	Corvina bocona	Bocone weakfish													B(Fa) de Pt	A	3
*Cynoscion reticulatus**	Corvina rayada	Striped corvina									1				B(Fb) de Pt	A	3

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12		
*Cynoscion squamipinnis**	Corvina pelona	Yellowmouth weakfish													B de Pt – E	A
*Cynoscion stolzmanni**	Corvina blanca	Pelona weakfish													B de Pt – E	A
*Elattarmus archidium**	Corvina	Bluish streaky croaker													B de Pt	A
*Isopisthus altipinnis**	Corvina	Silver weakfish													B(Fa) de Pt – E	A
Larimus acclivis	Barbirubia	Steeplined drum						1			1	1	1	1	B(Fb) de Pt	A
Larimus argenteus	Corvina Boquituerta	Silvery drum									1		1		B(Fb) de Pt	A
Larimus effulgens	Corvina chata	Shining drum											1		B(Fb) de Pt	A
Macrodon mordax	Corvina manteca	Toothed kingweakfish											1	1	B(Fb) de Pt	B
*Micropogonia furnieri**	Corvina lona	Croaker													B de Pt	A
Micropogonia altipinnis	Corvina	Golden croaker												1	B(Fb y Fr) de Pt – E	B
Menticirrhus panamensis	Cococha	Panama kingcroaker							1	1				1	B(Fb) de Pt	A
*Nebris occidentalis**	Guabina	Blind corvina													B(Fa) de Pt – E	A
Ophioscion sciera	Parita	Dusky croaker										1	1		B(Fb) de Pt	B
Ophioscion simulus	Pancha	Snub–nosed croaker										1			B(Fb) de Pt – E	B
*Paralunchurus dumerilli**	Herrero, sargento	Suco croaker													B(Fr) de Pt – E	A
Sciaena deliciosa	Roncacho	Lorna drum			1		1				1		1	1	B(Fb) de Pt y Plg – Ct	B
Stellifer furthi	Cococha blanca	Whitesmall drum												1	B(Fb) de Pt – E	B
Umbrina xanti	Barbirrubia	Common yellowtail croaker							1						B(Fb) de Pt	B
MULLIDAE																
Pseudopeneus grandiquamis	Barbita	Bigscale goatfish						1	1	1	1	1		1	B de Pt	A
KYPHOSIDAE																
*Sectator ocyurus**	Salema	Bluestriped chup													Plg – Oc	A
EPHIPPIDAE																
Chaetodipterus zonatus	Pollera	Pacific spadefish								1					B(Fa y Fr) de Pt	A
*Parapsettus panamensis**	Lenguado, media tapa	Panama spadefish													B(Fa) de Pt	A
CHAETODONTIDAE																
Chaetodon humeralis	Mariposa	Butterflyfishes						1	1						B(Fr) de Pt	C
TRICHIURIDAE																
Trichiurus lepturus	Pez-sable	Cutlassfish						1			1		1	1	B(Fb) de Pt y Plg Ct	C
SCARIDAE																
*Scaurus noyesi**	Pez loro	Bluechin parrotfish													B(Fr) de Pt	A
*Scaurus puntulatus**	Pez loro	Parrotfish													B(Fr) de Pt	A
GOBIIDAE																

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TYPE
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
Bathygobius soporator	Chupa piedras	Gobies		1								1			B(Fb,Fr) de Pt - E - R	C	6
Euctenogobius sp.	Chupa piedras	Gobies										1			B(Fb,Fr) de Pt - E - R	C	6
Gobionellus sagittula	Chupa piedras	Gobies		1	1	1									B(Fb,Fr) de Pt - E - R	C	6
TRIGLIDAE																	
Bellator loxias	Volador	Barred searobin						1	1	1	1	1	1	1	B de Pt	C	6
*Prionotus horrens**	Mal armao, torito	Bristly searobin													B de Pt	A	3
Prionotus quiescens	Volador	Quiet searobin									1				B de Pt	C	6
*Prionotus ruscarius**	Mal armao, torito	Common searobin													B de Pt	A	3
CENTROPOMIDAE																	
*Centropomus poeyi**	Robalo	Snook													B de Pt - E	A	3
SCOMBRIDAE																	
*Acanthocybium solandri**	Wahoo	Wahoo													Plg(Ct y Oc)	A	3
*Euthynnus alleteratus**	Bonito														Plg Ct - B de Pt	A	3
*Katsuwonus pelamis**	Barrilete	Skipjack tuna													Plg(Ct y Oc)	A	3
*Sarda orientalis**	Bonito blanco	Striped bonito													Plg Ct	A	3
*Scomber japonicus**	Bolillo	Chubmackered													B de (Pt y Tld) - Plg(Ct y Oc)	A	3
*Scomberomorus maculatus**	Sierra	Sierra													B de Pt - Plg Ct	A	3
*Scomberomorus regalis**	Sierra	Sierra													B de (Pt y Tld) - Plg(Ct y Oc)	A	3
*Scomberomorus sierra**	Sierra	Sierra													B de Pt - Plg Ct	A	3
*Thunnus alalunga**	Albacora	Albacore													Plg Oc	A	3
*Thunnus albacares**	Atun aleta amarilla	Yellowfin tuna													Plg Oc	A	3
XIPHIDAE																	
*Xiphias gladius**	Pez espada	Swordfish													Plg (Ct y Oc)	A	3
STROMATEIDAE																	
*Prepilus medius**	Palometa	Pacific harvestfish													B de Pt	A	3
Prepilus palometa	Palometa	Pacific harvestfish						1	1	1	1	1	1	1	B de Pt y Plg Ct	A	3-5
*Prepilus snyderi**	Palometa	Pacific butterfish													B de Pt - Plg Ct	A	3
POMACANTHIDAE																	
*Pomacanthus zonipectus**	Pollera	Cortiz angelfish													B(Fr) de Pt	A	3
MUGILIDAE																	
*Mugil cephalus**	Lisa	Striped mullet													B(Fa) - Plg Ct - E - R	A	3
*Mugil curema**	Lisa	White mullet	1	1		1									B(Fb) de Pt - Plg Ct - R	A	3
SPHYRAENIDAE																	

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	T
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
*Sphyraena ensis**	Barracuda	Mexican barracuda													B de Pt - Plg Ct	A	
LABRIDAE																	
*Bodianus rufus**	Pez perro	Dogfish													B(Fr) de Pt	A	
ATHERINIDAE																	
Atherinella panemensis	Pejerey	Panama silverside	1	1	1	1	1								B(Fb) de Pt - Plg Ct	B	
Melaniris pachylepis	Pejerey	Thickscale silverside	1	1	1										B(Fb) de Pt - E	B	
POLYNEMIDAE																	
Polydactylus approximans	Bobos	Blue bobos							1	1	1	1	1	1	B(Fb) de Pt	A	
Polydactylus opercularis	Bobo amarillo	Yellow bobo						1							B(Fb) de Pt	A	
BOTHIDAE																	
Ciclopsetta panamensis	Lenguado	Godis flounder						1	1	1	1	1	1	1	B(Fb) de Pt	A	
*Ciclopsetta querna**	Lenguado	Toothed flounder													B(Fa) de Pt	A	
Citharichthys gilberti	Lenguado	Bigmouth sanddab		1	1	1		1	1	1					B(Fb) de Pt - E	A	
Citharichthys platophrys	Lenguado	Small sandab									1				B(Fb) de Pt	A	
Etropus crossotus	Lenguado	Tringed flounder						1	1	1	1	1	1	1	B(Fb) de Pt	A	
*Hippoglossina bollmani**	Lenguado	Spotted flounder													B(Fb) de Pt	A	
Paralichthys woolmani	Lenguado	Speckled flounder						1	1	1	1	1	1	1	B(Fb) de Pt	A	
Pseudorhombus dentritica	Lenguado	Threespot flounder								1		1		1	B(Fb) de Pt	A	
SOLEIDAE																	
Achirus mazatlanus	Lenguado	Mazatlan sole								1			1		B(Fb) de Pt - E - R	B	
CYNOGLOSSIDAE																	
Symphurus elongatus	Lenguado	Tonguefish						1	1	1	1	1	1	1	B(Fb) de Pt	C	
Symphurus leei	Lenguado	Tonguefish												1	B(Fb) de Pt	C	
BALISTIDAE																	
Balistes naufragium	Pejepuerco	Triggerfish								1					B(Fb y Fr) de Pt - E	C	
TETRADONTIDAE																	
Guentheridia formosa	Tamboriles	Puffers						1	1	1	1	1	1	1	B(Fb y Fr) de Pt - E	C	
Sphoeroides annulatus	Tamboriles	Puffers		1		1		1	1	1	1	1	1	1	B(Fb y Fr) de Pt - E	C	
Sphoeroides lobatus	Tamboriles	Puffers						1							B(Fb y Fr) de Pt - E	C	
Tetrodon hispidus	Tamboriles	Puffers							1						B(Fb y Fr) de Pt - E	C	
DIODONTIDAE																	
Diodon holocanthus							1	1							B(Fb) de Pt	C	
Diodon hystrix									1	1					B(Fb) de Pt	C	

Table A.5. Cont...

TAXA	COMMON NAME		STATIONS												HABITAT	SEN	TYPE
	SPANISH	ENGLISH	1	2	3	4	5	6	7	8	9	10	11	12			
BATRACHOIDIDAE																	
Batrachoides pacifici	Pez rana	Pacific toadfish								1			1	1	B(Fb) de Pt	C	6
Daector dowi								1	1	1	1	1	1	1	B(Fb) de Pt	C	6
Daector reticulata								1	1		1	1			B(Fb) de Pt	C	6
Porichthys margaritatus								1	1	1	1	1	1	1	B(Fb) de Pt	C	6
RHINOPTERIDAE																	
Rhinoptera steindachneri	Raya hocico de vaca	Pacific cownose ray												1	B(Fb) de Pt y Plg Ct	C	6
Families: 35 Species: 102			8	20	12	15	10	40	39	52	42	38	44	52			

Bottom type key
B = Benthic
Fa = Sandy
Fb = Soft (mud)
Fr = Rocky
Fcr = Coralline

Ct = Coastal
Oc = Oceanic
Plg = Pelagic
Pt = Shelf
Tld = Sideslope

Sensitivity
A = Maximum
B = Intermediate
C = Minimum

Type
1 = Endemic (cited just for Panama)
2 = Major abundance or frequency
3 = Commercial fisheries

4 = Potential
5 = Game species
6 = Not used

Table A.6. National fisheries production (in metric tons) by activity and species groups from 1981 – 1990. (Dirección General de Recursos Marinos, 1992).

	1981	1982	1983	1984	1985	1986	1987	1988	1989	19
Totals	118,412	88,094	149,656	113,779	255,221	104,047	136,842	99,170	157,796	102,1
1. Industrial Fisheries	111,893	84,904	145,967	109,494	250,985	96,896	128,294	89,555	149,094	93,1
A. Directed										
1.1 Fishes	104,842	77,972	139,219	103,898	243,829	90,845	124,340	86,213	142,977	89,1
Anchovies	77,043	57,446	127,172	89,003	241,350	84,793	111,769	39,114	120,919	61,7
Herrings	24,547	19,011	11,775	14,400	2,294	4,669	9,656	40,472	17,507	23,2
Others	3,252	1,515	272	495	185	1,383	2,915	6,627	4,551	4,1
1.2 Crustaceans	7,051	6,932	6,748	5,596	7,156	6,051	3,954	3,342	6,117	4,0
Shrimps	7,051	6,932	6,748	5,596	7,156	6,051	3,954	3,342	6,117	4,0
White	1,949	1,670	1,775	1,693	1,701	1,489	1,576	1,111	1,344	1,0
Titi	2,960	2,829	3,314	2,103	2,963	1,690	1,173	1,105	1,961	1,0
Caraball	141	187	186	150	150	81	72	74	133	1
Red	1,001	1,112	781	1,424	1,784	1,369	758	891	1,515	1,1
Fidel	379	490	75	181	557	1,415	158	131	395	1
Northern nylon shrimp (*)	621	644	617	45	1	7	217	30	769	4
B. Incidental	2,450	928	975	673	295	405	328	383	523	8
Fishes	2,252	835	877	598	269	389	315	358	501	7
Crustaceans	7	19	20	16	4	7	8	15	8	
Mollusks	189	74	78	54	21	9	5	10	14	
Sea turtles	2	0	0	5	1					
2. Artisanal Fisheries	4,069	1,697	2,166	2,633	3,036	5,993	6,989	7,589	7,117	7,2
2.1 Fishes	3,116	1,235	1,627	1,976	2,355	1,635	1,841	6,581	5,910	6,1
Snappers	528	254	346	433	760	460	575	1,806	2,157	2,3
Mackarel	350	151	212	406	369	121	113	630	567	3
Jack	551	191	262	427	346	173	231	399	733	5
Croaker	354	138	173	176	242	187	185	396	325	3
Other species	1,333	501	634	534	638	694	737	3,350	2,128	2,5
2.2 Crustaceans	630	202	269	281	361	396	736	510	446	4
Shrimps	151	155	152	206	207	137	138	186	174	1

Table A.6. Cont...

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
White	89	91	91	152	171	90	81	132	123	130
Titi	60	62	54	53	32	47	51	53	49	14
Carabali	2	2	7	1	4		6	1	2	0
Lobsters	479	47	117	75	154	259	598	324	272	300
Spiny	474	31	114	72	149	250	594	319	262	240
Shield lipper lobster	5	16	3	3	5	9	4	5	10	60
2.3 Mollusks	322	259	268	376	320	3,962	4,412	498	761	684
Queen shell		1	1				1	2	3	7
Conch								2	6	
Squids	19	4	3	2	1	1	1	34	56	68
Conchuela	303	254	264	374	319	3,961	4,410	460	696	609
2.4 Sea turtles	1	1	2							
3. Aquaculture	0	565	548	979	905	753	1,231	1,643	1,062	893
Shrimps	0	565	548	979	905	753	1,231	1,643	1,062	893

(*) The weight is of complete shrimp.

Table A.7. Yield of commercial species in the Gulf of Panamá. (IMR, 1988).

Family	Species	Common name	Catch (kg/h)
ARIIDAE	*Arius troscheli*	Chili catfish	68.0
	Bagre pinnimaculatus	Red sea catfish	24.1
	Arius platypogon	Cominate sea catfish	8.7
	Arius lentiginosus	Freckled sea catfish	7.5
	Bagre panamensis	Chihuil sea catfish	7.2
	Cathorops gulosus	Sea catfish	4.7
	Arius sp.	Sea catfish	4.0
	Bagre sp.	Sea catfish	1.2
	Arius dasycephalus	Cuate sea catfish	0.6
BOTHIDAE	*Cyclopsetta querna*	Toothed flounder	23.3
	Citharichthys sordidus	Pacific sanddab	20.5
	Citharichthys sp.	Sanddab	9.5
	Cyclopsetta panamensis	God's flounder	6.9
	Syacium ovale	Oval flounder	5.6
	BOTHIDAE	Unidentified sp.	4.5
	Paralichthys sp.	Flounder	3.2
	Caulolatilus affinis		3.2
	Hippoglossina bollmani	Spotted flounder	2.6
	Ancylopsetta dendritica		2.5
	Monolene maculipinna	Pacific deepwater flounder	1.9
	Citharichthys platophrys	Small sanddab	1.7
	Engyophrys sancti-laurenti	Speckledtail flounder	1.7
	Hippoglossina tetrophthalmus	Fourspot flounder	1.4
	Etropus peruvianus	Peruvian flounder	1.2
	Citharichthys xanthostigma	Longfin sanddab	0.0
CARANGIDAE	*Gnathanodon speciosus*	Kingyellow jack	756.9
	Decapterus macarellus	Mackerel scad	511.4
	Seriola peruana	Amberjack	359.5
	Chloroscombrus orqueta	Pacific bumper	338.3
	Hemicaranx leucurus	Pacific bluntnose jack	37.7
	Selene peruvianus	Pacific moonfish	34.3
	Decapterus sp.	Scad	28.1
	Carangoides vinctus		13.8
	Selar crumenophthalmus	Bigeye scad	12.3
	Carangoides ortrynter		10.0
	Hemicaranx zelotes	Chumbo bluntnose jack	9.5
	Trachinotus kennedyi	Longfin pompano	9.0
	Caranx caballus	Green jack	8.5
	Alectis ciliaris	Threadfin fish	7.5
	Selene brevoorti	Hairfin lookdown	7.5
	Hemicaranx sp.	Jack	7.2
	Oligoplites altus	Bigjaw leatherjacket	6.6
	Selene oerstedii	Pac. lookdown	5.6
	Oligoplites refulgens	Slender leatherjack	4.9
	Seriola sp.	Amberjack	3.4

Table A.7. Cont...

Family	Species	Common name	Catch (kg/h)
	Oligoplites saurus inornatus	Yellowtail leatherjack	2.8
	Trachinotus paitensis	Pompano	2.4
	Caranx hippos	Common jack	2.0
	Oligoplites sp.	Leatherjack	1.6
	Selene sp.	Jack	0.0
CLUPEIDAE	*Opisthonema libertate*	Pac. thread herring	93.7
	Etrumeus teres	Round herring	67.8
	Opisthonema medirastre	Middling thread herring	47.9
	Neoopisthopterus tropicus	Tropical longfin herring	6.9
	Opisthopterus dovii	Pac. longfin herring	5.6
	Pliosteostoma lutipinnis	Yellowfin herring	5.1
	Opisthopterus equitorialis	Razor longfin herring	4.9
	Odontognathus panamensis	Panama longfin herring	3.5
	Harengula thrissina	Flatiron thread herring	3.5
	Opisthopterus macrops	Bigeye longfin herring	3.3
	Opisthopterus sp.	Herring	2.1
CYNOGLOSSIDAE	*Symphurus leei*	Tonguefish	57.5
	Symphurus sp.	Tonguefish	10.5
	CYNOGLOSSIDAE	Unidentified sp.	9.8
	Symphurus elongatus	Tonguefish	4.6
	Symphurus atricauda	California tonguefish	3.3
	Symphurus atramentatus	Tonguefish	2.3
ENGRAULIDIDAE	*Anchoa helleri*	Gulf anchovy	277.6
	Cetengraulis mysticetus	Pacific anchoveta	240.1
	Anchoa chamensis	Anchovy	37.1
	Anchoa ischana	Slender anchovy	24.9
	Anchoa walkeri	Walker's anchovy	18.1
	Anchoa curta	Short anchovy	11.8
	Anchoa argentivittata	Silvertripe anchovy	7.5
	Anchoa mundeola	Narrow band anchovy	7.2
	Anchoa sp.	Anchovy	5.8
	Anchoa spinifer	Spicule anchovy	4.4
	Anchoa lucida	Bright anchovy	3.1
	Anchovia macrolepidota	Anchovy	3.1
	Lycengraulis poeyi	Pacific toothed anchovy	2.4
	Anchoa starksi	Blacktail anchovy	1.6
	Anchoa exigua	Thin anchovy	1.3
	Anchoa eigenmannia	Pearl anchovy	0.4
	Anchoviella balboae	Balboa anchovy	0.2
	Anchoa nasus	Longsnout anchovy	0.0
GERREIDAE	*Diapterus peruvianus*	Peruvian mojarra	37.2
	Eucinostomus gracilis	Pacific flagfin mojarra	8.9
	Diapterus aureolus	Golden mojarra	6.6
	Eucinostomus argenteus	Silver mojarra	2.5

Table A.7. Cont...

Family	Species	Common name	Catch (kg/h)
	Diapterus sp.	Mojarra	0.8
	Eucinostomus sp.	Mojarra	0.0
LUTJANIDAE	*Lutjanus peru*	Pacific red snapper	562.9
	Lutjanus guttatus	Spotted rose snapper	42.9
	Lutjanus argentiventris	Yellowtail snapper	31.0
	Lutjanus colorado	Colorado snapper	27.7
	Hoplopagrus guntheri	Barred snapper	6.9
	Lutjanus inermis	Pacific rabirrubia	2.3
	Lutjanus sp.	Snapper	1.8
	Lutjanus viridis	Blue-and-Gold snapper	1.2
MULLIDAE	*Pseudupeneus grandisquamis*	Red goatfish	7.0
	MULLIDAE	Unidentified sp.	0.0
POLYNEMIDAE	*Polydactylus opercularis*	Yellow bobo	30.2
	Polydactylus approximans	Blue bobo	12.8
POMADASYIDAE	*Anisotremus dovii*	Spotted head sargo	264.6
	Orthopristis sp.	Grunt	246.8
	POMADASYIDAE	Unidentified sp.	95.7
	Orthopristis reddingi	Bronzestriped grunt	72.5
	Orthopristis chalceus	Brassy grunt	60.5
	Anisotremus interruptus	Burrito grunt	32.4
	Pomadasys panamensis	Panama grunt	28.7
	Pomadasys nitidus	Grunt	25.1
	Pomadasys macracanthus	Longspine grunt	9.7
	Pomadasys leuciscus	Grunt	9.6
	Pomadasys sp.	Grunt	7.1
	Haemulon steindachneri	Chere-chere grunt	4.8
	Xenichthys xanti	Bigeye salema	1.5
	Pomadasys bayanus	Purple mouth grunt	1.0
	Haemulon scudderi	Gray grunt	1.0
SCIAENIDAE	*Stellifer sp.*	Drum	48.4
	Bairdiella sp.	Croaker	37.9
	SCIAENIDAE	Unidentified sp.	34.6
	Ophioscion sciera	Duskey croaker	24.6
	Cynoscion xanthulus	Orangemouth corvina	24.6
	Micropogonias altipinnis	Golden croaker	22.2
	Cynoscion phoxocephalus	Cachema weakfish	20.7
	Stellifer zestocarus	Softhead drum	14.9
	Stellifer illecebrosus	Spur drum	12.9
	Larimus gulosus	Largemouth drum	11.9
	Bairdiella chrysoleuca		11.5
	Stellifer furthii	White small drum	11.2
	Isopisthus altipinnis	Silver weakfish	10.4
	Cynoscion squamipinnis	Yellowmouth weakfish	9.4

Table A.7. Cont...

Family	Species	Common name	Catch (kg/h)
	Cynoscion reticulatus	Striped corvina	8.0
	Cynoscion albus	Whitefin weakfish	7.2
	Cynoscion sp.	Weakfish	7.1
	Stellifer oscitans	Yawning drum	5.6
	Umbrina sp.	Croaker	4.8
	Menticirrhus nasus	Highfin corvina	4.3
	Stellifer ericymba	Chimbera drum	3.4
	Elattarchus archidium	Bluish streaky croaker	3.2
	larimus acclivis	Steeplined drum	2.8
	Larimus effulgens	Shining drum	2.2
	Ophioscion strabo	Blinkard croaker	2.1
	Larimus argenteus	Silvery drums	1.8
	Macrodon mordax	Toothed kingweakfish	1.6
	Ophioscion typicus	Tuza croaker	1.3
	Umbrina roncador	Yellowfin croaker	0.8
	Cynoscion altipinnis	Highfin weakfish	0.0
	Menticirrhus undulatus	California corvina	0.0
	Nebris occidentalis	Blind corvina	0.0
SCOMBRIDAE	*Euthynnus lineatus*	Black skipjack	28.0
	Scomberomorus sierra	Sierra mackerel	21.2
	Auxis sp.	Tuna	11.8
	Scomberomorus concolor	Mackarel	4.5
	Scomber japonicus	Mackarel	2.0
	SCOMBRIDAE	Unidentified sp.	0.0
SERRANIDAE	*Pronotogrammus multifasciatus*	Seabass	6237.9
	Hemanthias signifer		410.7
	Diplectrum euryplectrum	Widespurbass	50.6
	Mycteroperca xenarcha	Broomtail grouper	47.3
	Epinephelus sp.		32.8
	Diplectrum sp.	Seabass	22.6
	Diplectrum macropoma	Cagua seabass	21.2
	Diplectrum maximum	large seabass	14.1
	Diplectrum rostrum		10.0
	Diplectrum eumelum	Checkbeutiful seabass	7.5
	Epinephelus niveatus	Snowy grouper	5.8
	Diplectrum pacificum	Pacific sand perch	5.0
	Paralabrax sp.	Sandbass	4.5
	Pronotogrammus eos	Sunrise seabass	3.6
	Hemanthias peruanus	Split tail bass	2.9
	Epinephelus analogus	Spotted cabrilla	2.2
	Paralabrax callaensis	Sandbass	1.7
	Diplectrum labarum	Highfin seabass	0.4
	Epinephelus multiguttatus	Pac. guaseta	0.0
SPHYRAENIDAE	*Sphyraena ensis*	Barracuda	18.5

Table A.7. Cont...

Family	Species	Common name	Catch (kg/h)
STROMATEIDAE	*Peprilus medius*	Pacific harvestfish	222.7
	Peprilus snyderi	Pacific butterfish	32.7
	Peprilus sp.		7.3
SHARKS	*Galeocerdo cuvier*	Tiger shark	300.0
	Alopias sp.	Fox shark	200.0
	TRIAKIDAE	Smoothhound	56.1
	Mustelus sp.	Smoothhound	36.1
	Carcharhinus sp.		34.4
	Sphyrna media	Scoophead	30.4
	Carcharhinus limbatus	Blacktip	20.2
	Sphyrna tiburo	Bonnethead	17.6
	Mustelus lunulatus	Sicklefin smooth hound	17.5
	Carcharhinus porosus	Smalltail shark	13.4
	Sphyrna lewini	Bronze hammerhead	9.7
	Sphyrna corona	Scalloped bonnethead	7.0
	Ginglymostoma cirratum	Nurseshark	6.6
	Rhizoprionodon longurio	Pac. sharpnose shark	5.8
	Heterodontus mexicanus		3.6
	Sphyrna sp.	Hammerhead	3.4
SHRIMPS	*Heterocarpus vicarius*	Northern nylon shrimp	824.4
	PANDALIDAE	Unidentified sp.	426.1
	Protrachypene precipua	Titi shrimp	21.6
	Solenocera agassizii	Kolibri shrimp	17.8
	Shrimps small non comm.	Unidentified sp.	8.5
	SHRIMPS	Unidentified sp.	7.5
	Trachypenaeus byrdi	Carabali shrimp	6.3
	Sicyonia picta	Painted rock shrimp	4.2
	Xiphopenaeus riveti	Pacific seabob	3.0
	Penaeus californiensis	Yellow-leg shrimp	2.4
	Penaeus occidentalis	Western white shrimp	2.0
	Penaeus brevirostris	Crystal shrimp	2.0
	Penaeus stylirostris	Blue shrimp	1.5
	Sicyonia disdorsalis	Keeked rock shrimp	1.2
	Penaeus vannamei	White-leg shrimp	1.1
	Sicyonia sp.	Rockshrimp	0.7
	Solenocera mutator	Land shrimp	0.3
	Trachypenaeus fuscina	Pinto shrimp	0.0
LOLIGINIDAE	*Loliolopsis diomedeae*	Dart squid	146.8
	Lolliguncula panamensis	Squid	1.5

Table A.8. Tuna catches and exports (in metric tons) to the United States by ships with panamanian flag in the eastern Pacific (ITTC).

YEAR	CAPTURE							EXPORTS						
	AA	%	BB	%	P	%	TOTAL	AA	%	BB	%	P	%	TOTAL
1980	6,133	52.7	3,887	33.4	1,608	13.8	11,628	5,902	53.9	3,431	31.4	1,608	14.7	10,941
1981	8,810	63.7	4,166	30.1	853	6.2	13,829	8,738	63.5	4,166	30.3	853	6.2	13,757
1982	10,385	61.4	5,728	33.9	797	4.7	16,910	8,788	57.4	5,728	37.4	797	5.2	15,313
1983	3,001	70.3	755	17.7	510	12.0	4,266	2,858	69.3	755	18.3	510	12.4	4,123
1984	1,177	98.9	13	1.1			1,190	1,177	98.9	13	1.1			1,190
1985	12,237	91.9	1,083	8.1			13,320	12,145	91.8	1,083	8.2			13,228
1986	10,180	91.3	975	8.7			11,155	9,836	91.2	945	8.8			10,781
1987	8,161	91.2	785	8.8			8,946	6,388	95.7	287	4.3			6,675
1988	3,953	80.3	836	17.0	132	2.7	4,921							
TOTAL	64,037	74.3	18,228	21.2	3,900	4.5	86,165	55,832	73.5	16,408	21.6	3,768	5.0	76,008

AA = Thunnus albacares (yellowfin tuna)
BB = Katsuwonus pelamis (skipjack tuna)
P = Thunnus obesus (bigeye tuna)

Table A.9. Weight and value of the fishery exports of Panama (DGRM, 1992).

DETAIL		YEARS										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Totals	P:	24,213	14,449	27,102	16,560	75,074	36,628	45,668	25,238	44,988	28,557	33,022
	V:	59,928	63,303	72,725	60,838	85,525	114,453	117,235	78,818	90,488	65,934	74,758
Fish oil	P:	3,372	1,052	2,843	1,560	28,817	11,187	10,195	3,056	13,373	6,110	8,637
	V:	1,295	290	884	431	6,029	1,536	1,711	1,011	2,211	111	1,589
Shrimps	P:	6,426	7,636	7,678	7,183	9,159	9,477	7,397	6,625	7,846	6,076	6,439
	V:	42,654	54,973	57,467	55,316	66,459	72,022	68,007	54,119	64,090	44,878	50,671
Fish meal	P:	11,733	4,400	14,833	6,880	35,419	9,395	20,996	10,592	18,458	11,186	13,605
	V:	5,359	1,555	5,471	2,731	6,480	1,856	5,649	3,880	5,845	3,072	4,427
Lobsters	P:	210	44	115	73	149	415	595	310	265	295	353
	V:	3,243	610	1,765	1,185	2,282	6,067	9,877	5,026	3,955	4,247	5,024
Fish: Fresh/Frozen	P:	299	114	146	209	1,036	1,533	2,301	4,139	4,198	4,037	3,485
	V:	660	660	248	352	2,947	5,435	7,723	13,322	12,191	11,357	11,497
Can sardine	P:	697			255	193	131	31		59	136	112
	V:	1,334			384	345	238	49		102	175	184
Can molluska/ others	P:	1,468	947	1,216								
	V:	5,327	4,784	6,421								
Other Products	P:	8	256	271	400	301	4,490	4,153	516	789	717	391
	V:	56	431	469	439	983	27,299	24,219	1,460	2,094	2,094	1,366

P = Net weight in metric tons.
V = F.O.B. value in thousands of Balboas.

Table A.10. Annual registered landing (in metric tons) of artesanal fisheries by group of species and province for 1991 (DGRM, 1992).

Detail	Total	Coclé	Colón	Chiriquí	Darién	Herrera	L. Santos	Panamá	Veraguas
Total	2620	341		243	77	323	892	483	261
1. Fishes	2399	320		237	44	303	890	364	241
Snappers	738	14		191	10	70	331	79	43
Jacks	314	53			8	32	44	176	1
Mackarel	186	86		3		23	36	34	4
Croakers	100	32		9	1	14	16	16	12
Other sp.	1061	135		34	25	164	463	59	181
2. Crustaceans	219	21		6	33	20	2	118	19
Shrimps	200	15		1	33	20		118	13
White	195	15		1	33	16		117	13
Titi	4					4			
Carabali	1							1	
Lobster	19	6		5			2		6
Spiny lobster	19	6		5			2		6
Shield lipper lobster									
3. Mollusks	2							1	1
Squids									
Pac. melongena	2							1	1
Pac. calico scallop									
4. Sea turtles									

Table A.11. Invertebrate and fish species with commercial potential (not presently exploited commercially) in the Gulf of Panama (E. Nieto, pers. comm.).

SPECIES	COMMON NAME	NOMBRE COMUN
CEPHALOPODA: LOLIGINIDAE	INSHORE SQUIDS	CALAMARES
Loliolopsis diomedeae	dart squid	calamar saeta
SHARKS: TRIAKIDAE	HOUNDSHARKS	MUSOLAS
Mustelus sp.		
Mustelus lunulatus		
SHARKS: SPHYRNIDAE	HAMMERHEAD SHARKS	TIBURONES MARTILLO
Sphyrna media	hammerhead	martillo
FISHES: STROMATEIDAE	BUTTERFISHES, HARVESTFISHES	PALOMETAS
Peprilus medius	Pacific harvestfish	pajarita del golfo
P. snyderi	Pacific butterfish	salema
FISHES: ARGENTINIDAE	ARGENTINES	ARGENTINAS
Argentina aliceae	alicia argentine	argentina
FISHES: SPHYRAENIDAE	BARRACUDAS	BARRACUDAS
Sphyraena ensis	mexican barracuda	barracuda picuda
FISHES: HAEMULIDAE	GRUNTS, SALEMAS, SARGOS	BURROS, RONCOS
Anisotremus dovii	spotted head sargo	moro, puerquito, rompepaila
Pomadasys nitidus		
Orthopristis reddingi	bronzestrip grunt	burrito
Orthopristis sp.		
O. chalceus	bassy grunt	soldadito, brin
FISHES: POLYNEMIDAE	BOBOS, THREADFINS	BARBUDOS, BOBOS

Table A.11. Cont...

SPECIES	COMMON NAME	NOMBRE COMUN
Polydactylus approximans	blue bobo	bobo, bobo blanco
Polydactylus opercularis	yellow bobo	bobo, bobo amarillo
FISHES: MULLIDAE	GOATFISHES	CHIVOS, SALMONETES
Pseudupeneus grandisquamis	red goatfish	salmonete colorado
FISHES: ARIIDAE	CATFISHES	BAGRES
Arius troscheli	chili catfish	bagre, conguito
FISHES: BOTHIDAE	FLOUNDERS, SANDDABS	LENGUADOS
Cyclopsetta querna	toothed flounder	lenguado
Citharichthys sp.		
FISHES: GERREIDAE	MOJARRAS	PALMITOS
Eucinostomus gracilis	Pacific flagfin mojarra	mojarra, mojarra blanca
FISHES: ANTHIDAE	SEAPERCHES	
Hemanthias signifer	seaperch	
FISHES: FISTULARIDAE	CORNETFISHES	CORNETAS
Fistularia corneta	Pacific cornetfish	pez trompeta

Table A.12. Fish species collected in the Caribbean by the Biological Inventory by habitat and sensitivity (ACUPAN-ANCON, 1992-1993).

TAXA	COMMON NAME		STATION							HABITAT	SEN	TYI
	SPANISH	ENGLISH	13	14	15	16	17	18	19			
GINGLYMOSTOMATIDAE												
*Ginglymostoma cirratum**	Tiburón gata	Nurse shark								B de Pt - E	A	
CARCHARHINIDAE												
*Carcharinus sp**		Shark								B de Pt - Plg Ct	A	
*Galeocerdo cuvieri**	Tiburón tigre	Tiger shark								B de Pt - Plg (Ct y Oc) - E	A	
SPHYRNIDAE												
*Sphyrna sp**		Bannethead shark								B de Pt - Plg Ct - E	A	
RHINOBATIDAE												
Rhinobatos lentiginosus	Guitarras	Guitarfishes						1	1	B de Pt	B	
TORPEDINIDAE												
Narcine brasiliensis	Tembladera	Lesser electric ray						1		B(Fa)	B	
UROLOPHIDAE												
Urolophus jamaicencis	Tembladera	Yellow-spotted stingray			1					B(Fb) de Pt	B	
ALBULIDAE												
Albula vulpes	Macabí	Bananafish					1			B(Fb) de Pt - E	A	
ELOPIDAE												
*Elops saurus**	Banano, Carajo real	Big-eyed herring								B(Fa) de Pt - E	A	3/
CLUPEIDAE												
Harengula humeralis	Sardina de Ley	Red-ear sardine						1		Plg Ct - Mg	B	
Odontognathus compresus				1	1					B(Fb)	B	
Opisthonema oglinum	Machuelo	Atlantic thread herring		1				1		Plg - Ct	A	
ENGRAULIDAE												
Anchoa lamprotaenia	Anchoa	Anchovy	1	1	1	1				Plg - Ct	B	
Anchoa lyolepis	Anchoa	Dusky anchovy	1	1	1	1				Plg - Ct - Mg	B	
SYNODONTIDAE												
Synodus foetens	Lagarto	Lizardfish					1	1	1	B(Fb)	B	
CONGRIDAE												
Arisoma balliarica									1	B de Pt - Tld	B	
OPHICHTHIDAE												
Bascanichthys scuticaris						1				B(Fr) de Pt	B	6

Table A.12. Cont...

TAXA	COMMON NAME		STATION							HABITAT	SEN	TYPE
	SPANISH	ENGLISH	13	14	15	16	17	18	19			
BELONIDAE												
Strongylura marina			1		1					Plg – Mg	B	4
EXOCOETIDAE												
Hyporhamphus unifasciatus	Escribano	Halfbeak	1	1						Plg – Ct	B	4
Parexocoetus brachypterus	Pez volador	Flyingfish						1		Plg – Oc	B	4
HOLOCENTRIDAE												
Myripristis jacobus	Candil barreado	Black bar soldierfish					1			B(Fcr y Fr)	B	4
CENTROPOMIDAE												
*Centropomus poeyi**	Róbalo	Snock								B(fa) de Pt – E – R	A	3
*Centropomus undecimalis**	Róbalo	Snock								B(fa) de Pt – E – R	A	3
SERRANIDAE												
Serranus atrobranchus							1		1	B(Fa y Fb)	B	4
Diplectrum formosum	Serrano	Sand perch					1	1	1	B(Fa) – Mg	C	4
Epinephelus niveatus	Cherno	Snowy brouper					1			B(Fr) de Pt	A	3
LUTJANIDAE												
*Lutjanus apodus**	Pargo amarillo	Schoolmaster								B de Pt	A	3
*Lutjanus cyanopterus**	Cubera	Cuban snapper								B de Pt	A	3
Lutjanus jocu	Jocú	Dog snapper	1	1						B(Fr y Fcr)	A	3
Lutjanus synagris	Biajaiba	Biajaiba					1	1	1	B(Fr y Fcr)	A	3
Rhomboplites aurorubens							1			B(Fr y Fcr)	A	3
PRIACANTHIDAE												
Priacanthus arenatus	Catalufatoro	Bigeye					1	1		B(Fr, Fcr y Fa)	B	4
APOGONIDAE												
Apogon quadriscamatus							1			B(Fr) – Pt	C	6
SCIAENIDAE												
Cynoscion leiarchus	Corvinata blanca	Weakfish						1		B(Fb) de Pt – E	A	3
Larimus breviceps	Bombache cabezón	Shorthead drum							1	B(Fb) de Pt – E	A	3
Menticirrhus martinicensis				1	1	1		1	1	B(Fb) de Pt – E	A	3
Umbrina coroides	Verrugato petota	Sand drum				1				B(Fb) de Pt – E	A	3
CARANGIDAE												
*Alectis critinus**	Pámpano de hebra	African pompano								B de Pt – Plg(Ct y Oc)	A	3

Table A.12. Cont...

TAXA	COMMON NAME		STATION							HABITAT	SEN	TY
	SPANISH	ENGLISH	13	14	15	16	17	18	19			
*Caranx crysos**	Cojinua negra	Blue runner								Plg(Ct y Oc)	A	
Caranx hippos	Jurel común	Cravalle jack	1		1				1	Plg(Ct y Oc) – B de Pt – E	A	
Caranx latus	Jurel ojón	Horse–eyejack				1				Plg(Ct)	A	
Chloroscombrus chrysurus	Casabe	Atlantic bumper					1	1	1	Plg – Mg	B	
*Elegatis bipinnulatus**	Macarela salmón	Raimbow runner								Plg(Ct y Oc)	A	
Hemicaranx rhomboides			1							Plg Ct – E	B	
Oligoplites saurus saurus	Zapatero sietecueros	Atlantic leatherjack		1	1					Plg Ct	A	
Selar crumenophthalmus	Chicharro ojon	Bigeye scad					1		1	Plg Ct	A	
*Selene vomer**	Jorobado de penacho	Atlantic look down								B de Pt – Plg Ct	A	
*Seriola dumirili**	Medregal coronado	Greater amberjack								B de Pt – Plg Oc	A	
*Seriola rivoliana**	Medregal limón	Almacojack								B de Pt	A	
Vomer setapinnis								1	1	Plg Ct – B(Fa)	B	
GERREIDAE												
Diapterus olisthostomus	Mojarra cabucha	Irish mojarra	1	1						B(Fa) de Pt	C	
Diapterus rhombeus	Mojarra caitipa	Caitipa mojarra		1	1					B(Fa) de Pt	C	
Eucinostomus gula	Mojarrita española	Jenny mojarra			1	1				B(Fa) de Pt	C	
Eucinostomus jonesell			1	1	1	1	1	1	1	B(Fa) de Pt	C	
Gerres cinereus	Mojarra blanca	Yellowfin mojarra			1		1	1	1	B de Pt – E	B	
POMADASYIDAE												
Haemulon aurolineatum	Jeníguano	Tomtate grunt					1			B de Pt	B	
Haemulon spp.			1			1		1	1			
Haemulon steindachneri	Ronco chere–chere	Chere–chere grunt					1			B(Fr) de Pt – E	A	
Pomadasys corvinaeformis	Corocoro gris	Roughneck grunt	1							B de Pt	B	
Pomadasys crocro	Corocoro crocro	Burro grunt						1		B de Pt	B	
CHAETODONTIDAE												
Chaetodon ocellatus	Mariposas	Butterflyfishes					1			B(Fr) de Pt	B	
LABRIDAE												
Halichoeres spp.	Doncella arcoiris	Puddingwike wrasse					1			B de Pt – E –R	C	
TRICHIURIDAE												
Trichiurus lepturus	Sable	Cutlassfishes							1	B(Fa) de Pt – Plg Ct – E	C	

Table A.12. Cont...

TAXA	COMMON NAME		STATION							HABITAT	SEN	TYPE
	SPANISH	ENGLISH	13	14	15	16	17	18	19			
GOBIIDAE												
Bathygobius soporator	Madrejuiles	Gobies	1							B de Pt (Fr y Fb) - E - R	C	6
ESCOMBRIDAE												
*Scomberomorus maculatus**	Sierre	Apotted spanish meckerel								B de Pt - E	A	3
SCORPAENIDAE												
Scorpaena plumieri	Rascacio	Spotted scorpionfish					1	1		B(Fr) de Pt	C	6
TRIGLIDAE												
Prionotus adspersus	Testolin azul	Bluewing searobin					1	1	1	B de Pt	C	4
DACTYLOTERIDAE												
Dactylopterus volitans	Alón	Flying gurnard					1			B de Pt	C	6
OPHIDIIDAE												
Lepophidium brevibarbe	Congriperias	Cusk eels								B(Fa) de Pt	C	6
SPHYRAENIDAE												
Sphyraena barracuda	Barracuda	Great barracuda	1						1	Plg Ct - B(Fr, Fcr)	B	3-5
Sphyraena picudilla	Picudilla	Southern sennet						1	1	B(Fr, Fcr, Fa)	B	3-5
MUGILIDAE												
Mugil brasiliensis				1	1	1				B de Pt - Mg	B	4
Mugil incilis	Lisa rayada	Parassi mullet		1	1					B(Fb) de Pt - E	B	4
ATHERINIDAE												
Atherinomorus stipes	Pejerrey cabezón	Hardhead silverside	1							E - Mg	B	4
POLYNEMIDAE												
Polydactylus oligodon	Barbudo	Littlescale threadfin	1	1	1	1		1	1	B(Fa) - E - M	B	4
BOTHIDAE												
Citharichthys evermanni	Lenguados	Flounders		1						B(Fb) de Pt y Tld	B	4
Etropus crossotus	Lenguado ribete	Fringed flounder					1	1	1	B(Fb) de Pt	B	4
Syacium micrurum	Lenguado	Flounders					1	1	1	B(Fb) de Pt y Tld	B	4
SOLEIDAE												
Gymnanchirus melas	Suelas	Soles					1	1		B(Fb) de Pt y Tld	B	4
CYNOGLOSSIDAE												
Symphurus arawak	Lenguas	Tonguefishes						1		B(Fb) de Pt	B	4

Table A.12. Cont...

TAXA	COMMON NAME		STATION							HABITAT	SEN	TYI
	SPANISH	ENGLISH	13	14	15	16	17	18	19			
MONACANTHIDAE												
Alutera schoepfi	Lijas, cachuas	Filefishes						1		B(Fr, Fa) de Pt	C	
OSTRACIIDAE												
Acanthostracion quadricornis	Cofres	Trunkfishes					1		1	B(Fr, Fa) de Pt	C	
TETRADONTIDAE												
Sphoeroides greeleyi	Tamboriles	Puffers								B(Fr, Fa) de Pt – E	C	
Sphoeroides spengleri	Tamboriles	Puffers						1		B(Fr, Fa) de Pt – E	C	
Sphoeroides testudineus	Tamboriles	Puffers	1		1		1	1		B(Fr, Fa) de Pt – E	C	
DIODONTIDAE												
Diodon holocanthus								1		B(Fr, Fa) de Pt – E	C	
BATRACHOIDIDAE												
Porichthys porississimus							1	1	1	B(Fa) de Pt	C	
ANTENNARIIDAE												
Phryaelox scaber								1		B(Fa) de Pt	C	
OGCOCEPHALIDAE												
Ogcocephalus nasuatus							1	1	1	B(Fa) de Pt	C	
Families: 42 Species: 74			16	15	16	11	28	32	25			

Bottom type key
B = Benthic
Fa = Sandy
Fb = Soft (mud)
Fr = Rocky
Fcr = Coralline

Ct Ct = Coastal
Oc Oc = Oceanic
Plg Plg = Pelagic
Pt Pt = Shelf
Tld Tld = Sideslope

Sensitivity
A = Maximum B = Intermediate C = Minimum

Type
1 = Endemic (cited just for Panama)
2 = Major abundance or frequency
3 = Commercial fisheries

4 = 4 = Potential
5 = 5 = Game species
6 = 6 = Not used

Table A.13. Sediment clasification by size (Holme & McIntyre, ed. 1984).

SEDIMENT	SIZE (mm)
VERY COARSE SAND	1.00 - 2.00
COARSE SAND	0 .50 - 1.00
MEDIUM SAND	0.25 - 0.50
FINE SAND	0.125 - 0.25
VERY FINE FINA	0.062 - 0.125
SILT AND CLAY	< 0.062

Table A.14. Sediment granulometry in the Pacific Ocean and the Caribbean Sea inside the study area (UNIPAN-ANCON, 1992).

OCEAN	SITES	SAND %	CLAY %
PACIFIC	MB-01	17,70	82,30
	MB-02	23,88	76,12
	MB-03	10,27	89,73
	MB-04	7,80	92,20
	MB-05	7,65	92,35
	MB-06	8,61	91,39
	MB-07	11,34	88,66
	MB-08	23,50	76,50
CARIBBEAN	MB-09	61,85	38,15
	MB-10	44,01	55,99
	MB-11	20,51	79,49
	MB-12	36,75	63,25
	MB-13	20,88	79,12
	MB-14	40,22	59,78

Table A.15. List of subtidal invertebrates by communities and assemblages inhabiting subtidal communities in the Caribbean sea and the Pacific Ocean of Panama (Bayer et al., 1970).

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
CARIBBEAN					
Crabs-shrimps	Stomatopods-Portunids		CRUSTACEA: STOMATOPODA		
		carn	Squilla obtusa	alacranes de mar	mantis shrimps
			CRUSTACEA: DECAPODA		
		carni	Lupella forceps	cangrejo	crab
		carni	Portunus gibbesii	cangrejo	crab
			EQUINODERMATA: ECHINOIDEA		
		detri	Brissopsis elongata	erizo irregular	irregular urchin
Equinoderms	Crinoids-Star fishes		EQUINODERMATA: CRINOIDEA		
		suspen	Comactinia echinoptera	crinoideos	feather star
		suspen	Nemaster discoidea	crinoideos	feather star
			Jaegerothuria occidentalis	pepino de mar	sea cucumber
			EQUINODERMATA: ASTEROIDEA		
		carni	Tethyaster grandis	estrella de mar	sea star
		carni	Narcissa trigonaria	estrella de mar	sea star

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
Scallops			MOLLUSCA: GASTROPODA		
		carni	Antillophos candei		
		carni	Plystira albida		
		suspen	Costelloleda sp.		
		suspen	Pitar aresta		
		filt	Pecten laurentii	venera	scallop
Sponge			MOLLUSCA: BIVALVIA		
		filt	Aequipecten lineolaris	cambombia	scallop
		suspen	Microcardium tinctum	berberecho	cockle
		suspen	Tellina persica	bivalvo	tellin clam
			MOLLUSCA: GASTROPODA		
		carni	Murex olssoni	gastropodo	snail
		omni	Strombus pugilis	caracol	conch snail
			EQUINODERMATA: ASTEROIDEA		
		carni	Echinaster sentus	estrella de mar	sea star
			EQUINODERMATA: ECHINOIDEA		
		detri	Brissopsis elongata	erizo irregular	irregular urchin
			EQUINODERMATA: HOLOTHUROIDEA		

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
		detri	Jaegerothuria occidentalis	pepino de mar	sea cucumber
			CRUSTACEA: DECAPODA		
		carni	Scyllarus planorbis		slipper lobster
		carni	Portunus spinicarpus	cangrejo	crab
Starfish	Metula-Luidia		MOLLUSCA: BIVALVIA		
		susp	Nucula sp. 2		clam
		detri	Cuspidaria rostrata		
			MOLLUSCA: GASTROPODA		
		carni	Metula sp. 2		
		carni	Metula limonensis		snail
		herb	Calliostoma sp. 4		
			EQUINODERMATA: ASTEROIDEA		
		carni	Luidia clathrata	estrella de mar	sea star
	Urchin - Starfish				
			EQUINODERMATA: ECHINOIDEA		
		detri	Paleopneustes sp.	erizo	sea urchin
			EQUINODERMATA: ASTEROIRDEA		

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
		carni	Astropecten sp.	estrella de mar	sea star
			CRUSTACEA: DECAPODA		
		carni	Pylopagurus sp.	cangrejo hermitano	hermit crab
		carni	Portunus sp.	cangrejo	crab
PACIFIC					
Crab-Shrimp	Portunids				
			MOLLUSCA: BIVALVIA		
		detri	Microcardium panamense	berberecho	cockle
			CRUSTACEA: DECAPODA		
		carni	Portunus xanthusii affinis	cangrejo	crab
		carni	Calappa saussurii	cangrejo	crab
		carni	Portunus acuminatus	cangrejo	crab
	Stomatopods (mud)		CRUSTACEA: STOMATOPODA		mantis shrimp
		carni	Squilla parva	alacranes de mar	small mantis shrimp
		carni	Squilla panamensis	alacranes de mar	Panamá mantis shrimp
			MOLLUSCA: BIVALVIA		
		detri	Lophocardium sp.	berberecho	cockle
		detri	Trachycardium sp.	berberecho	cockle

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
		detri	Laevicardium sp.	berberecho	cockle
		detri	Chionopsis sp.		Venus clam
		detri	Eurytellina sp.		tellin clam
		detri	Cyclinella sp.		
			MOLLUSCA: GASTROPODA		
		carni	Natica sp.		moon snail
		carni	Solenosteira sp.		snail
		carni	Mitra sp.		snail
		carni	Nassarius sp.		snail
		carni	Conus sp.		cone snail
		carni	Polystira sp.		
Shrimp-Fish	Described in the section "Nekton"				
Gastropods (sand)	Crucibulum		MOLLUSCA: GASTROPODA		
			Crucibulum serratum		
			?? DEFINIR GRUPO		
			TAXONOMICO		
			Cancellaria albida		
	Eupleura		MOLLUSCA: GASTROPODA		
		carni	Eupleura muriciformis		
		carni	Trajana perideris		

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
	Dardanus		CRUSTACEA: DECAPODA		
		carni	Dardanus sp.	cangrejo hermitano	hermit crab
			?? DEFINIR GRUPO		
			TAXONOMICO		
			Bursa nana		
	Psammotreta		MOLLUSCA: GASTROPODA		
		carni	Ancistrosyrinx cedonulli		
			??DEFINIR GRUPO TAXONOMICO		
			Psammotreta aurora		
	Scalina		??DEFINIR GRUPO TAXONOMICO		
			Scalina ferminiana		
			MOLLUSCA: GASTROPODA		
		carni	Nassarius polistes		snail
	Clathrodrilla		MOLLUSCA: GASTROPODA		
		carni	Clathrodrilla sp.		
			MOLLUSCA: BIVALVIA		
		filt	Cyclopecten sp.		scallop
Crab-Octopus			MOLLUSCA: CEPHOLOPODA		
		carni	Octopus selene	pulpo	octopus
			MOLLUSCA: BIVALVIA		

Table A.15. Cont...

COMMUNITY	ASSAMBLAGE	TROPHIC LEVEL	TAXA	NOMBRE COMUN	COMMON NAME
		filt	Chione sp.	bivalvio	Venus clam
			MOLLUSCA: GASTROPODA		
		carni	Polinices sp.		moon snail
			CRUSTACEA: DECAPODA		
			Mursia sp.	cangrejo	crab
			Parthenope sp.	cangrejo	crab
			Hypoconcha sp.	cangrejo	crab
			Collodes sp.	cangrejo	crab

Legend:

carni= carnívoros, detri= detritivors, herb= herbivors, suspen= suspension feeders, filt= filter feeders.

Table A.16. Characteristics of the five zones of a tropical eastern Pacific rocky shore (Taboguilla Island, Gulf of Panama; Lubchenco et al., 1982).

PARAMETER	ZONE				
	SPLASH	HIGH TIDE	MID TIDE	LOW TIDE	VERY LOW TIDE
Substratum irregularity	high	highest	moderate	high	low
Wind influence	highest	moderate	low	lowest	no
Wave energy	no	high	high	high	low
Sessile dominant species	no data	bare	algal crust	algal crust	algal crust
Density of sessile organisms	no data	highest	moderate	low	lowest
Diversity	no data	lowest	moderate	high	highest

Table A.17. List of species inhabiting eastern Pacific rocky shores by trophic status and tide zone (Taboguilla Island, Gulf of Panama; Lubchenco et al., 1982)

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VERLOW
Carniv.	AVES (see table 39)	BIRDS	AVES	<---------->			
	FISHES: TETRAODONTIDAE	PUFFER FISHES	TAMBORILES				
	Arothron hispidus	spotted green puffer	tamboril verde	C	C	C	C
	Arothron meleagris	golden puffer	pez guineo/tamb. tigre			C	C
	Canthigaster punctatissima	spotted sharpnose puffer	pez globo narizón			C	C
	FISHES: DIODONTIDAE	PORCUPINE FISHES	PECES ERIZO				
	Diodon hystrix	spotted porcupine	pez erizo manchado	C	C	C	C
	FISHES: BALISTIDAE	TIGGERFISHES	PECES GATILLO				
	Balistes polylepis	finescale triggerfish	pez puerco/gatillo			C	C
	Pseudobalistes naufragium	blunthead triggerfish	pez puerco/gatillo		C	C	C
	Sufflamen verres	orangeside triggerfish	pez puerco/gatillo		C	C	C
	FISHES: LABRIDAE	WRASSES	VIEJAS/SEÑORITAS				
	Bodianus diplotaenia	mexican hogfish	vieja		C	C	C
	Thalassoma lucasanum	rainbowfish	arco iris		C	C	C
	FISHES: MONACANTHIDAE	FILEFISHES	PECES PUERCO				
	Alutera scripta			C	C	C	C
	ECHINODERMATA	SEASTARS	ESTRELLAS DE MAR				
	Heliaster microbrachius			FC	FC	FC	FC
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS				
	Eriphia squamata				C	A	
	Ozius verreauxii			FC	FC		

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VERY LOW
Carniv.	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Acanthina brevidentata	rock shell		C	C	A	A
	Columbella labiosa					FC	FC
	Conus nux					FC	FC
	Conus princeps					FC	FC
	Conus virgatus					FC	FC
	Leucozonia cerata					FC	FC
	Mitra tristis				FC	FC	FC
	Muricanthus princeps					FC	FC
	Muricanthus radix					FC	FC
	Neorapana muricata					FC	FC
	Opeatostoma pseudodon					C	A
	Purpura pansa			FC			
	Thais biserialis	blood-mouthed rock shell	púrpura de boca roja			FC	FC
	Thais melones			C	A	A	A
	Thais speciosa					FC	FC
	Thais triangularis					A	A
Omniv.	FISHES: POMACANTHIDAE	ANGELFISHES	PECES ANGEL				
	Holacanthus passer	king angelfish	pez angel reina			C	C
	Pomacanthus zonipectus	Cortez angelfish	pez ángel de Cortéz			C	C
	FISHES: POMACENTRIDAE	DAMSELFISHES	PECES DAMISELA				
	Microspathodon dorsalis	giant damselfish	damisela gigante			C	C

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VERLOW
Omniv.	FISHES: SCARIDAE	PARROTFISHES	PECES LORO				
	Scarus perrico	bumphead parrotfish	pez loro frentón		C	C	C
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS				
	Eriphides hispida				FC	C	
Herbiv.	FISHES: BLENNIDAE	BLENNIES	TRAMBOLLITOS				
	Ophioblennius steindachneri	panamic fanged	trambollito negro		C	C	C
	FISHES: KHYPHOSIDAE	CHUBS	CHOPAS				
	Kyphosus elegans	Cortez chub	chopa de Cortéz	C	C	C	C
	FISHES: POMACENTRIDAE	DAMSELFISHES	PECES DAMISELA				
	Eupomacentrus acapulcoensis	Acapuco damselfish	damisela		C	C	C
	Eupomacentrus flavilatus	beaubrummel	damisela bicolor			C	C
	Microspathodon bairdii	bumphead damselfish	damisela frentón		C	C	C
	FISHES: SCARIDAE	PARROTFISHES	PECES LORO				
	Nicholsina denticulata	loosetooth parrotfish	pez loro			C	C
	Scarus ghobban	bluechin parrotfish	pez loro azulado			C	C
	ECHINODERMATA: ECHINOIDEA	SEA URCHINS	ERIZOS DE MAR				
	Echinometra vanbrunti					C	C
	Eucidaris thouarsi				FC	C	
	Arbacia stellata					FC	C
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS				
	Grapsus grapsus	lightfoot crab	cangrejo de roca	C	<----->		
	Pachygrapsus transversus				FC	C	C

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VERLOW
Herbiv.	MOLLUSCA: GASTROPODA	LIMPETS	SOMBRERITOS CHINOS				
	Collisella pediculus	file limpet	acméas		FC		
	Fisurella longifissa	keyhole limpet	lapas, fisurelas		FC	FC	
	Fisurella morrisoni	keyhole limpet	lapa, fisurela			FC	A
	Fisurella microtrema	keyhole limpet	lapa, fisurela			FC	FC
	Fisurella virescens	keyhole limpet	lapa, fisurela		A	A	A
	Notoacmaea filosa				FC		
	Scurria stipulata	green limpet	acmea verde		FC		
	Siphonia gigas				A	A	
	Siphonaria maura				FC	FC	
	Siphonaria palmata				FC	FC	A
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Fossarus attratus			FC	FC		
	Littorina aspera			C			
	Littorina modesta			C			
	Nerita funiculata			FC	FC		
	Nerita scabricosta			C	FC		
	CHITONIDAE	CHITONS	CHITONES				
	Acanthochitona hirudiniformis				A	A	
	Ceratozoana angusta				FC	C	
	Chaetopleura sp.				FC	C	C
	Chiton stokesii				A	A	

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VERLOW
Herbiv.	*Tonicia forbesi*					C	C
Micro-carn.	ANTHOZOA	ANEMONES	ANEMONAS				
	Anthopleura dowii				C	C	
	Diadumene leucolena					C	
	GORGONIANS	SOFT CORALS	CORALES BLANDOS			FC	FC
	HYDROZOANS	HYDROZOAN	HYDROZOOS				
	Abietinaria sp.					FC	FC
	Obelia sp.				FC	FC	FC
Part. Feed.	ECHINODERMS	SEA CUCUMBERS	PEPINOS DE MAR			C	C
	VERMETIDS	VERMETIDS	VERMETIDOS		FC	C	C
	POLYCHAETA	POLIQUETES	POLIQUETOS				
	Sprorbis sp.					A	C
	Serpula sp.					A	C
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Hipponix sp.					FC	FC
	MOLLUSCA: BIVALVIA	CLAMS	ALMEJAS				
	Arca mutabilis					FC	FC
	Brachidontes semilaevis				A	A	
	Chama echinata				FC	A	FC
	Modiolus capax				FC	FC	FC
	Ostrea iridescens				FC	FC	A
	Plicatula penicillata				FC	FC	FC

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VER LOW
Part. Feed.	*Pinna* sp.					FC	FC
	BARNACLES	BARNACLES	BALANOS				
	Balanus inexpectatus					A	A
	Catophragmus pilsbryi				FC	FC	
	Chthamalus fissus			A	C	C	
	Euraphia imperatrix			A			
	Tetraclita panamensis				FC	FC	
	TUNICATES	SEA SQUIRTS	TUNICADOS			C	
	SPONGES	SPONGES	ESPONJAS			FC	FC
	BRYOZOA	MOSS ANIMALS	BRIOZOARIOS			FC	FC
	PROTOZOA	PROTOZOANS	PROTOZOOARIOS			FC	FC
Prim. Prod.	CHLOROPHYTA	GREEN ALGAE	ALGAS VERDES				
	Ulva spp.	sea lettuce	lechuga marina		C	C	ND
	Enteromorpha spp.				C	C	ND
	Cladophora spp.			C	C	C	ND
	Bryopsis spp.					C	ND
	Chaetomorpha sp.					C	ND
	Cladophoropsis sp.					C	ND
	Caulerpa botryoides				C		ND
	Caulerpa peltata				C		ND
	PHAEOPHYTA	ERECT BROWN ALGAE	ALGAS PARDAS BLANDAS				
	Giffordia sp.				C	C	ND

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VER LOW
Prim. Prod.	*Dictyota* spp.					C	ND
	Padina sp.					C	ND
	PHAEOPHYTA	ENCRUSTING BROWN	ALGAS PARDAS CALCAREAS				
	Ralfsia spp.				C	C	ND
	Mesospora sp.				C	C	ND
	Lobophora sp.					C	ND
	RHODOPHYTA	ERECT RED ALGAE	ALGAS ROJAS BLANDAS				
	Centroceros clavualtum					C	ND
	Gelidiella sp.					C	ND
	Gelidium pusillum					C	ND
	Hypnea sp.					C	ND
	Jania spp.					C	ND
	Amphiroa spp.					C	ND
	Corallina spp.					C	ND
	Laurencia spp.					C	ND
	Polysiphonia pacifica					C	ND
	Polysiphonia sp.					C	ND
	Spyridium sp.					C	ND
	RHODOPHYTA	ENCRUSTING RED ALGAE	ALGAS ROJAS CALCAREAS				
	Hildebrandia spp.				C	C	ND
	CYANOPHYTA	ERECT BLUE-GREEN	ALGAS VERDEAZULES BLANDAS				
	Microcoleus lyngbyaceae			C	C	C	ND

Table A.17. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES			
				HIG	MID	LOW	VER LOW
Prim. Prod.	CYANOPHYTA	ENCRUSTING BLUE-GREEN	ALGAS VERDEAZULES CALCAREAS				
	Schizothrix calcicola			C	C	C	ND

Legend:

ZONES: HIG= High-tide zone; LOW= Low-tide zone; MID= Mid-tide zone; VER LOW= Very Low.

ZONATION: A= Abundant; C= Common; FC- Fairly Common; ND= No Data; WC= Water Column; (<-->)= forage along the zone but do not inhabit it.

TROPHIC STATUS: Bent. Zoopl.= Benthonic Zooplankton; Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Macrozoopl:= Macrozooplankton; Meropl.= Meroplankton; Microcarn.= Microcarnivores; Microzoopl.= Microzooplankton; Omniv.= Omnivores; Part. Feed.= Particle Fedders; Prim. Prod.= Primary Producers; Surf & Susp. Phytopl.= Surf and Suspende Phytoplankton; True Zoopl.= True Zooplankton.

Table A.18. Characteristics of the six zones of a tropical sandy beach (Dexter, 1979; Brown & McLachlan, 1990).

PARAMETER	ZONE					
	SUPRA LITTORAL	HIGH TIDE	MID TIDE	LOW TIDE	TRANSITION	OUTER TURBULENT
Sand condition	dry	damp	damp	saturated	saturated	saturated
Wind	high	moderate	low	very low	no	no
Wave energy	no	low	moderate	moderate	highest	high
Sand particle size	highest	high	moderate	moderate	low	lowest
Chlorophyll content	lowest	low	moderate	highest	-	-

Table A.19. List of species inhabiting Caribbean sandy beaches by trophic status and tide zone (Sherman beach, Province of Colon; Dexter, 1979; Brown & McLachlan, 1990).

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE				
				SUP	HIG	MID	LOW	SUB
Carniv.	AVES (See Table 39)			<---------->				
	FISH: SCIAENIDAE	DRUMS	CORVINAS					
	Menticirrhus martinicensis				<---------->			
	Umbrina coroides	sand drum			<---------->			
	FISH: ENGRAULIDAE	ANCHOVIES	ANCHOAS					
	Anchoa lamprotaenia	bigeye anchovie	anchoa		<---------->			
	Anchoa lyolepis	dusky anchovy	anchoa		<---------->			
	FISH: MUGILIDAE	MULLETS	LISAS					
	Mugil brasiliensis				<---------->			
	Mugil iricilis				<---------->			
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS					
	Arenaeus cribrarius			C	<----->			
	Hippa testudinata					C	C	FC
	Ocypode quadrata			C	<----->			
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES					
	Olivella petiolita	olive snail			FC	FC	C	
	Terebra cinerea					FC	FC	
Omniv.	REPTILIA: CHELONIDAE	SEA TURTLES	TORTUGAS MARINAS					
	Chelonia mydas	green turtle	tortuga verde/blanca	<---------->				
	Eretmochelys imbricata	hawksbill turtle	tortuga carey	<---------->				
	Caretta caretta	caguama	tortuga caguama	<---------->				
	REPTILIA: DERMOCHELIDAE	LEATHERBACKS	TORTUGAS MARINAS					
	Dermochelys coriacea	leatherback turtle	tortuga canal/baula	<---------->				

Table A.19. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE				
				SUP	HIG	MID	LOW	SUB
Part. Feed.	CRUSTACEA: AMPHIPODA	AMPHIPODS	ANFIPODOS					
	Trichophoxus floridanus				FC	FC	FC	
	CRUSTACEA: ISOPODA	ISOPODS	ISOPODOS					
	Ancinus brasiliensis				C	A	A	
	Excirolana brazilensis				A	A	C	
	Exosphaerma diminutum				C	C	C	
	CRUSTACEA: CUMACEA	CUMACEANS	CUMACEOS					
?	*Cyclaspis* sp. B					A	A	
	POLYCHAETA	ROUND WORMS	POLIQUETOS					
	Scolelepis agilis	spionid polychate				C	C	
Filt. Feed.	CRUSTACEA: DECAPODA	CRABS	CANGREJOS					
	Emerita brasiliensis	mole crab			FC	FC	FC	
	MOLLUSCA: BIVALVIA	CLAMS	ALMEJAS					
	Donax denticulatus					FC	FC	
True Zoopl.	CRUSTACEA: MYSIDACEA	MYSID SHRIMPS	CAMARONES MISIDACEOS		WC	WC	WC	WC
Benth. Zoopl.	CRUSTACEA: ISOPODA	ISOPODS	ISOPODOS		C	A	A	C
	CRUSTACEA: AMPHIPODA	AMPHIPODS	ANFIPODOS		C	A	A	C
Micro-zoopl.	CRUSTACEA: COPEPODA (Nauplii)	COPEPOD LARVAE	LARVAS DE COPEPODOS		WC	WC	WC	WC
	CILIATES	CILIATES	CILIADOS		WC	WC	WC	WC
Macro-zoopl.	CRUSTACEA: COPEPODA	COPEPODS	COPEPODOS		WC	WC	WC	WC
	CRUSTACEA: CLADOCERA	CLADOCERANS	CLADOCEROS		WC	WC	WC	WC
	CHAETOGNATHA	ARROW WORMS			WC	WC	WC	WC
	COELENTERATA	JELLYFISHES	MEDUSAS/AGUAMALAS		WC	WC	WC	WC

Table A.19. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE				
				SUP	HIG	MID	LOW	SUB
Meropl.	PISCES LARVAE	FISH LARVAE	LARVAS DE PECES		WC	WC	WC	WC
	DECAPODA LARVAE	CRAB LARVAE	LARVAS DE CANGREJOS		WC	WC	WC	WC
	BIVALVE LARVAE	CLAMS LARVAE	LARVAS DE ALMEJAS		WC	WC	WC	WC
	POLYCHAETA LARVAE	POLYCHAETES LARVAE	LARVAS DE POLIQUETOS		WC	WC	WC	WC
Surf & Susp. Phytopl.	CYANOBACTERIA	CYANOBACTERIA	BACTERIAS CIANOFITAS		WC	WC	WC	WC
	FLAGELLATES	FLAGELLATES	FLAGELADOS		WC	WC	WC	WC
	CYANOPHYTA	DIATOMS	DIATOMEAS					
	Aulacodiscus spp.				WC	WC	WC	WC
	Asterionella spp.				WC	WC	WC	WC
	Chaetoceros spp.				WC	WC	WC	WC
	Analurus spp.				WC	WC	WC	WC

Legend:

ZONES: HIG= High-tide zone; LOW= Low-tide zone; MID= Mid-tide zone; SUB= Subtidal zone; SUP= Supratidal zone.

ZONATION: A= Abundant; C= Common; FC- Fairly Common; ND= No Data; WC= Water Column; (<-->)= forage along the zone but do not inhabit it.

TROPHIC STATUS: Bent. Zoopl.= Benthonic Zooplankton; Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Macrozoopl:= Macrozooplankton; Meropl.= Meroplankton; Microcarn.= Microcarnivores; Microzoopl.= Microzooplankton; Omniv.= Omnivores; Part. Feed.= Particle Fedders; Prim. Prod.= Primary Producers; Surf & Susp. Phytopl.= Surf and Suspende Phytoplankton; True Zoopl.= True Zooplankton.

Table A.20. List of species inhabiting eastern Pacific sandy beaches by trophic status and tide zone (Culebra beach, Naos Island, Panama City; Dexter, 1979; Brown & McLachlan, 1990).

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES				
				SUP	HIG	MID	LOW	SUB
Carniv.	AVES (see Table 39)	BIRDS	AVES	<---------->				
	FISH: SCIAENIDAE	CROACKERS	CORVINAS					
	Menticirrhus panamensis		corvina		<---------->			
	Umbrina coroides	sand drum	corvina		<---------->			
	Umbrina xanti		corvina		<---------->			
	FISH: CARANGIDAE	POMPANOS	JURELES					
	Trachinotus kennedy	longfin pompano	pfmpano		<---------->			
	Trachinotus paitensis	pompano	pfmpano		<---------->			
	FISH: MUGILIDAE	MULLETS	LISAS					
	Mugil cephalus	striped mullet	lisa		<---------->			
	Mugil curema	mullet	lisa		<---------->			
	FISH: BOTHIDAE	FLOUNDERS	LENGUADOS					
	Citharichthys platophrys				<---------->			
	Ciclopsetta panamensis				<---------->			
	Ciclopsetta querna				<---------->			
	Etropus crossatus				<---------->			
	Hippoglossina bollmani				<---------->			
	Paralichthys woolmani				<---------->			
	PLATYHELMINTHES	FLATWORMS	GUSANOS PLANOS			FC	FC	
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS					
	Ocypode occidentalis			C	<---->			
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES					

Table A.20. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES				
				SUP	HIG	MID	LOW	SUB
Carniv.	*Olivella semistriata*	olive snails			FC	C	C	
Omniv.	REPTILES: CHELONIDAE	SEA TURTLES	TORTUGAS MARINAS					
	Chelonia mydas agassisii	Pacific green turtle	tortuga verde/blanca		FC	FC	FC	FC
	Eretmochelys imbricata squamata	Pacific hawksbill turtle	tortuga carey		FC	FC	FC	FC
	Lepidochelys olivacea	Pacific ridley turtle	tortuga mulata		FC	FC	FC	FC
	Caretta caretta	caguama turtle	torutuga caguama					
	REPTILIA: DERMOCHELIDAE	SEA TURTLES	TORTUGAS MARINAS					
	Dermochelys coriacea schlegelii	Pacific leatherback turtle	tortuga canal/baula		FC	FC	FC	FC
	FISHES: CLUPEIDAE							
	Opisthonema liberate	Pacific thread herring	sardina machete					
	Opisthopterus dovii	Pacific longfin herring	sardina sin sangre					
Part. Feed.	ECHINODERMATA	SEA STARS	ESTRELLAS DE MAR					
	Encope stokesii						FC	FC
	CRUSTACEA: DECAPODA	CRABS	CANGREJOS					
?	*Ambidexter panamense*						FC	
	Callianassa sp.						FC	FC
	Ocypode quadichaudii			FC	<--------->			
	CRUSTACEA: AMPHIPODA	AMPHIPODS	ANFIPODOS					
	Paraphoxus obtusidens				FC	FC	C	
	CRUSTACEA: ISOPODA	ISOPODS	ISOPODOS					
	Ancinus panamensis				C	A	A	
	Excirolana brazilensis				A	A	C	
	Exosphaerma diminutum				C	C	C	

Table A.20. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES				
				SUP	HIG	MID	LOW	SUB
Part. Feed.	CRUSTACEA: CUMACEA	CUMACEANS	CUMACEOS					
	Cyclaspis sp. A					A	A	A
	POLYCHAETA	ROUND WORMS	POLIQUETOS					
?	*Armandia bioculata*						C	C
?	*Paraonides platybranchia*						A	
	Scolelepis agilis					C	C	
	MOLLUSCA: BIVALVIA	CLAMS	ALMEJAS					
	Tellina spp.					C	C	
Susp. Feeders	CRUSTACEA: DECAPODA	CRABS	CANGREJOS					
	Emerita rathbunae	mole crab			C	C	C	
	MOLLUSCA: BIVALVIA	CLAMS	ALMEJAS					
	Donax panamensis					FC	FC	
True Zoopl.	CRUSTACEA: MYSIDACEA	MYSID SHRIMPS	CAMARONES MISIDACEOS		WC	WC	WC	WC
Benth. Zoopl.	CRUSTACEA: ISOPODA	ISOPODS	ISOPODOS		C	A	A	C
	CRUSTACEA: AMPHIPODA	AMPHIPODS	ANFIPODOS		C	A	A	C
Micro-zoopl.	CRUSTACEA: COPEPODA (Nauplii)	COPEPOD LARVAE	LARVAS DE COPEPODOS		WC	WC	WC	WC
	Ciliates				WC	WC	WC	WC
Macro-zoopl.	CRUSTACEA: COPEPODA	COPEPODS	COPEPODA		WC	WC	WC	WC
	CRUSTACEA: CLADOCERA	CLADOCERANS	CLADOCEROS		WC	WC	WC	WC
	CHAETOGNATHA	ARROW WORMS			WC	WC	WC	WC
	COELENTERATA	JELLYFISHES	MEDUSAS/AGUAMALAS		WC	WC	WC	WC
Meropl.	FISH LARVAE	FISH LARVAE	LARVAS DE PECES		WC	WC	WC	WC

Table A.20. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONES				
				SUP	HIG	MID	LOW	SUB
Meropl.	DECAPODA LARVAE	CRAB LARVAE	LARVAS DE CANGREJOS		WC	WC	WC	WC
	BIVALVE LARVAE	CLAM LARVAE	LARVAS DE ALMEJAS		WC	WC	WC	WC
	POLYCHAETA LARVAE	POLYCHAETE LARVAE	LARVAS DE POLIQUETOS		WC	WC	WC	WC
Surf & Susp. Phytopl.	CYANOBACTERIA	CYANOBACTERIA	BACTERIAS CIANOFITAS		WC	WC	WC	WC
	FLAGELLATES	FLAGELLATES	FLAGELADOS		WC	WC	WC	WC
	CYANOPHYTA	DIATOMS	DIATOMEAS					
	Aulacodiscus spp.				WC	WC	WC	WC
	Asterionella spp.				WC	WC	WC	WC
	Chaetoceros spp.				WC	WC	WC	WC
	Analurus spp.				WC	WC	WC	WC

Legend:

ZONES: HIG= High-tide zone; LOW= Low-tide zone; MID= Mid-tide zone; SUB= Subtidal zone; SUP= Supratidal zone.

ZONATION: A= Abundant; C= Common; FC- Fairly Common; ND= No Data; WC= Water Column; (<-->)= forage along the zone but do not inhabit it.

TROPHIC STATUS: Bent. Zoopl.= Benthonic Zooplankton; Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Macrozoopl:= Macrozooplankton; Meropl.= Meroplankton; Microcarn.= Microcarnivores; Microzoopl.= Microzooplankton; Omniv.= Omnivores; Part. Feed.= Particle Fedders; Prim. Prod.= Primary Producers; Surf & Susp. Phytopl.= Surf and Suspende Phytoplankton; True Zoopl.= True Zooplankton.

Table A.21. List of benthic invertebrate species inhabiting Bique Beach, Gulf of Panama (Villalaz et al., 1978).

TROPHIC LEVEL	SPECIES	COMMON NAME
	POLYCHAETA	round worms
Dep Feed	*Owenia sp.*	
Dep Feed	*Ctenodrilus sp.*	
Carn	*Notrhia sp.*	
Carn, escav	*Biborin sp.*	
Filt Feed	*Sabella sp.*	
omniv,Carn	*Nereis sp.*	
Dep Feed	*Clymenella sp.*	
	OPHIUROIDEA	brittle stars
Dep Feed	*Ophiolepis elegans*	
Filt Feed, Dep Feed	*Ophionereis annulata*	
	MOLLUSCA: GASTROPODA	coiled snails
Dep Feed, omniv	*Nassarius luteostoma*	
Dep Feed, omniv	*Nassarius complanatus*	
Dep Feed, omniv	*Cetrithium stercusmuscarum*	
??	*Littorina varia*	
??	*Modulus catenulatus*	
Filt Feed	*Crepidula striolata*	
Filt Feed	*Crepidula arenata*	
??	*Crucibulum spinosum*	
Carn	*Natica unifasciata*	
??	*Thais biserialis*	
??	*Thais kiosquiformis*	
	MOLLUSCA: BIVALVIA	clams
Filt Feed	*Protothaca asperrima*	
Filt Feed	*Protothaca mcginty*	
Filt Feed	*Chione subrugosa*	
??	*Mytella guyamensis*	
??	*Atrina maura*	
??	*Cardita radiata*	

Table A.21. Cont...

TROPHIC LEVEL	SPECIES	COMMON NAME
??	*Diplonta suprema*	
??	*Pitar paytensis*	
??	*Petricola parallela*	
??	*Mactra fonsecana*	
Filt Feed	*Mulinea pallida*	
??	*Florimetris dombei*	
Dep Feed	*Tagelus affinis*	
Filt Feed	*Corbula tennius*	
Filt Feed	*Corbula tumaca*	
	MOLLUSCA: POLYPLACOPHORA	
??	*Chiton squamosus*	
??	*Chiton stokesii*	
??	*Radsiella tenuisculpata*	
??	*Radsiella dispar*	
	CRUSTACEA: DECAPODA	crabs
??	*Synalpheus sp.*	
??	*Hepatus sp.*	
	Familia Penaeidae	shrimps
	Familia Porcellanidae	crabs
	Familia Paguridae	
	Familia Callianassidae	
	Familia Xanthidae	
	Familia Ocypodidae	
	Familia Portunidae	

Legend:

TROPHIC STATUS: Carn= Carnivores; Dep Feed= Deposit Feeders; Filt Feed= Filter Feeders; Omniv= Omnivores; ?= Unknown.

Table A.22. List of animal species inhabiting a sandy-muddy beaches (Bique beach, Gulf of Panama) by trophic chain and zonation (Villaláz et al., 1978).

TROPHIC STATUS	SPECIES	COMMON NAME	SEDIMENT ZISE		
			COARSE	INTERMEDIAT	FINE
Carn	Polychaeta	Round worms			
	Notria sp.			X	X
	Biborin sp.		X	X	X
	Birds[1]				
Omniv	Decapoda	Crabs			
	Callianasidae		X		
Filt Feed	Polychaeta	Round worms			
	Sabella sp.			X	
	Ophiuridea	Seastars			
	Ophionereis annulata			X	X
	Mollusca: Bivalvia	Clams			
	Protothaca asperrima			X	
	Protothaca mcginty			X	
	Chione subrugosa			X	
Dep Feed	Polychaeta	Round worms			
	Owennia sp.				X
	Ctenodrilus sp.				X
	Ophiuroidea	Seastars			
	Ophiolepis elegans				X
?	Mollusca: Gastropoda	Coiled snails			

TROPHIC STATUS	SPECIES	COMMON NAME	SEDIMENT ZISE		
			COARSE	INTERMEDIAT	FINE
	Nassarius leteostoma			X	
	Cerithium estercusmuscarum			X	
	Littorina varians			X	

Legend:

TROPHIC STATUS: Carn= Carnivores; Dep Feed= Deposit Feeders; Filt Feed= Filter Feeders; Omniv= Omnivores; ?= Unknown.

1- See Table 39 (shorebirds)

Table A-23. Zonation of typical Caribbean (Jamaica; Goureau & Goureau, 1975) and Eastern Pacific (Uvas and Secas Islands, Gulf of Chiriqui; Glynn 1976) coral reefs.

CARIBBEAN REEFS[1]	EASTERN PACIFIC REEFS[2]
THE BACK REEF 1) the inshore zone (0.1 to 3 m) 2) the lagoon zone (0.5 to 5 m).	THE BACK REEF 1) the reef flat
REEF FRAMEWORK - THE REEF CREST 3) the rear zone (0.2 to 3 m) 4) the reef-flat or Zoanthus zone (0 to 1 m) 5) the surf, breaker or palmata zone (0 to 5 m) 6) the barren, moat, or lower palmata zone (2 to 8 m) 7) the mixed, annularis-cervicornis zone (7 to 15 m) 8) the buttress zone (2 to 20 m)	REEF FRAMEWORK 2) the reef crest 3) the upper reef slope
THE SEAWARD SLOPE 9) the fore reef terrace, or sill, escarpment zone (15 to 40 m) 10) the fore reef slope (30 to 65 m) 11) the deep fore reef zone (60 m down)	THE SEAWARD SLOPE 4) the lower reef slope and the reef base

Table A-24. List of species inhabiting Caribbean coral reefs by trophic status and reef zone (Goureau & Goureau, 1974).

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Carniv.	SHARKS: SPHYRNIDAE	HAMMERHEAD SHARKS											
	Sphyrna spp.	hammerheads						V	V	V	V	V	V
	SHARKS: GYNGLYMOSTOMIDAE	NURSE SHARKS											
	Gynflymostoma cirratum	nurse shark	FC	FC	FC		C	C	C				
	SHARKS: HEXANCHIDAE	COW SHARKS											
	Notorynchus cepedians						V	V	V	V			
	FISHES: SPHYRAENIDAE	BARRACUDAS											
	Sphyraena barracuda	great barracuda					C	C	C	C	C		
	Sphyraena pecridilla	barracuda	C	C	C	C	C	C	C				
	FISHES: SERRANIDAE	GROUPERS											
	Epinephelus itajara	jawfish					FC	C	C	C			
	Epinephelus affer	muttom hamlet	C	C	C	C	C	C	C	C	FC	FC	
	Epinephelus guttatus	red hind							FC	C	C	C	
	Epinephelus niveatus	snowy grouper											
	FISHES: CARANGIDAE	JACKS											
	Caranx latus	horse-eye jack											
	FISHES: LUTJANIDAE	SNAPPERS											
	Lutjanus jocu	dog snapper											
	Lutjanus synagris	lane snapper					FC	FC	FC				
	Lutjanus vivans												
	Ocyurus chrysurus	yellowtail snapper					FC	FC	FC				
	Rhomboplictes aurorubens	vermilion snapper							FC	FC	FC	FC	

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Carniv.	FISHES: HOLOCENTRIDAE	SQUIRRELFISHES											
	Holocentrus rufes	longspine squirrelfish											
	Myripristis jocobus	blackbar soldierfish											
	FISHES: POMADASIDAE	GRUNTS											
	Haemulon steindachneri	latin grunt											
	Haemulon plumieri	white grunt											
	Haemulon album												
	Haemulon aerolineatum	tomtate											
	FISHES: PRIACANTHIDAE	BIGEYES											
	Priacanthus arenatus	bigeye											
	FISHES: APOGONIDAE	CARDINALFISHES											
	Apogon quadriscamatus	sawcheek cardinalfish											
	FISHES: MONACANTHIDAE												
	Aleutera schopfii												
	FISHES: DACTYLOTERIDAE	FLYING GURNARDS											
	Dactylopterus volitans	flying gurnard											
	FISHES: GERRIDAE	MOJARRAS											
	Gerres cinereus	yellowfin mojarra	C	C	C		C	C	FC				
	FISHES: MURAENIDAE	MORAY EELS											
	Gymnothorax funebris	green moray					FC	FC	FC				
Corall.	FISH: EPHIPPIDAE	SPADEFISHES											
	Chaetodipterus faber	spadefish	C	C	C	FC	C	C	C	FC			
	FISH: POMACANTHIDAE	BUTTERFLYFISHES											

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Corall.	*Chaetodon capistratus*	foureye butterflyfish					C	C	C				
	FISH: POMACENTRIDAE	DAMSELFISHES											
	Microspathodon chrysurus	yellowtail damselfish	C	C	C	FC	C	C	C				
	Stegastes planifrons	threespot damselfish	C	C	C	FC	C	C	C				
	Stegastes dorsopunicans												
	FISH: SCARIDAE	PARROTFISHES											
	Scarus coelestinus	midnight parrotfish											
	Scarus guacamaia	rainbow parrotfish											
	Scarus croicensis	striped parrotfish											
	Scarus vetula	queen parrotfish											
	Scarus taeniopterus	princess parrotfish											
	Sparisoma viride	stoplight parrotfish											
	Sparisoma aurofrenatum	redband parrotfish											
	FISH: MONACANTHIDAE												
	Alutera scripta												
	Cantherhines macrocerus												
	Cantherhines pullus												
	ECHINODERMATA	URCHINS & SEA STARS											
	Diadema antillarum	long-spine black urchin											
	Oreaster reticulatus	cushion sea star											
	MOLLUSCA: GASTROPODA	SNAILS											
	Calliostoma javanicum	chocolate-lined top snail											
	Coralliophila abbreviata	short coral snail											

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Corall.	*Coralliophila caribbaea*												
	POLYCHAETA	ROUNDWORMS											
	Hermodice carunculata	fierworm											
Omniv.	REPTILES: CHELONIDAE	SEA TURTLES											
	Chelonia mydas	green turtle			FC	FC	C	C	C	FC			
	Etertmochely imbricata	hawksbill turtle			FC	FC	C	C	C	FC			
	Caretta caretta	caguama turtle			FC	FC	C	C	C	FC			
	REPTILIA: DERMOCHELIDAE												
	Dermochelys coriacea	leatherback turtle			FC	FC	FC	FC	C	FC			
Hervib.	FISHES: POMACENTRIDAE	DAMSELFISHES											
	Abudefduf saxatilis	seargent major	FC	FC	C	FC	C	C	C				
	Chromis insolatus	sunshinefishes											
	Chromis multinileatus	brown chromis											
	Pomacentrus fuscus	dusky damselfish	FC	FC	FC	FC	C	C	C				
Filt. Feed.	CORAL: MILLEPORIDAE												
	Millepora alcicornis	crenelated fire coral	C	C	C	FC	FC	C	C	C	C	FC	
	Millepora complanata	flat-topped fire coral	FC	C	A	A	A	A	C	A			
	Millepora squarrosa	encrusting fire coral											
	CORAL: STYLASTERIDAE												
	Stylaster roseus												
	CORAL: ASTROCOENIIDAE												
	Stephanocoenia michelinii		FC	FC	FC			FC	FC	FC	C	C	FC
	Stephanocoenia intercepta												

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Filt. Feed.	CORAL: POCILLOPORIIDAE												
	Madracis formosa								FC	FC	CP	C	FC
	Madracis decactis		FC	FC				FC	FC	FC	CP	FC	
	Madracis mirabilis	branching coral							FC	FC	C	C	
	Madracis pharensis										FC	FC	C
	Madracis asperula												
	Madracis myriaster												
	Madracis senaria												
	CORAL: ACROPODIDAE												
	Acropora palmata	elkhorn coral	FC	FC	FC	C	A	A	C	A			
	Acropora cervicornis	staghorn coral	FC	FC	FC	FC	FC	FC	C	FC	C	C	
	Acropora prolifera		FC	FC	FC	FC	FC	FC	CP	C	C	C	
	Acropora valida												
	CORAL: AGARICIIDAE												
	Agaricia agaricites agaricites		FC	FC	FC	FC	C	C	C	A	A	A	C
	Agaricia agaricites danai												
	Agaricia agaricites carinata												
	Agaricia agaricites humilis												
	Agaricia agaricites crassa												
	Agaricia agaricites purpurea												
	Agaricia tenuifolia								FC	AP			
	Agaricia lamarcki	Lamark's lettuce-leaf coral								FC	CP	C	FC

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Filt. Feed.	*Agaricia fragilis*		C	FC	FC	FC	FC	FC	FC	C	C	C	
	Agaricia grahamae										CP	C	C
	Agaricia undata										CP	A	A
	Leptoseris digitata												
	Helioseris cucullata	sunray lettuce-leaf coral	C				FC	FC	C	FC	C	C	C
	CORAL: FUNGIDAE												
	Cycloseris elegans												
	CORAL: SIDERASTREIDAE												
	Siderastrea siderea	round starlet coral	FC	FC	FC	FC	FC	C	C	C	FC	FC	FC
	Siderastrea radians	shallow-water starlet coral	C	C	C	FC	FC	FC	FC	FC	FC	FC	
	CORAL: PORITIDAE												
	Porites astreoides	yellow porous coral	C	C	C	FC	FC	FC	C	C	C	C	FC
	Porites colonensis												
	Porites porites	thik finger coral	C	C	C	FC	FC	FC	C	C	C	C	
	Porites porites furcata	thin finger coral	FC	FC	FC	FC		FC	FC	C	C	C	FC
	Porites porites divaricata		C	C	C	CP	CP		FC	FC	FC	FC	
	Porites porites clavaria												
	Porites porites branneri				CP	CP	CP						
	CORAL: FAVIIDAE												
	Favia fragum	star coral	C	C	C	C	C	FC	C	FC	FC	FC	
	Diploria clivosa	sharp-hilled brain coral	C	C	C	FC	FC	FC	C	FC	FC	FC	
	Diploria strigosa	common brain coral	FC	FC	FC	C	C	C	C	C	C	FC	

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Filt. Feed.	*Diploria labyrinthiformis*	depressed brain coral	FC	FC	C	FC	FC	C	C	C	FC	FC	
	Manicina areolata areolata	common rose coral	CP	CP	CP		FC	FC	C	FC	FC	FC	FC
	Manicina areolata mayori												
	Colpophyllia sp.												
	Colpophyllia natans	large grooved brain coral	FC	FC	C	C	FC	FC	C	C	FC	FC	FC
	Colpophyllia amaranthus												
	Colpophyllia breviserialis												
	Cladocora arbuscula	tube coral	CP	CP	CP				FC	FC			
	Montastrea annularis	boulder coral	C	C	A	C	C	FC	A	A	C	C	C
	Montastrea cascada												
	Montastrea cavernosa	large-cupped boulder coral	C	C	C	C	C	FC	C	C	A	A	A
	Solenastrea bournoni		FC	FC	FC						FC	FC	
	Solenastrea hyades												
	CORAL: RHIZANGIIDAE												
	Phyllangia americana												
	Astrangia solitaria												
	CORAL: OCULINIDAE												
	Oculina difussa	ivory bush coral	FC	FC	FC				FC	FC	FC	FC	
	CORAL: MEANDRINIDAE												
	Meandrina meandrites meandrites	tan brain coral	FC	FC	FC			FC	FC	C	C	C	C
	Meandrina meandrina danai												
	Dichocoenia stokesi		C	C	C	C	C	FC	C	C	FC	FC	FC

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Filt. Feed.	*Dichocoenia stellaris*	stokes' starlet coral							FC	FC	C	C	FC
	Dendrogyra cylindrus	pillar coral	FC	FC	FC	FC	FC	FC	C	CP	CP	CP	
	CORAL: MUSSIDAE												
	Scolymia cubensis		FC						FC	C	C	C	C
	Scolymia lacera	large-cupped fungus coral							FC	FC	FC	CP	CP
	Mussa angulosa	large flower coral			FC	FC		FC	C	C	C	C	FC
	Isophyllia multiflora												
	Isophyllia sinuosa	cactus coral	FCP	FCP	FCP	FC	FC	FC	C	FC			
	Isophyllastrea rigida	rough star coral	FC	FC	FC	FC		FC	C	C	FC	FC	
	Mycetophyllia lamarckiana	large cactus coral						FC	A	A	C	FC	FC
	Mycetophyllia ferox				FC	FC		FC	C	FC	FC	FC	
	Mycetophyllia aliciae									FC	C	C	FC
	Mycetophyllia danaana		FC	FC	FC	C	FC	C	C	C	C	FC	
	Mycetophyllia reesi										FC	FC	C
	CORAL: CARYPHYLLIDAE												
	Eusimilia fastigiata	flower coral	FC	FC	FC	FC			FC	C	C	C	FC
	Stephanocyanthus paliferus												
	Coenocyanthus bartschi												
	CORAL: FLABELLIDAE												
	Flabellum moseleyi												
	CORAL: TUBASTREIDAE												
	Tubastrea coccinea	red/orange coral											

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Prim. Prod.	CHLOROPHYTA	GREEN ALGAE											
	Halimeda tuna		A	FC	A	A		FC	AP	FC	C	A	
	Halimeda tuna platydisca										C	A	FC
	Halimeda opuntia		A	A	A	A	A	C	FC	FC	FC	CP	FC
	Halimeda gracilis opuntioides		FC					CP			AP	A	FC
	Halimeda discoidea platyloba							AP			FC	C	
	Halimeda goreauii		FC	FC	FC	CP	FC	FC	C	AP	A	A	FC
	Halimeda incrassata		A	A	A	FC	FC					A	FC
	Halimeda simulans		A	A	A	FC				FC	FC	A	FC
	Halimeda monile		A	AP	A	FC							
	Halimeda favulosa								FC				
	Halimeda cryptica										A	A	A
	Halimeda copiosa										AP	A	FC
	Penicillus capitatus		FC	FC	A	FC						A	
	Penicillus lamourouxii		FC	FC	A	FC						A	
	Penicillus pyriformis		FC	FC	A	FC					C	C	
	Penicillus dumetosus		A	A	C							C	A
	Rhipocephalus phoenix		FC	FC	FC							A	C
	Udotea flabellum		A	A	A	A			FC		FC	FC	
	Udotea cyathiformis		C	C	A	FC	FC				A	A	FC
	Udotea conglutinata		AP	AP	AP							A	C
	Udotea wilsoni		A	A	A						C	A	A
	Udotea spinulosa		FC	FC	FC						FC		

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Prim. Prod.	*Acetabularia* spp.		C	FC	FC							FC	
	Cymopolia spp.		C		A								
	Neomeris spp.		C	FC	C	FC						FC	
	RHODOPHYTA	RED ALGAE											
	Liagora valida		C	FC	A	FC	FC					FC	
	Liagora ceranoides		C	FC	A						AP	FC	
	Liagora pinnata		C	C	C				FC		AP	FC	
	Liagora farinosa		C	FC	C	FC					FC		
	Liagora mucosa		FC		FC								
	Liagora pedicellata		FC		FC								
	Galaxaura squalida		C	FC	C	A	A						
	Galaxaura subverticillata		C	FC	C	A	A						
	Galaxaura oblongata		C										
	Galaxaura cylindrica		CP	FC	FC	FC							
	Galaxaura obtusata major										FC	A	C
	Galaxaura lapidescens		C	FC	C	C	C						
	Galaxaura marginata		C	FC	C	C	C						
	Galaxaura flagelliformis		FC		FC	FC	FC						
	Peyssonnelia spp.		C	FC	C	C	C	C	C	FC	C	FC	FC
	Lithothamnium spp.		FC	FC	C	A	A	A	A	A	A	A	C
	Goniolithon spp.		C	FC	FC	FC	C	C	C	C	C	A	C
	Amphiroa spp.		FC	FC	C	A	C	FC	FC	C	A	FC	
	Corallina spp.		C	FC	FC	C	FC	FC	FC	FC	FC		

Table A-24. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	ZONE										
			INS	LAG	REA	FLA	SUR	BAR	MIX	BUT	TER	SLO	DEE
Prim. Prod.	*Jania* spp.		C	FC	FC	C	FC	FC	FC	FC	FC		
	PHAEOPHYTA	BROWN ALGAE											
	Padina spp.		C	FC	FC	A	FC	FC	FC	C	C	FC	

Legend:

ZONES: INS= Inshore zone; LAG= Lagoon zone; REA= Rear zone; FLA= Reef-Flat or *Zoanthus* zone; SUR= Surf, breaker or *palmata* zone; BAR= Barren, moat, or lower *palmata* zone; MIX= Mixed, *annularis-cervicornis* zone; BUT= Buttress zone; TER= Fore-Reef Terrace, or sill, escarpment zone; SLO= Fore-Reef Slope; and, DEE= Deep Fore-Reef zone.

ZONATION: A= Abundant; C= Common; FC- Fairly Common; ND= No Data; WC= Water Column; (<-->)= forage along the zone but do not inhabit it.

TROPHIC STATUS: Bent. Zoopl.= Benthonic Zooplankton; Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Macrozoopl:= Macrozooplankton; Meropl.= Meroplankton; Microcarn.= Microcarnivores; Microzoopl.= Microzooplankton; Omniv.= Omnivores; Part. Feed.= Particle Fedders; Prim. Prod.= Primary Producers; Surf & Susp. Phytopl.= Surf and Suspende Phytoplankton; True Zoopl.= True Zooplankton.

Table A.25. Characteristics of the four Eastern Pacific coral reef zones (Glynn, 1976).

CHARACTERISTIC	ZONE			
	REEF FLAT	REEF CREST	UPPER REEF SLOPE	REEF SLOPE AND REEF BASE
Coral cover	moderate highly variable, both spatially and temporally, due to low water exposure.	high due to wave action during low water exposures.	high	moderate to low
Species diversity	low	low	low	highest because depth ranges of corals are greatly compressed, thus resulting in species overlap.
Common Genera	*Pocillopora* spp. *Porites panamensis* *Psammocora* spp.	*Pocillopora* spp. *Psammocora* spp.	*Pocillopora* spp.	*Pocillopora* spp. *Porites* spp. *Pavona* spp. *Gardinoseris* sp. *Millepora* spp.
Crustose coralline algae	common	rare	rare	rare
Filamentous algae	common	rare	rare	rare
Low tide exposure	> 2 hours	low due to wave action	no	no

Table A.25. Cont...

CHARACTERISTIC	ZONE			
	REEF FLAT	REEF CREST	UPPER REEF SLOPE	REEF SLOPE AND REEF BASE
Pocillopora symbionts density	highest seasonal changes due to massive *Pocillopora* death	high	moderate to high	moderate to high
Community structure affected by:	Physical Environment 1) aperiodic tidal exposure 2) rainfall and freshwater contact	Physical Environment 1) turbulence and high wave action during low tide exposure	Physical Environment 1) turbulence	Biotic Processes 1) competition for space 2) destruction by corallivores 3) disruptive effects by bioturbation 4) mutualistic and symbiotic interactions

Table A.26. List of species inhabiting Eastern Pacific coral reefs by trophic status and reef zonation (Glynn, 1976, 1982; Glynn et al., 72; Glynn & Wellington, 83; Guzmán et al., 1991; Guzmán 93; Prahl & Erhardt, 85; Díaz, in revision).

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Carniv.	AVES (see table 7)						
	SHARKS: CARCHARINIDAE	REQUIEM SHARKS	TIBURONES				
	Carcharhinus leucas	bull shark	tiburón toro			FC	FC
	Carcharhinus limbatus	blacktip shark	tiburón puntinegro				V
	Galeocerdo cuvieri	tiger shark	tiburón tigre				V
	Triaenodon obesus	reef whitetip shark	tiburón puntiblanco	FC	FC	C	C
	SHARKS: SPHYRNIDAE	HAMMERHEAD SHARKS	TIBURONES MARTILLOS				
	Sphyrna lewinii	common hammerhead	martillo común				V
	Sphyrna makkaran	great hammerhead	martillo gigante				V
	Sphyrna sp.	hammerhead	martillo				V
	RAYS: MYLIOBATIDAE	EAGLE RAYS	RAYAS				
	Aetobatus narinari	spotted eagle ray	raya moteada, aguila de mar				V
	FISHES: CARANGIDAE	JACKS & POMPANOS	JURELES				
	Alectis ciliaris	threadfin fish	caballa, pejeblanco			V	V
	Caranx caballus	green jack	cojinúa			V	V
	Caranx hippos	common jack	cojinúa, jurel			V	V
	Elagatis bipinnulata	rainbow runner	salmón, salmonete			V	V
	Gnathanodon speciosus	kingyellow jack	boquipenda, ojicandela			V	V
	Selene brevoortii						

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Carniv.	*Seriola lalandi dorsalis*	cobalt amberjack	bojalá			V	V
	Seriola rivoliana	pacific amberjack	bojalá			V	V
	Trachinotus humeralis	pompano	pámpano			V	V
	FISHES: CIRRHITIDAE	HAWKFISHES	HALCONES				
	Cirrhitichthys oxycephalus	coral hawkfish	halcón de coral			C	C
	FISHES: CORYPHAENIDAE	DOLPHINFISHES	DORADOS				
	Coryphaena hippurus	dolphinfish	dorado, pez hacha			V	V
	FISHES: GRAMMISTIDAE	SOAPFISHES	JABONEROS				
	Rypticus nigripinnis	blackfin soapfish	jabonero negro			C	C
	FISHES: LUTJANIDAE	SNAPPERS	PARGOS				
	Hoplopargus guentheri	barred snapper	pargo roquero			FC	FC
	Lutjanus argentiventris	yellowtail snapper	pargo amarillo			C	C
	Lutjanus novemfasciatus	Pacific dog snapper	pargo dientón				FC
	Lutjanus viridis	blue-and-gold snapper	pargo rayado			C	C
	FISHES: MURAENIDAE	MORAYS	MORENAS				
	Echidna zebra	zebra moray	morena zebra	C	C		
	Gymnothorax castaneus	panamic green morey	morena verde			C	C
	Gymnothorax panamensis	masked moray	morena verde			FC	FC
	Muraena lentiginosa	jewel moray	morena pintada	C	C	FC	
	FISHES: NEMATISTIDAE	ROOSTERFISHES	PECES GALLOS				
	Nematistus pectoralis	roosterfish	pez gallo			V	V

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Carniv.	FISHES: SCOMBRIDAE	MACKERELS & TUNAS	SIERRAS Y ATUNES				
	Scomberomorus sierra	sierra mackerel	sierra			V	V
	Thunnus albacares	yellowfin tuna	atún de aleta amarilla			V	V
	FISHES: SERRANIDAE	GROUPERS	MEROS				
	Epinephelus afer	motton hamlet	guaseta			C	C
	Epinephelus itajara	jewfish	mero gigante			FC	FC
	Epinephelus labriformis	flag cabrilla				FC	FC
	Epinephelus multiguttatus	pacific guaseta				C	C
	Epinephelus panamensis	Panama graysby	perro			C	C
	Hemanthias peruans	split tail bass	pollera			A	A
	FISHES: SPHYRAENIDAE	BARRACUDAS	BARRACUDAS				
	Sphyraena ensis	barracuda	barracuda, picuda	V	V	V	V
	MOLLUSCA: CEPHALOPODA	OCTOPUSES	PULPOS				
	Octopus vulgaris	common octopus					
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Conus spp.	cone snail	cono				
Corall.	FISHES: SCARIDAE	PARROTFISHES	PECES LOROS				
	Scarus ghobban	bluechin parrotfish	pez loro	FC	C	A	C
	Scarus perrico	bumphead parrotfish	pez loro frentón	FC	C	A	C
	Scarus rubroviolaceus	red lip parrotfish	pez loro pintado	FC	C	A	C
	FISHES: TETRAODONTIDAE	PUFFER FISHES	TAMBORILES				

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Corall.	*Arothron hispidus*	spotted green pufferfish	tamboril verde	C	C	A	C
	Arothron meleagris	golden puffer	pez guineo/ tamboril tigre	C	C	A	C
	Canthigaster amboinensis			A	C	A	C
	FISHES: BALISTIDAE	TRIGGERFISHES	PECES GATILLO				
	Balistes polylepis	finescale triggerfish	pez puerco/gatillo	C	C	C	FC
	Sufflamen verres	orangeside triggerfishes	pez puerco/gatillo	C	C	C	FC
	ECHINODERMATA	SEA STARS & URCHINS	ESTRELLAS Y ERIZOS DE MAR				
	Acanthaster planci	crown of thorn starfish				C	C
	Eucidaris thouarsii						
	Nidorellia armata						
	Pharia pyramidata						
	CRUSTACEANS: DECAPODA	SHRIMPS & CRABS	CANGREJOS Y CAMARONES				
	Aniculus elegans			A	A	A	A
	Trizopagurus magnificus			A	A	A	A
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Aeolid nudibranch						
	Jenneria pustulata						
	Latiaxis hindsii						
	Muricopsis zeteki						

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Corall.	*Quoyula madreporarum*						
Omniv.	REPTILES: CHELONIDAE	SEA TURTLES	TORTUGAS MARINAS				
	Chelonia mydas agassizii	Pacific green turtle	tortuga verde/blanca	FC	FC	C	C
	Etertmochely imbricata squamata	Pacific hawksbill turtle	tortuga carey	FC	FC	C	C
	Lepidochelys olivacea	Pacific ridley turtle	tortuga mulata	FC	FC	C	C
	Caretta caretta	caguama turtle	tortuga caguama	FC	FC	C	C
	REPTILIA: DERMOCHELIDAE	SEA TURTLES	TORTUGAS MARINAS				
	Dermochelys coriacea schlegelii	Pacific leatherback turtle	tortuga canal/baula	FC	FC	FC	FC
	FISHES: MULLIDAE	GOATFISHES	SALMONETES				
	Pseudopeneus grandisquamis	red goatfish	salmonete	V	V	V	V
	FISHES: POLYNAEMIDAE	THREADFINS	PECES BOBO				
	Polydactilus approximans	blue bobo, threadfin	bobo, barbudo	C	C	C	C
Herbiv.	FISHES: CLUPEIDAE	SARDINES					
	Opisthonema liberate	Pacific thread herring	sardina, arenque	V	V	V	V
	FISHES: POMACENTRIDAE	DAMSELFISHES	PECES DAMISELA				
	Abudefduf troschelii	panamic seargent	chogorro	FC	C	C	C
	Eupomacentrus acapulcoensis	Acapulco damselfish	damisela			C	C
	Eupomacentrus flavilatus	beaubrummel	damisela bicolor			C	C

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Herbiv.	*Microspathodon bairdii*	bumphead damselfish	damisela			C	C
	Microspathodon dorsalis	giant damselfish	damisela gigante			C	C
	Stegastes acapulcoensis					C	C
	Stegastes arcifrons					C	C
	Stegastes flavilatus	Pacific beaubrumel				C	C
	ECHINODERMATA: ECHINOIDEA	SEA URCHINS	ERIZOS				
	Arbacia stellata						
	Asropyga pulvinata						
	Echinometra vanbrunti						
	Diadema mexicanum						
	Lytechinus panamensis						
	Toxopneustes roseus						
	Tripneustes depressus						
	MOLLUSCA: GASTROPODA	COILED SNAILS	CARACOLES				
	Fasciolaria princeps	prince horse conch					
	Strombus galeatus	giant Eastern Pacific conch					
Part. Feed.	CRUSTACEA: NEPHROPIDAE	LOBSTERS	LANGOSTAS				
	Nephropsis occidentalis	Pacific lobsterette	cigala del Pacífico			FC	FC
	CRUSTACEA: PALINIDAE	LOBSTERS	LANGOSTAS				
	Panulirus gracilis	Green spiny lobster	langosta barbona			C	C
	Panulirus inflatus	Blue spiny lobster	langosta barbona			FC	FC

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Part. Feed.	CRUSTACEA: SCYLLARIDAE	LOBSTERS	LANGOSTAS				
	Evibacus princeps	shield slipper lobster	langosta china			FC	FC
	CRUSTACEA: LITHODIIDAE	KING CRABS	CENTOLLOS				
	Lithodes panamensis	Panama king crab	centollo	C	C	C	C
Cleaners Cleaners	FISHES: CHAETODONTIDAE	BUTTERFLYFISHES	PECES MARIPOSA				
	Johnrandalia nigrirostris	barberfish	mariposa, barbero	C	C	C	C
	FISHES: LABRIDAE	WRASSES	VIEJAS Y SEÑORITAS				
	Thalassoma lucasanum	rainbowfish	arco iris	A	A	A	A
	Thalassoma lutescens	susnset wrasse	arco iris	C	C	C	C
Pocill. Symb	CRUSTACEANS: DECAPODA	CRABS	CANGREJOS				
	Alpheus lottini						
	Trapezia ferruginea						
Filt. Feed.	MOLLUSCA: BIVALVIA	CLAMS	ALMEJAS				
	Glycymeris maculata	speckled bittersweet					
	Modiolus capax	horse mussel					
	Pinctada mazatlanica	Mazatlan pearl oyster					
	Pteria sterna	western wing oyster					
	CORALS: MILLEPORIDAE						
	Millepora intricata[1]	fire coral			FC	C	C
	Millepora platyphulla[1]	fire coral					

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Filt. Feed.	*Millepora sp.*[1]	fire coral					
	CORAL: THAMNASTERIDAE						
	Psammocora brighami[1]						
	Psammocora stellata[12]			FC			
	Psammocora superficialis[12]			FC			
	CORAL: POCILLOPORIDAE						
	Pocillopora capitata[1]			C	C		
	Pocillopora damicornis[12]			A	A	A	A
	Pocillopora danae			C	C	C	C
	Pocillopora elegans[12]			FC	FC	A	A
	Pocillopora eydouxi[1]			FC	FC	C	A
	Pocillopora lacera[1]			C	C		
	Pocillopora meandrina[12]						
	Pocillopora robusta[1]						
	Madracis asperula						
	Madracis pharensis						
	CORAL: ACROPORIDAE						
	Acropora crassa						
	Acropora valida						
	CORAL: AGARICIIDAE						
	Pavona clavus[12]					C	C
	Pavona gigantea[12]					C	C

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Filt. Feed.	*Pavona varians*[12]				FC	C	C
	Gardineroseris planulata[1]					FC	FC
	Leptoseris sp.[1]						
	CORALES: FUNGIIDAE						
	Cycloseris elegans						
	Cycloceris mexicana						
	CORAL: SIDERASTERIDAE						
	Siderastrea sp.[12]			ND	ND	ND	ND
	CORAL: PORITIDAE						
	Porites californica[1]			FC		FC	FC
	Porites lobata[12]					FC	FC
	Porites panamensis[12]			FC			C
	Porites paschalensis[1]						C
	CORALS: RHIZANGIIDAE						
	Astrangia brownii						
	Astrangia equatorialis						
	Astrangia hondaensis						
	Bathycyathus consagensis						
	Phyllangia consagensis						
	CORALS: FAVIIDAE						
	Cladocora arbuscula						
	CORALS: FLABELLIDAE						

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Filt. Feed.	*Flabellum daphnense*						
	Flabellum gallapagense						
	CORAL: DENDROPHYLLIDAE						
	Tubastrea aurea[1]						
	Tubastrea faulkneri						
	Tubastrea floreana						
	Tubastrea tagusensis						
	Tubastrea coccinea[1]					FC	FC
Prim. Produc.	CALCAREOUS ALGAE	CALCAREOUS ALGAE	ALGAS CALCAREAS				
	Archeolithothamnium sp.			C	C	FC	
	Lithophyllum imitans			C	C	FC	
	Lithophyllum sp.			C	C	FC	
	Lithothamnium sp.			C	C	FC	
	Mesophyllum sp.			C	C	FC	
	Polystrata compacta			C	C	FC	
	Porolithon cocosicum			C	C	FC	
	BACILLARIOPHYACEAE						
	Licmophora flabellata			WC	WC	WC	WC
	CYANOPHYTA	CRUST. BLUE-GREENS	ALGAS VERDEAZULES CRUST.				
	Calothrix crustacea			WC	WC	WC	WC
	CHLOROPHYTA	GREEN ALGAE	ALGAS VERDES				
	Enteromorpha prolifera			WC	WC	WC	WC

Table A.26. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	NOMBRE COMUN	ZONE			
				FLA	CRE	UPP	BAS
Prim. Prod.	PHAEOPHYTA	BROWN ALGAE	ALGAS PARDAS				
	Giffordia mithellae			WC	WC	WC	WC
	Giffordia rallsiae			WC	WC	WC	WC
	RHODOPHYTA	RED ALGAE	ALGAS ROJAS				
	Goniotrichum alsidii			WC	WC	WC	WC
	Herposiphonia secunda			WC	WC	WC	WC

Legend:

ZONES: FLA= Reef Flat; CRE= Reef Crest; UPP= Upper Reef-Slope; BAS= Low Reef-Slope and Reef Base.

ZONATION: A= Abundant; C= Common; FC- Fairly Common; ND= No Data; V= Visitor; WC= Water Column; (<-->)= forage along the zone but do not inhabit it.

TROPHIC STATUS: Bent. Zoopl.= Benthonic Zooplankton; Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Macrozoopl:= Macrozooplankton; Meropl.= Meroplankton; Microcarn.= Microcarnivores; Microzoopl.= Microzooplankton; Omniv.= Omnivores; Part. Feed.= Particle Fedders; Prim. Prod.= Primary Producers; Surf & Susp. Phytopl.= Surf and Suspende Phytoplankton; True Zoopl.= True Zooplankton.

1- Coral species present in Panamanian Eastern Pacific.
2- Coral species listed by the Biological Inventory 1993.

Table A.27. Some contrasting characteristics of Eastern Pacific and Caribben coral reefs environments (Glynn, 1982).

	EASTERN PACIFIC	CARIBBEAN
Physical environment	Thermocline and high nutrient levels occur at shallow depths.	Thermocline and high nutrient levels occur to lower depths.
	Upwelling areas and cool water currents are widespread.	Upwelling areas and cool currents are limited i extent.
	Tidal amplitude large (>6m) and predictable.	Tidal amplitude small (c. 1m) and unpredictable
	Turbidity high near coast with increasing clarity on offshore islands.	Ligh penetration moderate to high.
Nature of reefs	Reefs small, one to a few ha in area.	Reefs large, from one hundreds of ha in area.
	Reefs are discontinuous and relatively isolated (island-like).	Reefs are widespread and often occur continuously over large geographic areas.
	Maximum Holocene framework thickness about 12m.	Maximum Holocene framework thickness about 33m.
	Mean reef frame accumulation rates = 1.3-7.5m 1000/yr.	Mean reef frame accumulation rates = 0.6-3.9m 1000/yr.
	Reefs form in sheltered habitats and are not well-consolidated.	Reefs form in low to high energy environments and are well-consolidated.
	Framework construction occurs at shallow depth, usually no deeper than 10-15m; submerged reefs on insular and continental shelves are unknown.	Framework construction occurs in shallow and deep water, to a 60 m depth; submerged bank or barrier reefs on insular and continental shelve are common.
	Habitat diversity is low, with three to four vertical zones per reef.	Habitat diversity is high, with up to 11 vertical zones per reef.
	Number of reef-building corals is low, with eight to ten species per reef.	Number of reef-building corals is high, with 30 50 species per reef.
	Seagrass and mangrove communities are not present near coral reefs.	Seagrass and mangrove communities overlap extensively with coral communities.
	Crustose coralline algae rarely form an algal ridge.	Crustose coralline algae commonly serve as cementing agents and often construct algas ridge features.

Table A.27. Cont...

	EASTERN PACIFIC	CARIBBEAN
Ecological attributes	Impoverished with respect to numerous sedentary taxa, i.e. calcareous green algae, large fleshy algae, sea grasses, large fleshy sponges, hermatypic corals, sclerosponges, gorgonaceans, actiniarians, zoanthids, crinoids, colonial tunicates.	With relatively rich an diversified sedentary biota.
	Number of individuals per species generally high.	Number of individuals per species is low to moderately high.
	Corallivores are abundant with significant effects on coral growth and relative abundances of corals.	Corallivores relatively insignificant.
	Predation on motile, invertebrate corallivores is high.	Predation on motile, invertebrate corallivores is low.
	Sponge predatores abundant and possibly responsible for low sponge cover on reefs.	Sponge predation is limited.
	Competition for space among corals is intense.	Competition for space between corals and other benthic taxa is intense.
	Branching corals contain protective symbiotic crustaceans.	Branching corals without protective symbiotic crustaceans.
	Pathogens are presently unknown in Eastern Pacific coral communities.	Pathogenic blue-green algae and bacteria are reported in reef corals and associated fauna.
	Organisms capable of binding calcareous skeletal remains are generally rare.	Biotic binding agents (e.g., encrusting red and calcarous green algae, sea grasses, sponges, zoanthids, gorgonaceans) are abundant.
	Bioerosion is intense.	Bioerosion is moderate.

Table A.28. List of seagrass species of Panama (Batelle, 1970).

CAREBBEAN	SEA	PACIFIC	OCEAN
SPECIES	COMMON NAME	COMMON NAME	SPECIES
Thalassia testuninum	turtle grass	turtle grass	*Thalassia hemprichii*
Syringodium filiforme	manatee grass		*Syringodium isoetifolium*
Halodule beudettei			*Halodule uninervis*

Table A.29. Fauna that inhabit seagrasses in Caribbean panamanian coasts (D'Croz, 1977).

TROPHIC LEVEL	TAXA	COMMON NAME
	GROUP 1	
	PISCIS:SCORPANEIDEA	scorpionfishes
	Scorpaena grandironis	
	Scorpaena brasiliensis	
	PISCIS:LABRIDAE	wrasses
	Halichoeres radiatus	
	PISCIS:SCARIDAE	parrotfishes
herb	*Sparisoma radians*	
	PISCIS:GOBIIDAE	gobids
	Bathyogobius soporator	
	MOLLUSCA: GASTROPODA	coiled snails
	Strombus gigas	
	Cerithium literatum	
pred, detri	*Nassarina metabrunne*	
	Tegula fasciata	
herb	*Aplysia diomedae*	
	CRUSTACEA:DECAPODA	shrimps
	Tozeuma carolinense	
	Panapeus herbstii	
	Alpheus normanni	
	Alpheus armatus	
	Alpheus heterochaelis	
	Microphyrys bicornutus	
	CRUSTACEA: STOMATOPODA	mantis shrimps
	Gonadactylus oerstedii	

Table A.29. Cont...

TROPHIC LEVEL	TAXA	COMMON NAME
	EQUINODERMATA: ECHINOIDEA	sea urchins
herb	*Tripneustes ventricosus*	
herb	*Lytechinus variegatus*	
herb	*Diadema antillarum*	
	GROUP 2	
	PISCIS:LUTJANIDAE	snappers
omni	*Lutjanus analis* (juveniles)	
omni	*Lutjanus jocus* (juveniles)	
	PISCIS:POMADSYIDAE	grunts
	Haemulon sciurus (juveniles)	
	PISCIS:ENGRAULIDAE	anchovies and sardines
omni	*Anchoa lamprotaenia* (juveniles)	
	CRUSTACEA: DECAPODA	shrimps
	Panaeus schimitti (juveniles)	
	Penaeus brasiliensis (juveniles)	
	Metapenaeopsis simithi (juveniles)	
	Sycionia parri (juveniles)	
	GROUP 3	
	PISCIS: CHAETODONTIDAE	butterflyfishes
omni	*Chaetodon capistratus*	
omni	*Chaetodon striatus*	
	PISCIS: SCARIDAE	parrotfishes
coral	*Scarus taeniopterus*	

Table A.29. Cont...

TROPHIC LEVEL	TAXA	COMMON NAME
herb	*Sparisoma rupripinne*	
	PISCIS: GERREIDAE	
herb	*Eucinostomus gula*	
	PISCIS: LUTJANIDAE	snappers
carni	*Lutjanus analis*	
carni	*Lutjanus synagris*	
carni	*Ocyurus chrysurus*	
	PISCIS: ACANTHURIDAE	surgeonfishes
herb	*Acanthurus bahianus*	
herb	*Acanthurus chirurgus*	

Legend:

TROPHIC LEVEL: herb=herbivor, pred=predator, detri=detritivor omni=omnivor, carni=carnivor, coral=corallivor.

Group 1= Typical organisms of *Thalassia testudinum*.
Group 2= Organisms that spend part of their life cycle in segrass beds.
Group 3= Organisms that ocasionally visit seagrass beds in search of food and protection.

Table A.30. List of invertebrates that inhabit seagrass beds in the Caribbean coast of Panama (Heck, 1977; D'croz, 1975; Marshall, 1991).

TAXA	COMMON NAME	ABUNDANCE
INFAUNA		
MOLLUSCA: GASTROPODA		
Acmaea pustulata		ND
Cerithium eburneum		A
Cerithium variabile		ND
Diodora sp. A		ND
Fasciolaria tulipa		ND
Nudibranchios spp.		ND
Polinices hepticus		ND
Smaragadia viridis		ND
MOLLUSCA: BIVALVIA	Clams	
Anadara notialis		ND
Arcopsis adamsi		ND
Cadakia orbicularis		ND
Corbula sp. A		ND
Diplodonta punctata		ND
Panapeus occidentalis		ND
Tagelus divisus		ND
Tellina alternata		FC
SIPUNCULA		
Sipunculidos spp.		ND
ANNELIDA: POLYCHAETA	round worms	
Ampharetid sp. A		ND
Arabella mutans		ND
Arabellid sp. A		ND
Aricidea suecia		ND

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
Armandia bioculata		ND
Capitellidos		ND
Ceratonereis mirabilis		ND
Chloeia viridis		ND
Chone sp. A		ND
Cirratulus cirrata		ND
Cirratulus sp. A		ND
Cirratulus sp. B		ND
Cirratulus sp. C		ND
Cirriformia luxuriosa		ND
Cirriformia punctata		ND
Clymenella sp.		ND
Dodecaceria concharum		ND
Dorvillea rubrovittatus		ND
Driloneries nuda		ND
Eualia myriacyclum		ND
Eunice sp. A		ND
Eunice websteri		ND
Eupolymia nebulosa		ND
Eurythoe complanata		ND
Glycera robusta		ND
Goniada aciculata		ND
Goniada sp. A		ND
Hypsicomus phaeotania		ND
Isolda bipinatta		ND
Kinbergonuphis sp.		ND
Lumbrinereis treadwelli		ND
Lysidice ninetta		ND

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
Marphysa sanguinea		ND
Megalomma bioculatum		ND
Megalomma vesiculosum		ND
Nematoneries unicornis		ND
Nereis riisei		ND
Orbiniid sp. A		ND
Osrbiniid sp. B		ND
Owenia collaris		ND
Pectinaria gouldii		ND
Pherusa inflata		ND
Phyllodocid sp. A		ND
Pista sp. A		ND
Platynereis dumerili		ND
Podochela riisei		ND
Poechilochaetus johnsoni		ND
Polynoidos		ND
Prionospio cirrifera		ND
Prionospio heterobranchia texana		ND
Psammolyce spinosa		ND
Sabella melonostigma		ND
Sabellido sp. A		ND
Sabellido sp. B		ND
Schistomeringos longicornis		ND
Scoloplos rubra		ND
Scoloplos sp. B		ND
Scoloplos sp. B		ND
Spio sp. A		ND

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
Syllidos		*ND*
Terebellidos		*ND*
Trachytyrpane sp. A		*ND*
CRUSTACEA: OSTRACODA		
Ostracodes		*ND*
CRUSTACEA: STOMATOPODA	*mantis shrimp*	
Stomatopodes		ND
CRUSTACEA: DECAPODA	shrimps and crabs	
Alpheideos		ND
Ambidexter symmetricus		ND
Callianaseos		ND
Clibinarius antillarum		FC
Hepatus pudibundus		FC
Hippolyte zostericola		ND
Latreutes fucorum		*ND*
Periclimenes americanus		*ND*
Pinnixia sp. A		*ND*
Pitho aculeata		*ND*
Pitho laevigata		*ND*
Pitho sp. A		*ND*
Processa fimbriata		*ND*
Scyonia laevigata		*ND*
Thor floridanus		*ND*
Trachycaris restrictus		FC
Upogebia affinis		ND
Xanthideos		ND
CRUSTACEA: MYSIDACEA	mysid shrimps	
Mysidaceos		ND

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
CRUSTACEA: CUMACEA	cumaceans	
Cumaceos		ND
CRUSTACEA: TANAIDA		
Tanaideos		ND
CRUSTACEA: ISOPODA	isopods	
Isopodos		ND
CRUSTACEA: AMPHIPODA	amphipods	
Amphipodos		ND
EPIFAUNA		
PLATYHELMINTHES	faltworms	
Platyhelmintos		ND
MOLLUSCA: GASTROPODA	coiled snails	
Aplysia dactylomelia		C
Cerithium eburneum		A
Cerithium litteratum		C
Conus sp.		FC
Modulus modulus		C
Gastropodos		ND
MOLLUSCA: BIVALVIA	clams	
Panopeus occidentalis		FC
MOLLUSCA: POLYPLACOPHORA		
Polyplacophoros		ND
ANNELIDA: POLYCHAETA	roundworms	
Hermodice carunculata	fireworm	A
CRUSTACEA: OSTRACODE	ostracodes	
Ostracodes		ND
CRUSTACEA: STOMATOPODA	mantis shrimps	
Stomatopodes		ND

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
CRUSTACEA: DECAPODA	shrimps and crabs	
Alpheideos		ND
Ambidexter symmetricus		ND
Callinectes danae		C
Clibinarius antillensis	hermit crab	FC
Gnathophyllum americanum		ND
Hippolyte zostericola		ND
Latreustes fucorum		ND
Latreustes parvulus		ND
Leander tenuicornis		FC
Majideos		ND
Microphrys bicornutus	majid crab	C
Paguridos		ND
Pagurus bonairensis	hermit crab	A
Pagurus brevidactylus	hermit crab	FC
Palaemon northropi		ND
Panulirus argus	lobster	FC
Parthenopidos		ND
Penaeus duororum notialis	shrimp	A
Periclimenes americanus		ND
Periclimenes longicaudatus		ND
Petrolisthes armatus	crab	FC
Petrolisthes galathinus		C
Pinnixia sp.A		ND
Processa fimbriata		ND
Sicyonia laevigata		ND
Sternorhynchus seticornis	spider crab	FC
Synalpheus fritzmulleri	shrimp	FC

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
Synalpheus pandionis		FC
Thor manningi		ND
Tozeuma carolinense		A
Trachycaris restrictus		ND
Typton tortugae		ND
CRUSTACEA: MYSIDACEA	mysid shrimps	
Mysidaceos		ND
CRUSTACEA: CUMACEA	cumaceans	
Cumaceos		ND
CURSTACEOS: TANAIDAE		
Tanaidaceos		ND
CRUSTACEOS: AMPHIPODA	amphipods	
Amphipodes		ND
EQUINODERMATA: ASTEROIDEA	seastars	
Astropecten duplicatus		C
Oreaster reticulatus		FC
EQUINODERMATA: ECHINOIDEA	sea urchins	
Diadema antillarum		FC
Echinometra lucuntre		ND
Eucidaris tribuloides		FC
Lytechinus variegatus		C
Tripneustes ventricosus		FC
EQUINODERMATA: HOLOTHUROIDEA	sea cucumbers	
Holothuria mexicana		A
Holuturidos		ND
EQUINODERMATA: OPHIUROIDEA	brittle stars	
Ophiros		ND
Ophiactis savignyi		FC

Table A.30. Cont...

TAXA	COMMON NAME	ABUNDANCE
Ophiothrix angulata		FC
CORDATA: PECES		ND

Legend

ABUNDANCE: A= Abundant; C= Common; FC= Fairly Common; ND= No Data.

Table A.31. Species and distributions of mangrove trees in Panama.

Species	Common Names	Distr.
Rhizophora mangle	red mangrove	P,C
R. harrisonni (=*R. brevistilla*)	mangle caballero, or mangle rojo	P,C
R. racemosa[1]	red mangrove	?
Avicennia germinans (=*A. nitida*)	black mangrove	P,C
A. bicolor	mangle salado o mangle negro salt mangrove or black mangrove	P,C
Laguncularia racemosa	white mangrove	P,C
Conocarpus erectus	mangle botón o botoncillo button mangrove	P,C
Pelliciera rhizophorae[2]	el piñon o pie de santo piñon or saint's foot	P

Legend:

[1] - Mentioned by earlier works, but needs confirmation.

[2] - This sp. has been seen in Panama on the Caribbean coast (J. Tejada, pers. comm.)

P = Pacific coast, C = Caribbean coast.

Table A.32. Mangrove coverage in Panama by area (Anguizola et al., 1988).

Location	Coverage (in hectares)
Gulf of Chiriquí	44,688
Gulf of Montijo	23,439
Azuero Peninsula	6,213
Parita Bay	11,553
Chame Bay	5,044
Panama Bay	26,192
Gulf of San Miguel	46,489
Other Areas	1,350
TOTAL	**164,968**

Table A.33. Invertebrate taxa from prop roots of the red mangrove (Rhizophora mangle) near Galeta Point, Caribbean coast, Panama (from Batista, 1980; Garrity & Levings, 1991).

PROTOZOA	
Foraminifera	*Quinqueloculina sp.*
PORIFERA	
Haplosclerida	*Niphates erecta*
	Sigmadocia sp.
	Sigmadocia caerulea
Poecilosclerida	*Tedania ignis*
Keratosa	*Spongia sp.*
	Species A
	Species B
	Species C
	Species D
CNIDARIA	
Actiniaria	*Aiptasia tagetes*
	Bartholomea annulata
	Bunodeopsis globulifera?
Zoanthidea	*Palythoa variabilis*
	Zoanthus sociatus
Ceriantharia	*Ceriantheopsis americanus*
Scleractinia	*Porites porites*
	Porites astreoides
	Siderastrea siderea
	Siderastrea radians
	Favia fragum
Hydrozoa	Species A
PLATYHELMINTHES	
Polycladida	Species A
SIPUNCULA	Species A
POLYCHAETA	
Amphinomidae	*Hermodice carunculata*
Eunicidae	*Lysidice sp.*
Arabellidae	*Arabella sp. cf. mutans*
Lumbrineridae	*Lumbrinereis sp. cf. tetraura*

Table A.33. Cont...

	Lumbrinereis sp. cf. latreille
Cirratulidae	*Chaetozone sp.*
Neridae	*Perinereis sp. cf. anderssoni*
	Nereis sp.
	Nematonereis sp.
Syllidae	*Trypanosyllis taeniaformis*
Sabellidae	*Megaloma sp.*
	Sabella sp.
Serpulidae	*Spirorbis sp.*
CRUSTACEA	
Ostracoda	Species A
Harpacticoida	Species A
Cirripedia	*Chthamalus sp.*
Tanaidacea	Species A
Isopoda	Species A (Gnathiidae)
	Alcinora sp.
	Ligia sp.
	Limnoria sp.
	Sphaeromid-type
	Species A (Limnoriidae)
Amphipoda	*Elasmopus sp.*
Caridea	*Alpheus sp.*
	Stenopus hispidus
Brachyura	*Sesarma curacoense*
	Sesarma cinereum
	Aratus pisonii
	Pachygrapsus gracilis
	Uca sp.
	Ocypode quadrata
	Panopeus herbsti
	Microphrys bicornutus
Anomura	*Clibanarius sp.*
Hoplocarida	*Pseudosquilla ciliata*
	Gonodactylus bredini
	Gonodactylus oerstedi
	Gonodactylus austrinus
MOLLUSCA	
Archaeogastropoda	*Nerita tessellata*
	Neritina virginea

Table A.33. Cont...

Mesogastropoda	*Latirus distinctus*
	Littorina nebulosa
	Littorina angulifera
	Cerithium litteratum
	Batillaria minima
	Petaloconchus sp.
	Caecum sp.
Neogastropoda	*Drupa nodulosa*
Nudibranchia	*Chromodoris sp.*
Tectibranchia	*Bursatella pleii*
Bivalvia	*Brachidontes exustus*
	Isognomon alatus
	Teredo sp.
Amphineura	*Acanthochitona sp.*
BRYOZOA	
Cheilostomata	*Gemellipora sp.*
ECHINODERMATA	
Echinoidea	*Diadema antillarum*
	Lytechinus variegatus
	Eucidaris tribuloides
Ophiuroidea	*Ophioderma sp. cf. appresum*
	Ophiocoma sp.
ASCIDIACEA	
Aplousobranchia	*?Clavelina sp.*

Table A.34. Vertical zonation of the open-coast red mangrove (Rhizophora mangle) fouling community, Galeta Point, Panama. Species listed in order of abundance (either weight or number). From Batista, 1980.

Level (cm MLW)	Dominant Flora	Dominant Fauna
+50–60	-	*Littorina angulifera*
+40–50	-	-
+30–40	-	*Chthamalus sp.*, *Littorina sp.*
+20–30	*Bostrychia sp.*, *Catenella sp.*	*Spirorbis sp.*, *Littorina sp.*
+10–20	*Bostrychia sp.*, *Catenella sp.*	*Spirorbis sp.*, foraminiferans, *Littorina sp.*
+0–10	*Bostrychia sp.*, *Catenella sp.*, *Polysiphonia sp.*, Cyanophyta	Sponge sp. A, *Spirorbis sp.*, copepods
-0–10	*Peyssonnelia rubra*, *Bostrychia sp.*, *Catenella sp.*, *Polysiphonia sp.*	Sponge sp. A, hydrozoans
-10–20	Cyanophyta, *Peyssonnelia rubra*, *Polysiphonia sp.*	Sponge sp. A, hydrozoans, *Spirorbis sp.*, tanaids
-20–30	*Polysiphonia sp.*, Cyanophyta	Hydrozoans, tanaids, copepods, *Spirorbis sp.*
-30–40	*Polysiphonia sp.*	Hydrozoans, foraminiferans, tanaids
-40–50	*Polysiphonia sp.*	Hydrozoans, tanaids

Table A.35. Algal species from prop roots of the red mangrove (Rhizophora mangle) near Galetta Point, Caribbean coast, Panama (from Batista, 1980; Garrity & Levings, 1992).

CYANOPHYTA	*Lyngbya sp.*
	Spirulina sp.
CHRYSOPHYTA	*Biddulphia sp.*
	Coscinodiscus sp.
	Rhizosolenia sp.
CHLOROPHYTA	
Ulotrichales	*Percursaria percursa*
Cladophorales	*Rhizoclonium sp.*
	Cladophora sp.
	Chaetomorpha sp.
Siphonocladiales	*Acetabularia crenulata*
	Cladophoropsis sp.
	Struvea sp.
	Anadyomene stellata
Siphonales	*Derbesia sp.*
	Bryopsis pennata
	Bryopsis sp.
	Caulerpa verticillata
	Caulerpa racemosa
	Caulerpa sertularioides
	Codium sp.
	Udotea flabellum
	Halimeda opuntia
	Halimeda monile
PHAEOPHYTA	
Sphacelariales	*Sphacelaria sp.*
Dictyotales	*Dictyota bartayresii*
Chordariales	*Ralfsia sp. cf. expansa*
Punctariales	*Colponemia sinuosa*
RHODOPHYTA	
Nemalionales	Species A
Cryptonemiales	*Peyssonnelia rubra*
	Fosliella affinis?
	Amphiroa fragilissima
	Amphiroa rigida
Gigartinales	*Catenella sp.*
Ceramiales	*Ceramium sp.*
	Centroceras clavulatum
	Spyridia filamentosa
	Antithamnion sp.
	Caloglossa sp.
	Polysiphonia sp.
	Bostrychia sp.
	B. tenella
	Acanthophora spicifera
	Laurencia papillosa
	unidentified red alga no. 1

Table A.36. Catalog of macroscopic marine algae and invertebrates collected from fine sand, mud and coral fragments, at the base of prop roots of the red mangrove (Rhizophora mangle), near Galeta Point, Caribbean coast of Panama. From Birkeland et al. (1976).

CYANOPHYTA	SIPUNCULA (continued)	CRUSTACEA (continued)
filamentous blue-green	*Paraspidosiphon fisheri*	*Panopeus sp. 1*
large bulbous blue-green	*P. spinososcoutatus*	*Panopeus sp. 2*
	P. steenstrupi	*Panopeus sp. 3*
CHLOROPHYTA	*Paraspidosiphon sp. 4*	*Pachygrapsus sp. 1*
Caulerpa fastigiata	*Phascolosoma antillarum*	*Microphrys bicornutus*
Chaetomorpha brachygona	*P. perlucens*	*Uca sp. 1*
C. clavata	*Phascolosoma sp. 3*	
Chaetophoraceae (appressed	*Phascolosoma sp. 4*	GASTROPODA
green coalesced filaments)		*Batillaria minima*
Cladophora sp.	POLYCHAETA	*Neritina virgines*
Cladophoropsis membranacea	*Eurythoe complanata*	*Nassarius vibex*
Halimeda opuntia	*Arabella mutans*	*Planaxis nucleus*
	Notomastus lineatus	*P. lineatus*
RHODOPHYTA	*Glycera oxycephala*	*Tricolia bella*
Bostrychia binderi	*Eunice afra*	*Gastropod sp.*
Caloglossa leprieurii	*E. aphroditois*	*Cerithiid sp.*
Catenella repens	*E. caribaea*	*Bailya intricata*
Centroceras clavulatum	*Nereis callaona*	*Cerithium sp.*
crustose red coralline	*Perinereis elenacasoi*	*Hyalina avena*
creeping gelidiale	*Platynereis dumerilii*	*Rissoina decussata*
Laurencia papillosa	*Pseudonereis gallapagensis*	*Cantharus auritulus*
Murrayella periclados	*Eulalia myriacyclum*	*Cerithiopsis emersoni*
Peyssonnelia amorica	*Hypsicomus torquatus*	*Heliacus infundibulus*
Polysiphonia howei	*Autolytus magnus*	*Anachis crassilabris*
Spyridia filamentosa	*Langerhansia cornuta*	
	Opisthosyllis brunnea	BIVALVIA
PORIFERA	*Serpulid sp. 1*	*Phacoides pectinatus*
Geodia sp.	*Serpulid sp. 2*	*Isognomon bicolor*
Porifera sp. 1	*Spirorbis sp.*	*Codakia orbicularis*
Porifera sp. 2	*Eupolymnia ?nebulosa*	*C. orbiculata*
	Loimia medusa	*Arcopsis adamsi*
COELENTERATA		*Cyathodonta semirugosa*
Anthopleura krebsi	CRUSTACEA	*Brachidontes exustus*
Zoanthus sociatus	*Natantia sp. 1*	*Lithophaga nigra*
	Pasiphaeid sp. 1	*L. bisulcataa*
SIPUNCULA	*Alpheus sp.*	*Pinctada radiata*
Golfingia sp. 1	*A. viridari*	*Diplodonta punctata*
Golfingia ? sp. 2	*A. armillatus*	
Golfingia ? sp. 3	*Ambidexter symmetricus*	ECHINODERMATA
Golfingia ? sp. 4	*Upogebia sp.*	*Ophiolepis paucispina*
Lithacrosiphon sp. 3	*Clibanarius sp.*	*Ophiuroid sp.*

Family	Binomial	Common Name
Holocentridae	*Adioryx coruscus*	
Atherinidae	*Atherinomorus stipes*	Hardhead silverside
Serranidae	*Mycteroperca venenosa*	Yellowfin grouper
Lutjanidae	*Lutjanus griseus*	Gray snapper
	Lutjanus apodus	Schoolmaster
	Lutjanus jocu	Dog snapper
	Lutjanus analis	Mutton snapper
	Lutjanus mahogoni	Mahogany snapper
	Ocyurus chrysurus	Yellowfaie snapper
Pomadasyidae	*Haemulon aurolineatum*	Tomtate grunt
	Haemulon bonariense	Black grunt
	Haemulon flavolineatum	French grunt
	Anisotremus virginicus	Porkfish
Bothidae	*Bothus lunatus*	Peacock flounder
Apogonidae	*Apogon maculatus*	Cardinalfish
Gerreidae	*Gerres cinereus*	Yellowfin mojarra
Acanthuridae	*Acanthurus coeruleus*	Blue tang surgeonfish
Chaetodontidae	*Chaetodon capistratus*	Foureye butterflyfish
	Chaetodon ocellatus	Spotfin butterfly fish
Pomacanthidae	*Pomacanthus paru*	French angelfish
Pomacentridae	*Pomacentrus variabilis*	Cocoa damselfish
	Pomacentrus leucostictus	Beaugregory
	Abudefduf saxatilis	Sergeant major
	Abudefduf taurus	Night sergeant
Labridae	*Thalassoma bifasciatum*	Bluehead wrasse
Dasyatidae	*Dasyatis americana*	Southern stingray
Sphyraenidae	*Sphyraena barracuda*	Great barracuda
	Sphyraena picudilla	Southern sennet
Gobidae	*Gnatholepis thompsoni*	Goldspot goby
	Gobiosoma evelynae	Bogy
Diodontidae	*Diodon holocanthus*	Balloonfish
	Diodon hystrix	Porcupinefish

Table A.38. Vertebrate Species Associated with Juan Diaz Mangroves.

Reptiles

- Sphaerodactylidae
  - *Gonatodes fuscus*
- Iguanidae
  - *Ctenosaura similis*
  - *Iguana iguana*
  - *Anolis auratus*
- Teiidae
  - *Ameiva ameiva*

Birds

- Fregatidae
  - *Phalacrocorax olivaceus*
  - *Fregata magnificens*
- Ardeidae
  - *E. thula*
  - *Florida caerulea*
  - *Hydranassa tricolor*
  - *Butorides virescens*
  - *Nicticorax nicticorax*
  - *Nictinassa violacea*
- Anatidae
  - *Dendrocygna autumnalis*
- Cathartidae
  - *Coragyps atratus*
  - *Cathartes aura*
- Acciptridae
  - *Buteo magnirostris*
  - *Buteogallus antrhacinus*
- Pandionidae
  - *Pandion haliaetus*
- Cuculidae
  - *Coccyzus minor*
  - *Crotophaga major*
  - *Tapera naevis*
- Tytonidae
  - *Tyto alba*
- Caprimulgidae
  - *Chordeiles acutipennis*
  - *Nyctidromus albicollis*
  - *Caprimulgus rufus*
- Apodidae
  - *Chaetura brachyura*
- Trochilidae
  - *Chlorostilbon canivetti*
  - *Lepidopyga coeruleogularis*
- Falconidae
  - *Milvago chimachime*
- Gracidae
  - *Ortalis cinereicens*
- Rallidae
  - *Aramides cajanea*
  - *Amaurolimnas concolor*
- Scolopacidae
  - *Actitis macularia*
  - *Catoptrophorus semipalmatus*
  - *Numenius phaeopus*
- Columbidae
  - *Columba cayannensis*
  - *Columbina talpacoti*
  - *Claravis pretiosa*
  - *Leptotila verreauxi*
- Psittacidae
  - *Brtotogeris jugularis*
  - *Pionopsitta haematotis*
  - *Amazona ochrocephala*
- Hirudinidae
  - *Hirundo rustica*
  - *Progne chalybea*
- Trogloditidae
  - *Thryothorus leucotis*
  - *T. musculus*
- Turdidae
  - *Turdus grayileucotis*
  - *Catharus ustulata*
- Sylviidae
  - *Polioptila plumbea*
  - *Ramphocaenus rufiventris*
- Cyclarhidae
  - *Cyclarhis gujanensis*

Table A.38. Cont...

Birds (Continue)

Alcedinidae
- *Ceryle torquata*
- *Chloroceryle americana*
- *C. inda, C. aenea*

Bucconidae
- *Notharchus macrorhynchus*

Picidae
- *Picumnus olivaceus*
- *Chrysoptilus puntigula*
- *Dryocopus lineatus*
- *Melanerpes rubricapillus*

Dendrocolaptidae
- *Sittasomus griseicapillus*
- *Xiphorhynchus picus*
- *X. guttatus*

Furnaridae
- *Thamnophilus doliatus*

Pipridae
- *Chiroxiphia lanceolata*

Cotingidae
- *Pachyramphus cinamomeus*
- *P. polycopterus*

Tyrannidae
- *Tyrannus tyrannus*
- *T. melancholicus*
- *Legatus leucophaius*
- *Myodynastes maculatus*
- *Myiarchus panamensis*
- *Contopus virens*
- *C.sordidulus*
- *Myiobius spp.*
- *Tolmonias sulphurescens*
- *Todirostrum sylvia*
- *T. cinereum*
- *Elaenia chiriquensis*
- *Camptostoma obsoletum*

Vireonidae
- *Vireo olivaceus*
- *Hylophilus aurantiifrons*
- *H. flavipes*

Parulidae
- *Mniotilta varia*
- *Protonotaria citrea*
- *Vermivora chyrsoptera*
- *V. peregrina*
- *Dendroica petechia*
- *D. erithachorides*
- *D. magnolia*
- *Seiurus noborascensis*
- *Setophaga ruticilla*

Icteridae
- *Cassicix mexicanus*
- *Icterus galbula*
- *I. auricapillus*

Thraupidae
- *Euphonia luteicapilla*
- *E. laniirostris*
- *Thraupis episcopus*
- *Ramphocelus dimidiatus*
- *Piranga rubra*
- *P. olivacea*

Fringillidae
- *Saltator albicollis*
- *Sporophila aurita*
- *Arremonops coniirostris*

Mammals

Emballonuridae (Chiroptera)
- *Rhynchonycteris naso*
- *Saccopterix bilineata*
- *S. leptura*

Noctilionidae
- *Noctilio leporino*
- *N. albiventris*

Phylostomatidae
- *Artibeus jamaicensis*

Vespertilionidae
- *Rhogeesa tumida*

Molossidae
- *Molossus sinaloae*
- *M. molossus*

Procyonidae (Carnivora)
- *Procyon lotor*
- *P. cancrivorus*

Mustellidae
- *Galictis vittata*

Table A.39. List of marine bird species of the Caribbean Sea and the Pacific Ocean of Panama (Ridgely & Gwynne, 1989).

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT						PRESENCE	OCE	NESTING SITE
					COR	ROC	SAN	MUD	MAN	PEL			
Carniv.	FAMILY PROCELLARIIDAE	SHEARWATERS & PETRELS											
	Pterodroma phaeopygia	dark-rumped petrel								U	Mar-Jun	P	
	Procellaria parkinsoni	black petrel								FC	Mar-Jun	P	
	Calonectris diomedea	Cory's shearwater								U		C	
	Puffinus pacificus	wedge-tailed shearwater								U		P	
	Puffinus griseus	sooty shearwater								FC	Jun-Sep	P	
	Puffinus lherminieri	Audubon's shearwater			A-C	A-C	A-C	A-C		A-C		B	
	FAMILY HYDROBATIDAE	STORM-PETRELS											
	Oceanites oceanicus	Wilson's storm-petrel								U	May-Oct	P	
	Oceanites gracilis	white-vented storm-petrel								U	Sep	P	
	Oceanodroma tethys	wedge-rumped storm-petrel								FC-C	May-Nov	P	
	Oceanodroma melania	black storm-petrel								U		P	
	Oceanodroma markhami	Markham's storm-petrel								U	Jun	P	
	Oceanodroma microsoma	least storm-petrel								U-FC	Nov-Jun	P	

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
Carniv.	FAMILY PHAETHONTIDAE	TROPICBIRDS											
	Phaethon aethereus	red-billed tropicbird								FC-C		B	
	FAMILY SULIDAE	BOOBIES & GANNETS											
	Sula dactylatra	masked booby								FC-C		B	
	Sula nebouxii	blue-footed bobby				U	U	U		FC		P	several small islands
	Sula variegata	Peruvian booby								El Ni°o		P	
	Sula leucogaster	brown booby			U	U	U	U		U		B	several small is. Gulf of Panama and Bocas del Toro
	Sula sula	red-footed booby								El Ni°o		B	
	FAMILY PELECANIDAE	PELICANS											
	Pelecanus occidentalis	brown pelican	B		A-C	A-C	A-C	A-C		A-C		B	Taboga, small Pac. Is.
	FAMILY PHALACROCORACIDAE	CORMORANTS											
	Phalacrocorax olivaceus	neotropic cormorant	B			C	C	C		C	Dec-May	B	Small Is. Gulf of Pma & Lake Bayano
	Phalacrocorax bougainvilli	Guanay cormorant								El Ni°o		P	
	FAMILY FREGATIDAE	FRIGATEBIRDS											

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
	Fregata magnificens	magnificent frigatebird	B		C-VC	C-VC	C-VC	C-VC		C-VC		B	Small Pacific Is.
Carniv.	FAMILY ARDEIDAE	HERONS											
	Casmerodius albus	great egret	B				FC	FC				P	
	Egretta thula	snowy egret	B				FC	FC				P	
	Egretta caerulea	little blue-heron	B					FC	FC		Sep-Mar	P	
	Egretta rufescens	reddish egret					U	U				P	
	Egretta tricolor	tricolored heron	P				FC	FC				B	
	Butroides striatus	green-backed heron	B						FC			B	
	Agamia agami	agami heron										B	
	Nycticorax nycticorax	black-crowned night heron	B						U			P	
	Nyctanassa violacea	yellow-crowned night-heron	B			C		C	C			P	
	Cochlearius cochlearius	boat-billed heron	P					U	U			P	
	FAMILY THRESKIORNITHIDAE	IBISES & SPOONBILLS											
	Eudocimus albus	white ibis	P					FC	FC			B	Changam & Taborcilla Is.
	Eudocimus ruber	scarlet ibis						U			Jan-Mar	P	
	FAMILY ACCIPITRIDAE	HAWKS, EAGLES & KITES											

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
Carniv.	Pandion haliaetus	osprey	B			FC	FC	FC	FC	FC	Sep-May	B	
	Buteogallus anthracinus	common black hawk	B						FC			C	
	Buteogallus subtilis	mangrove black-hawk							FC-C			P	
	FAMILY FALCONIDAE	FALCONS & CARACARAS											
	Falco peregrinus	peregrine falcon				U	U	U	U		Oct-May	P	
	FAMILY CHARADRIIDAE	PLOVERS & LAPWINGS											
	Pluvialis squatarola	black-bellied plover					C	C			Oct-May	P	
	Pluvialis dominica	American golden plover						U	U		Aug-Nov; Mar-Apr	B	
	Charadrius collaris	collared plover					FC					B	
	Charadrius alexandrinus	snowy plover					U					B	
	Charadrius wilsonia	Wilson's plover	P				FC	FC				B	
	Charadrius semipalmatus	semipalmated plover	P				VC	VC			Sep-Apr	B	
	FAMILIA HAEMATOPODIDAE	OYSTERCATCHERS											
	Haematopus palliatus	American oystercatcher				VC	VC					P	Pearl Is.
	FAMILIA RECURVIROSTRIDAE	STILTS & AVOCETS											

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
Carniv.	Himantopus mexicanus	black-necked stilt						U			Sep-Mar	B	
	FAMILIA SCOLOPACIDAE	SANDPIPERS & ALLIES											
	Tringa melanoleuca	greater yellowlegs	P					FC			Aug-Apr	P	
	Tringa flavipes	lesser yellowlegs					FC	FC			Aug-Nov	C	
	Tringa solitaria	solitary sandpiper	P			C	C	C	C		Aug-Apr	B	
	Catoptrophorus semipalmatus	willet	P			VC			VC		Aug-Apr	B	
	Heteroscelus incanus	wandering tattler				FC					Aug-Apr	P	
	Actitis macularia	spotted sandpiper	B			VC	VC	VC	VC		Aug-May	B	
	Numenius phaeopus	whimbrel	B				VC	VC	VC		Aug-Apr	B	
	Numenius americanus	long-billed curlew										C	
	Limosa fedoa	marbled godwit						U				B	
	Arenaria interpres	ruddy turnstone	P			C	C	C			Aug-Apr	B	
	Aphriza virgata	surfbird				FC		FC			Aug-Apr	P	
	Calidris canutus	red knot					U	U			Sep-Oct; Mar-Apr	B	
	Calidris alba	sanderling				U-FC	U-FC				Aug-Apr	P	

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
Carniv.	Calidris pusilla	semipalmated sandpiper					FC-C	FC-C			Aug-Apr	B	
	Calidris mauri	western sandpiper	P				C-A	C-A			Aug-Apr	B	
	Calidris minutilla	least sandpiper	P					U			Sep-Oct; Mar-Apr	B	
	Calidris fuscicollis	white-rumped sandpiper						U			Sep-Oct; Apr-May	B	
	Calidris melanotos	pectoral sandpiper						U			Aug-Nov; Mar-Apr	B	
	Calidris alpina	dunlin						U			Dec-Mar	B	
	Calidris himantopus	stilt sandpiper					U	U			Aug-Sep	B	
	Limnodromus griseus	short-billed dowitcher						FC-C			Aug-Apr	B	
	Phalaropus lobatus	red-necked phalarope								I	Aug-Nov; Apr-May	P	
	FAMILY LARIDAE	SKUAS, GULLS, TERNS & SKIMMERS											
	Stercorarius pomarinus	pomarine jaeger								U-FC	Aug-Apr	B	
	Stercorarius parasiticus	parasitic jaeger								U	Aug-Apr	B	
	Catharacta maccormicki	south polar skua								I	Feb-Nov	P	
	Larus atricilla	laughing gull	P	VC	VC	VC	VC	VC	VC	VC	Nov-May	B	

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIL	INV	HABITAT COR	ROC	SAN	MUD	MAN	PEL	PRESENCE	OCE	NESTING SITE
Carniv.	Larus pipixcan	Franklin's gull			FC	FC	FC	FC	FC	FC	Nov-Dec; Apr-May	B	
	Larus belcheri	band-tailed gull				U					Dec-May	P	
	Xema sabini	Sabine's gull								U-FC	Sep-Dec; Apr-Jun	P	
	Sterna nilotica	gull-billed tern					U-C	U-C			Apr-Jul	P	
	Sterna caspia	caspian tern	P							C	Nov-Mar	C	
	Sterna maxima	royal tern	P			FC-C	FC-C	FC-C		FC-C		P	
	Sterna sanvicensis	sandwich tern	P		U-C	U-C	U-C	U-C				B	
	Sterna hirundo	common tern	P		FC	FC	FC	FC		FC	Oct-Nov	B	
	Sterna antillarum	least tern			U-FC	U-FC	U-FC	U-FC		U-FC	Aug-Jan	B	
	Sterna anaethetus	bridled tern			C	C	C	C		C		P	Frailes del Sur
	Sterna fuscata	sooty tern			C	C	C	C		C		P	Frailes del Sur
	Chlidonias niger	black tern			FC-C	FC-C	FC-C	FC-C		FC-C		B	
	Anous stolidus	brown noddy			C	C	C	C		C		B	Frailes del Sur
Scaven.	FAMILY CATHARTIDAE	AMERICAN VULTURES											
	Coragyps atratus	black volture	B			VC	VC	VC	VC			B	
	Cathartes aura	turkey vulture	B			C	C	C	C		Mar-Oct	B	

Table A.39. Cont...

TROPHIC STATUS	SPECIES	COMMON NAME	BIOL INV	HABITAT						PRESENCE	OCE	NESTING SITE
				COR	ROC	SAN	MUD	MAN	PEL			
Omniv.	FAMILY ANATIDAE	DUCKS, GEESE & SWANS										
Omniv.	Dendrocygna autumnalis	black-bellied whistling-duck	P					U-I			B	
	Cairina moschata	Muscovy duck						U			B	
Filt. Feed.	FAMILY THRESKIORNITHIDAE	IBISES & SPOONBILLS										
	Ajaia ajaja	roseate spoonbill	P				U	U			B	

Legend:

HABITAT: COR= Coral; ROC= Rocky; SAN= Sandy; MUD= Mudflat; MAN= Mangrove; PEL= Pelagic.

OCEAN (OCE) & BIOLOGIGAL INVENTORY (BIOL INV): P= Pacific; C= Caribbean; B= Both.

ABUNDANCE (ABUND): A= Abundant; C= Common; FC= Fairly Common; I= Irregular; U= Uncommon; VC= Very Common.

TROPHIC STATUS: Carniv.= Carnivores; Filt. Feed.= Filter Feeders; Herbiv.= Herbivores; Omniv.= Omnivores; Scaven.= Scavengers.

Table A.40. Aquatic macrophytes in Gatun Lake, Panama (PCC, 1985; UNIPAN-ANCON, 1992)

Submerged Plants	Free-floating Plants	Emergent Plants	Marginal Plants
Hydrilla verticillata	*Eichhornia crassipes* (water hyacinth)	*Eichhornia azurea* (water hyacinth)	*Jussiaea natans*
Ceratophyllum demersum	*Pistia stratiotes* (water lettuce)	*Pontederia rotundifolia* (pickerelweed)	*Paspalum repens*
Cabomba aquatica	*Lemna minor* (duckweed)	*Marsilea polycarpa*	*Ceratopteris pteridoides*
	Lemna minima *Spirodela oligorhiza*		
Utricularia vulgaris	*Azolla filiculoides*	*Hydrocotyle umbellata*	*Montrichardia arborescens*
Najas guadalupensis	*Azolla caroliniana*	*Nymphaea ampla*	
Najas marina	*Salvinia rotundifolia*	*Polygonum hydropiperoides* (smartweed)	*Luziola subintegra*
Chara spp.	*Spirodela oligorhiza*	*Sagittaria spp.* *Acrostichum aureum* (arrowhead)	
		Cyperus sp. *Scirpus sp.* *Eleocharis sp.*	
		Panicum purpurascens *Panicum grande* (guinea grass) *Panicum hemitomom* *Panicum maximum* *Typha angustifolia* Ludwigia erecta	

species of algae found in Gatun Lake phytoplankton (Gliwicz, 1976)*

CYANOPHYCEAE (blue–green algae)	
Anabaena sp.	+
Anacystis	
Chroococcus	
Cylindrospernium sp.	
Dactylococcopsis	
Gleocapsa crepidinum	+
Gomphospaeria rosea	+
Lyngbya contoria	+
Lyngbya perelegunts	
Lyngbya sp.	+
Merismopedia sp.	+
Microcystics aeruginosa	+++
Microcystis viridis	
Microcystis Wesenbergii	+
Oscillatoria geminata	+
Oscillatoria limnetica	+
Oscillatoria Redeckei	
Oscillatoria sp.	
Phormidium sp.	
Rhabdoderma	
Synechocystis	
DINOPHYCEAE (PERIDINEAE)	
Ceratium hirimeinella	+
Chroomonas	
Glenadinium quadridens	+
Glenadinium pulvisculus	
Glenadinium sp.	+
Gymnodinium sp.	+++
Peridinium aciculiferum	
Peridinium Gutwihski	+
Peridinium palatinum	+
Peridinium intermedium	+
Peridinium sp.	+
CHRYSOPHYCEAE	
Dinchryon basoricum	+
BACCILARIOPHYCEAE	
Amphora sp.	+
Attheya	
Cyclotella sp.	+
Fragilaria crotonensis	++
Melosira granuluta	+++
Melosira granulata var. argustissima	+++
Melosira islandica	+
Nitzschia	
Nuricula sp.	+
Rhizosolenia	
Stepitanodiscus sp.	+
Synedra	
CHLOROPHYCEAE (green algae)	
Anbistronlesomus angustus	++

Table A.41. Cont...

Anbistronlesomus falcatus	+
Ankistrodesmus	
Arthrodesmus	
Chrysococcus	
Closterium pronum	++
Closterium Ehrenbergii	+
Closterium turgidum	+
Coelastrum cambricium	+
Coelastrum microporum	+
Cosmarium contructum	+
Cosmarium manliforme	+++
Cosmarium sp.	+
Dictyosphaericum Ehrenbergianum	+
Desmidium aptogenum	+
Elakatothrix	
Eudorina elegans	+
Gloeocystis	
Gonatozygon sp.	+
Gonium pectorale	+
Microsterias sp.	+
Oocystis elliptica	+
Onychorema Laeve West	+
Pediastrum duplex	+
Pediastrum simplex	+
Pleodorina californica	++
Pleurotcenium sp.	+
Scenedesmus	
Schraederia setigera	+
Staurastrum brasilience	++
Staurastrum buliardii	++
Staurastrum hystrix	+
Staurastrum linneticum	+
Staurastrum leptocaldum	++
Staurastrum leptocathum	+
Staurastrum lastkemmelleri	+
Staurastrum mincesofense	+
Staurastrum pecidosebaldi	+
Staurastrum ritula	+++
Staurastrum Sebaldi	+
Staurastrum sp.	+
Staurodesmus clepsydra	++
Staurodesmus cuspidetas	+
Staurodesmus dickiei	+
Staurodesmus lubatus	+
Staurodesmus sp.	+
Tetraedron	
Volvox	
Xanthidium sp.	+

* Those species without abundance estimates (no plus signs) are common to Lake Gatun, according to Zaret (1984).

Table A.42. Cladocerans, copepods and rotifers recorded from Gatun Lake. a = species indicated by Dodds to be abundant. (Dodds, 1926; Zaret, 1972, 1984; Garcés, 1982)

Species	Dodds, 1926	Zaret, 1972	Garcés, 1982
Cladocera			
Alona affinis	+		
Alona rectangula	+		
Bosmina longirostris	+ a	+	
Bosmina longispina	+		
Bosminopsis dietersi	+	+	
Ceriodaphnia cornuta	+ a	+	
Ceriodaphnia lacustris			
Chydorus eurynotus		+	
Chydorus sphaericus	+		
Diaphanosoma branchyurum	+ a	+	
Dunhevedia setigera	+		
Eubosmina tubicens			
Ilyocryptus spinifer	+		
Macrothrix rosea	+		
Moina micrura	+		
Moina minutus		+	
Simocephalus serrulatus			
Copepoda			
Cyclops albidus	+		+
Cyclops dentimanus	+		+
Cyclops leuckarti	+		+
Cyclops serrulatus	+		+
Cyclops tenuis	+ a		+
Diaptomus gatunensis	+	+	+
Diaptomus leoninicollinus	+ a		
Diaptomus marshi	+		
Eucyclops agilis		+	
Rotifera			
Asplanchna sp.			
Bdelloid sp.			
Chromagaster			
Euchlanis sp.			
Filinia camascela			
Hexarthra sp.			
Kellicottia bostoniensis			
Lecane sp. I			
Macrochaetus			
Philodina sp.			
Platyias quadricornis			
Stephanoceros funbriatos			
Testudinella patina			

Table A.43. List of fish species that inhabit Lake Gatun and tributaries by habitat, senstivity and diet types (Briceño, 1978).

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
PECES PRIMARIOS						
CHARACIDAE						
Astyanax fasciatus	Sardina, mojarra, mojarrita		R-E-L	C	2,9	Omnívora: algas, insectos terrestres. y acuáticos y crías de peces.
Astyanax ruberrimus	Sardina, mojarra, mojarrita		R-L	C	2,9	
Brycon argenteus	Sábalo		R-L	A	1,2,8,9	
Brycon chagrensis	Sábalo		R-L	A	1,2,8,9	Omnívoro: frutos, flores, semillas, insectos, crustáceos y peces.
Brycon petrosus	Sábalo		R-L	A	1,2,8,9	Insectos terrestres y acuáticos adultos herbívoros.
Brycon striatulus	Sábalo		R-L	B	1,2,8,9	Insectos terrestres y acuáticos adultos herbívoros.
Bryconamericus cascajalensis	Sardina		R-L	A	1,2,8,9	
Bryconamericus emperador	Sardina		R-L	B	2,9	Omnívoro
Characidium sp.	Sardina, mojarrita		R-L	A	1,2,8,9	
Cheirodon affinis	Sardina		R-L	A	1,2,8,9	Herbívoro, diatomeas, algas y semillas
Cheirodon gorgonae	Sardina		R-L	B	9	Herbívoro, diatomeas, algas y semillas
Ctenolucios hujeta			R-L	C	9	
Curimata magdalanae	Lisa de río, bocachica		R-L	C	9	Detritívora, diatomeas y algas
Gasteropelecus maculatus			R-L	C	9	
Gephyrocharax atricaudata			R-L	A	1,2,8,9	Insectívoro
Hoplias microlepis	Pejeperro		R-L	C	2,6,9	Piscívoro
Hyphessobrycon panamensis	Sabalete		R-L	C	2,9	Insectos terrestres y a veces plantas.
Piabucina panamensis	Candela		R-L	A	1,8,9	Insectos terrestres
Roeboides guatemalensis	Sardina		R-L	C	2,6,9	Insectos acuáticos y escamas de peces
Roeboides occidentalis	Sardina		R-L	A	1,2,8,9	Insectos acuáticos y escamas de peces
Saccoderma sp.			R-L	A	1,8,9	
DORADIDAE						
Trachycorystes amblops			R-L	A	1,8,9	
PIMELODIDAE						
Imparales sp.			R-L	A	1,8,9	
Pimelodella chagresi	Barbudo, doncella		R-L	C	2,7,9	Omnívora, insectos y lombrices
Rhamdia wagneri	Barbudo		R-L	C	2,7,9	Insectos acuáticos, semillas y alevines
PIGIDIIDAE						
Pygidimun striatum	Barbudo		R-L	C	2,9	Insectos acuáticos
CALLICHTHYIDAE						
Hoplosternum thoracathum			R-L	C	9	

Table A.43. Cont...

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
LORICARIIDAE						
Ancistrus chagresi	Chupa piedra		R-L	A	1,8,9	Algas y microorganismos asociados
Chaetostoma fischeri	Vieja		R-L	C	9	Algas y microorganismos asociados
Leptoancistrus canensis	Vieja, vieja de agua		R-L	A	1,8,9	Algas y microorganismos asociados
Loricaria uracantha			R-L	C	9	Algas y microorganismos asociados
Plecostomus plecostomus	Vieja de agua, Cascarudo		R-E-L	C	9	Algas y microorganismos asociados
ASTROBLEPIDAE						
Astroblepus longifilis			R-L	A	1,8,3	
HYPOPOMIDAE						
Hipopomus occidentalis			R-L	C	7,9	Insectos acuáticos y dípteros
STERNACHIDAE						
Eigenmannia virescens			R-L	C	4,9	
PECES SECUNDARIOS						
CYPRINIDAE						
Ciprinus carpio	Carpa china		R-L	C	4,9	
Ctenopharyngodon idella			R-L	C	4,9	
CYPRINODONTIDAE						
Rivulus brunneus	Olomina		R-E-L	A	1,8,9	
Rivulus chucunaque	Olomina		R-E-L	A	1,8,9	
Rivulus montium	Olomina		R-E-L	A	1,8,9	
POECILIIDAE						
Brachyrhaphis cascajalensis	Parivivo, comemosquito		R-E-L	B	6,7,9	Insectívoro
Brachyrhaphis episcopi	Parivivo, comemosquito		R-L	A	1,6,7,8,9	Insectívoro
Brachyrhaphis sp.	Parivivo, comemosquito		R-L	A	1,6,7,8,9	Insectívoro
Gambusia nicaraguensis	Parivivo, comemosquito		R-E-L	C	1,6,7,8,9	Insectos acuáticos
Neoheterandria tridentiger	Parivivo, comemosquito		R-E-L	A	1,6,7,8,9	Insectos acuáticos, detrito y cieno
Phallicthys amates	Paritivo, comemosquito		R-E-L	C	7,9	Insectos, detrito y cieno
Poecilia gilii	Parivivo, comemosquito		R-E-L	C	6,9	Detritívora y algas filamentosas
Poecilia mexicana	Parivivo, comemosquito		R-E-L	C	6,9	Detritívora, herbívora
Poeciliopsis elongata	Parivivo, comemosquito		R-E-L	B	6,9	Detritívora
Priaphichthys darienensis	Parivivo		R-E-L	A	1,8,9	

Table A.43. Cont...

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
CICHLIDAE						
Aequidens coeruleopunctatus	Chogorro		R-E-L	B	2,4,9	
Astronotus sp.	Astor		R-L	C	4,9	
Cichla ocellaris	Sargento		R-L	A	2,3,4,5,6	Piscívoro
Cichlasoma maculicauda	Vieja, pis pis		R-E-L	C	2,6,9	Detritus vegetal
Geophagus crassilabris			R-E-L	A	1,8,9	
Neetroplus panamensis	Mogo		R-E-L	A	1,8,9	Algas filamentosas y epífitas de troncos sumergidos
Oreochromis sp.			R-L	C	4	
Tilapia nilotica	Tilapia		R-E-L	C	4	
Tilapia rendalli	Tilapia		R-E-L	C	4	
SERRASALMIDAE						
Colossoma macropomun	Pacú, dientón		R-L	C	4,9	
PECES PERIFERICOS						
PRISTIDAE						
Pristis microdon	Sierra	Sawfish	M-E-R-L	C	9	
ELOPIDAE						
Eleops saurus	Banano, macabí	Tarpon	M-E-R-L	C	5,6	Camarones y peces
Eleops affinis	Macabí	Tarpon	M-E-R-L	C	5,6	Camarones y peces
Megalops atlantica	Tarpón	Tarpon	M-E-R-L	C	5,6	Mugílidos
ANGUILLIDAE						
Anguilla rostrata	Culebra, anguila	True eels	M-E-R-L	C	9	Peces y langostinos de ríos
CLUPEIDAE						
Ilisha fuerthii	Machete, macabí, pellorra	Pacific ilisha	M-E-R-L	C	9	
Sardinella stolifera	Sardina	Pacific piquitinga	M-E-R-L	C	9	
ENGRAULIDAE						
Anchoa panamensis	Anchoveta	Panama anchovy	M-E-R-L	C	9	
Anchoa spinifer	Anchoveta, sardinilla	Spicule anchovy	M-E-R-L	C	9	
Anchoviella curta	Anchoveta, sardina	Short anchovy	M-E-L	C	9	
Anchoviella elongata	Anchoveta, sardina	Long anchovy	M-E-L	C	9	
Anchoviella lucida	Anchoa	Bright anchovy	M-E-L	C	9	

Table A.43. Cont...

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
ARIIDAE						
Arius multiradiatus	Bagre, congo, barbudo	Box sea catfish	M-E-R-L	C	7,9	
Felichthys pinnimaculatus	Bagre, cominate	Red sea catfish	M-E-R-L	C	7,9	
Galeichthys jordani	Congo	Jordan sea catfish	M-E-R-L	C	7,9	
Galeichthys seemani	Congo	Tete sea catfish	M-E-R-L	C	7,9	Peces, crustáceos y otros invertebrados
Netuma oscula	Bagre, bocachica	Thicklip sea catfish	M-E-R-L	C	7,9	
Netuma planiceps	Bagre, cabeza chata	Flathead sea catfish	M-E-R-L	C	7,9	
Selenaspis dowi	Cominate, congo	Brown sea catfish	M-E-R-L	C	7,9	
GOBIESOCIDAE						
Gobiesox nudus	Pejesapo	Marbled clingfish	M-E-L	C	9	Piscívoro, escamas de peces e insectos
BELONIDAE						
Strongylura marina	Aguja	Chere needlefish	M-E-L	C	9	
ATHERINIDAE						
Melaniris chagresi	Pejerey, listado	Thickscale silverside	E-R-L	B	6,9	Zooplancton, insectos, diatomeas y algas filamentosas
SYNGNATHIDAE						
Oosthethus lineatus			M-E-L	C	9	
Pseudophalus mindii			M-E-R-L	C	9	Insectos acuáticos
Syngnathus elcapitanense			M-E-R-L	C	9	
SYNBRANCHIDAE						
Synbranchus marmoratus	Anguila	Well eel	M-E-R-L	C	9	Piscívoro y langostinos de ríos
CENTROPOMIDAE						
Centropomus armatus	Róbalo	Armed snook	M-E-L	C	5,9	
Centropomus ensiferus	Róbalo		M-E-L	C	5,9	Camarones y engráulidos
Centropomus nigrescens	Róbalo	Black snook	M-E-R-L	C	5,9	Crustáceos y peces
Centropomus parallelus	Róbalo		M-E-R-L	C	5,9	Crustáceos y peces
Centropomus pectinatus	Róbalo	Tarpon snook	M-E-R-L	C	5,9	Crustáceos y peces
Centropomus robalito	Robalo aleta amarilla	Yellowfin snook	M-E-L	C	5,9	Crustáceos, peces y moluscos
Centropomus undecimalis	Róbalo blanco	Common snook	M-E-L	C	5,9	Camarones, engráulidos y bagres
Centropomus unionensis	Róbalo, gualajo, gualaso	Union snook	M-E-L	C	5,9	
CARANGIDAE						
Caranx hippos	Jurel	Crevalle jack	M-E-R-L	C	9	Piscívoro
Oligoplites saurus	Longino, chaqueta de cuero	Atlantic leather jack	M-E-R-L	C	9	
LUTJANIDAE						
Lutjanus argentiventris	Pargo amarillo	Yellow snapper	M-E-R-L	C	5,9	Piscívoro, cangrejos y camarones

Table A.43. Cont...

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
Lutjanus aya	Pargo del golfo	Northern red snapper	M-E-L	C	5,9	Carnívoro, curstáceos y peces
Lutjanus colorado	Pargo rojo, pargo colorado	Colorado snapper	M-E-L	C	5,9	
Lutjanus novemfasciatus	Pargo dientón, pargo negro	Dog snapper	M-E-L	C	5,9	Piscívoro, cangrejos y camarones
GERRIDAE						
Diapterus peruvianus	Mojarra	Peruvian mojarra	M-E-R-L	C	9	
Eucinostomus argenteus	Mojarrita plateada	Silver mojarra	M-E-L	C	9	
Eugerres plumieri	Mojarra rallada	Striped mojarra	M-E-R-L	C	9	
Gerres cinereus	Mojarra	Yellowfin mojarra	M-E-R-L	C	9	
POMADASYIDAE						
Pomadasys bayanus	Roncador	Purple mouth grunt	M-E-R-L	C	9	Crustáceos y peces
Pomadasys crocro	Roncador	Burro grunt	M-E-R-L	C	9	Crustáceos y peces
SCIAENIDAE						
Bairdiella ronchus	Corvina	Ground croaker	M-E-L	C	5,9	
Cynoscion albus	Corvina amarilla	Whitefin weakfish	M-E-L	C	5,9	
Micropogon altipinnis	Corvina lona	Golden croaker	M-E-L	C	5,9	
MUGILIDAE						
Agonostomus macracanthus			E-R	C	9	
Agonostomus monticola			E-R	C	9	
Chaenomugil proboscideus	Lisa jocicona	Snouted mullet	M-E-L	C	9	
Joturus pichardi			M-E-R-L	C	9	Langostinos y algas sobre las rocas
Mugil curema	Lisa	Whilet mullet	M-E-R	C	9	Detritos, algas y organismos del bentos
ELEOTRIDAE						
Dormitator latifrons	Porroco, guapote, vieja	Fat sleeper	M-E-R-L	C	4,9	Detritívoro y a veces filtra plancton
Dormitator maculatus	Porroco	Fat sleeper	M-E-R-L	C	9	
Eleotris amblyopsis	Pez perro		M-E-R-L	C	9	Carnívoro de peces y crustáceos
Eleotris picta	Vieja		M-E-R-L	C	9	Peces y camarones del bentos
Eleotris pisonis	Pez perro		M-E-R-L	C	9	Peces y crustáceos
Eleuptoeleotris clarki			M-E-R-L	C	9	
Eleuptoeleotris shropshirei			M-E-R-L	C	9	
Gobiomorus dormitor	Guavina		M-E-R-L	C	6,9	Crustáceos y peces del bentos
Gobiomorus maculatus	Guavina		M-E-R-L	C	9	Crustáceos y peces del bentos
Guavina guavina	Guavina		M-E-R-L	C	9	
Hemieleotris latifasciatus	Guavina		M-E-R-L	C	9	
Leptophilypnus fluviatilis	Guavinilla		M-E-R-L	C	9	

Table A.43. Cont...

TAXA	COMMON NAME		HABITATS	SENSIBILITY	TYPE	DIET
	SPANISH	ENGLISH				
Leptophilypnus panamensis	Guavina		M-E-R-L	A	1,8,9	
GOBIIDAE						
Awaous tajasica	Chupapiedra	Gobies	M-E-L	C	9	Insectos acuáticos, detrito y forminíferos
Awaous transandeanus	Chupapiedra	Gobies	M-E-L	C	9	Detrito, algas filamentosas, microbivalvos y quironómidos
Bathygobius soporator	Chupapiedra	Gobies	M-E-L	C	9	
Garmannia hildebrandi	Chupapiedra	Gobies	M-E-L	A	1,8,9	
Garmannia homochroma	Chupapiedra	Gobies	M-E-L	A	1,8,9	
Gobionellus microdon			M-E-R-L	C	9	
Microgobius miraflorensis			M-E-R-L	C	9	
Sicydium antillarum			M-E-L	C	9	
Sicydium salvini			M-E-L	C	9	
BOTHIDAE						
Citarichthys gilberti	Lenguado	Bigmouth sanddab	M-E-R-L	C	9	Crustáceos decápodos
SOLEIDAE						
Achirus fluviatilis	Lenguado		M-E-R-L	C	9	Insectos acuáticos y crustáceos
Achirus mazatlanus	Lenguado	Mazatlan sole	M-E-R-L	C	9	
Trinectes maculatus	Lenguado		M-E-R-L	C	9	Insectos acuáticos
TETRAODONTIDAE						
Sphoeroides annulatus	Tamboril	Puffers	M-E-R-L	C	9	
Sphoeroides testidinius	Tamboril	Puffers	M-E-R-L	C	9	

Clave de Biotopos:
E = Estuarios
L = Lagos
R = Ríos
M = Marino

Sensibilidad:
A = Máxima
B = Intermedia
C = Mínima

Tipo:
1 = Endémica citada solamente para Panamá
2 = Abundante o frecuente
3 = Uso comercial y/o pesca artesanal
4 = Potencialmente explotable
5 = Uso recreativo
6 = Interés biótico en el ecosistema
7 = Interés toxicológico y/o control de insectos
8 = Interés taxonómico
9 = No utilizada

Table A.44. Bird species associated with lakes, rivers, and streams.

TAXONOMIC CATEGORY	HABITATS			Diet	Residence Status
	Lakes	Rivers	Streams		
PODICIPEDIDAE	Grebes				
Podilymbus podiceps	+			AI,Fish	Res
Tachybaptus dominicus	+			AI,Fish	Res
PELECANIDAE	Pelicans				
Pelecanus occidentalis	+			Fish	Res;LV
Phalacrocoracidae	Cormorants				
Phalacrocorax olivaceus	+			Fish	LV
ANHINGIDAE	Anhingas, darters				
Anhinga anhinga	+	+		Fish	Res
ARDEIDAE	Herons, egrets				
Agami agami			+	AV	Res
Ardea herodias	+			AV	M-NA
Butorides striatus	+	+	+	AV	Res
Casmerodius albus	+	+		AV	LV
Cochlearius cochlearius		+		AV	Res
Egretta caerulea		+		AV	M-NA, CA
Egretta thula	+	+		AV	LV
Egretta tricolor		+		AV	LV
Tigrisoma lineatum		+	+	AV	Res
ANATIDAE	Ducks, geese				
Anas americana	+			O	M-NA
Anas discors	+			O	M-NA
Aythya collaris	+			O	M-NA

Table A.43. Cont...

TAXONOMIC CATEGORY	HABITATS			Diet	Residence Status
	Lakes	Rivers	Streams		
Aythya affinis	+			O	M-NA
Oxyura dominica	+			O	Res
ACCIPITRIDAE	Hawks				
Buteogallus anthracinus		+		Crabs;AV	Res
Pandion haliaetus	+	+		Fish	M-NA
RALLIDAE	Rails, gallinules				
Fulica americana	+			O	M-NA
Gallinula chloropus	+			O	Res
Porphyrula martinica	+	+			Res
HELIORNITHIDAE	Sungrebe				
Heliornis fulica	+	+	+	AI;AV	Res
EURYPYGIDAE	Sunbittern				
Eurypyga helias			+	AI;AV	Res
ARAMIDAE	Limpkin				
Aramus guarauna	+			Snails	Res
JACANIDAE	Jacanas				
Jacana jacana	+	+		O	Res
SCOLOPACIDAE	Sandpipers				
Actitis macularia	+	+		I	M-NA
Tringa solitaria		+	+	I	M-NA
LARIDAE	Gulls, terns				
Chlidonias niger	+			I,Fish	M-NA
Larus atricilla	+	+		I,Fish	LV

Table A.43. Cont...

TAXONOMIC CATEGORY	HABITATS			Diet	Residence Status
	Lakes	Rivers	Streams		
Sterna maxima	+			Fish	M-NA
CUCULIDAE	Cuckoos, anis				
Crotophaga major	+	+		I	Res
ALCEDINIDAE	Kingfishers				
Ceryle alcyon	+	+		Fish	M-NA
Ceryle torquata	+	+		Fish	Res
Chloroceryle aenea			+	Fish	Res
Chloroceryle amazona	+	+		Fish	Res
Chloroceryle americana	+	+	+	Fish	Res
TYRANNIDAE	Tyrant-flycatchers				
Fluvicola pica	+			I	Res

Legend:

FOOD HABITS: I = Invertebrates; AI = Aquatic Invertebrates; O = Omnivores; AV = Aquatic Vertebrates (fish, frogs).

RESIDENCE STATUS: M - NA = Migrant from North America; M - CA = Migrant from Cen. America (not Panama); Res = Resident, assumed to breed in area; LV = Local Visitor, breeds within country but not in study area

HABITATS: LAKE= Lakes Gatun, Miraflores, Alajuela; RIVER = larger rivers; big enough to have open sky in forested areas; STREAM = smaller waterways; esp. forest streams with unbroken canopy overhead.

Table A.45 Wetland areas which may be impacted by canal alternatives

Wetland Location (General)	Wetland** Area, ha	Location: N-S	E-W	Notes
SEA LEVEL ROUTE:				
mouth, R. Canyito	6	0.5-1N	31.5-32E	
mouth, R. Trinidad *	140	93-95S	13-14.5E	***See note below
mouth, Qbda la Mendoza	17	98.5-99S	26.3-26.6E	
mouth, Qbda de Chico	23	99.5-100S	24-25E	
1km S Cerro Gigante	32	3-4N	22.5-24E	
Los Hules	80	0.5-02N	23.5-24.5E	
mouth, R. Pescado	110	97.5-98.5S	28.5-30.5E	area includes ca 10% ponds @ time of photo
mouth, R. Gatun, Qbda del Pato	262	23-26N	33-37.5E	from 1:50000 map
Sea Level: FW subtotal	670			
mangrove, mouth R Caimito	325			estimated from 1:50000 map
mangrove, Pta. Salazar	70			""; mangrove area just W of R. Caimito mouth
Sea Level:Mangrove subtotal	395			
Sea Level: grand Total	1065			
HIGH RISE ROUTE:				
mouth, R. Paja	5	3-3.5N	33-33.5E	includes mouth stream ca 0.5km to N
inland RR pond	9	9.5-10.5N	34-35E	along L. Gatun, formed by RR
S of Isla Gorgona	9.5	6.5N	40.5-41E	flora sampling site; 3 subsections
Lagos Calamito, RR	19.5	8.5-9.5N	37-38E	several ponds formed by railroad
mouth, R. Trinidad *	140	93-95S	13-14.5E	***See note below
mouth, R. Ciri	100	92-93.5S	4-6E	
High Rise Total:	283			

NOTES:

UTM coordinates: those marked "N" are in '10' grid; those marked "S" are in '9' grid
those marked "E" are in '6' grid; those marked "W" are in '5' grid

* On Rio Trinidad: shadows on 1:9000 photo obscures large area; 88ha est too low
actual area probably closer to 190ha estimated from 1:50,000 map

** areas estimated by grid placed over 1:18000 photos, unless stated otherwise

*** 1:9k&1:50k photo/map used; shadow obscured part of photo: 88-190 ha=Min/Max estimates

Table A.46 Amphibians and Reptiles in Wetlands

Class	Family	Species
Amphibia	Bufonidae	*Bufo marinus*
	Hylidae	*Agalychnis callidryas*
		Hyla microcephala
	Leptodactylidae	*Leptodactylus insularum*
		L. labialis
		L. pentadactylus
		Physalaemus pustulosus
Reptilia	Crocodilidae	*Crocodylus acutus*
	Emydidae	*Trachemys scripta*
	Iguanidae	*Anolis auratus*
		Basiliscus basiliscus
		Iguana iguana
	Teiidae	*Ameiva ameiva*
	Boidae	*Boa constrictor*
	Colubridae	*Leptodeira annulata*
	Viperidae	*Bothrops atrox asper*

Table A.47. Comparison between four successional stages, from pioneer to mature primary forest. (Modified from Budowski 1965)

	Pioneer	Early secondary	Late secondary	Climax
Age of communities observed, years	1–3	5–15	20–50	more than 100
Height, meters	5–8	12–20	20–30, some reaching 50	30–45, some up to 60
Number of woody species	few, 1–5	few, 1–10	30–60	up to 100 or a little more
Floristic composition of dominants	Euphorbiaceae, *Cecropia, Ochroma, Trema*	*Ochroma, Cepropia, Trema,* most frequent	mixture, many Meliaceae Bombacaceae, Tiliaceae	mixture, except on edaph association
Natural distribution of dominants	very wide	very wide	wide, includes drier regions	usually restricted, endemi frequent
Number of strata	1, very dense	2, well differentiated	3, increasingly difficult to discern with age.	4–5, difficult to discern
Upper canopy	homogeneous, dense	verticillate branching, thin horizontal crowns	heterogeneous, includes very wide crowns	many variable shapes of crowns
Lower stratum	dense, tangled	dense, large herbaceous species frequent	relatively scarce, includes shade-tolerant species	scarce, with shade-tolera species
Growth	very fast	very fast	dominants fast, others slow	slow or very slow
Life span, dominants	very short, less than 10 years	short, 10–25 years	usually 40–100 years, some more	very long, 100–1000, some probably more
Tolerance to shade, dominants	very intolerant	very intolerant	tolerant to juvenile stage, later intolerant	tolerant, except in adult stage
Regeneration of dominants	very scarce	practically absent	absent or abundant with large mortality in early years	fairly abundant

Table A.47. Cont...

	Pioneer	Early secondary	Late secondary	Climax
Dispersal of seeds of dominants	birds, bats, wind	winds, birds, bats	wind principally	gravity, mammals, rodents, birds
Wood and stem, dominants	very light, small diameters	very light, diameters below 60 cm.	light to medium hard, some very large stems	hard and heavy, includes large stems
Size of seed, or fruits dispersed	small	small	small to medium	large
Viability of seeds	long, latent in soil	long, latent in soil	short to medium	short
Leaves of dominants	evergreen	evergreen	many deciduous	evergreen
Epiphytes	absent	few	many in number, but few species	many species and life forms
Vines (including Lianas)	abundant, herbaceous, but few species	abundant, herbaceous, but few species	abundant, but few of them large	abundant, includes very large woody species (Lianas)
Shrubs	many, but few species	relatively abundant but few species	few	few in number but many species
Grasses	abundant	abundant or scarce	scarce	very scarce

TABLE A.48 PROTECTED MAMMALS IN THE AREA OF THE PANAMA CANAL ALTERNATIVES

TAXA	COMMON NAME	STATUS	AUTHORITY				OTHER NOTES
			INRENARE	CITES	IUCN	US: ESA	
EDENTATA							
Bradypus variegatus	3-toed sloth	THR		C2			
Dasypus novemcintus	armadillo	END/THR	END				
Cabassous centralis	Naked-tail armadillo	END/THR	END				
Cyclopes didactylus	silky anteater	END/THR	END				in study area?
Myrmecophaga tridactyla	giant anteater	END	END	C2	V		
Tamandua mexicana	anteater	END/THR	END			END	in study area? USE
PRIMATES							
Saguinus geoffroyi	tamarin	END	END	C1		END	US:E
Alouatta palliata	howler monkey	END	END	C1		END	US:E; LE:C1; NILS:C
Aotus lemurinus	night monkey	END/THR	END	C2			
Ateles geoffroyi	spider monkey	END	END	C1	V	END	US:E; LE:C1; NILS:C
Cebus capucinus	white-faced monkey	END/THR	END	C2			
RODENTIA							
Agouti paca	paca	END/THR	END				
Dasyprocta punctata	agouti	END/THR	END				
Hydrochaeris hydrochaeris	capybara	END/THR	END				
CARNIVORA							
Speothos venaticus	bush dog	END		C1	V		
Urocyon cinereoargenteus	gray fox	END/THR	END				VRARE(NS)
Bassaricyon gabbii	olingo	RARE/THR		C3:CR			
Bassariscus sumichrasti	cacomistle	RARE/THR		C3:CR			BI-TH
Nasua narica	coati	END/THR	END	C3:CR			LE:Rare; C3 in C.R.
Procyon cancrivorous	crab-eating raccoon	END/THR	END				
Procyon lotor	raccoon	END/THR	END				
Eira barbara	tayra	RARE/THR		C3:HOND			
Galictis vittata	grison	RARE		C3:CR			BI-TH
Lutra longicaudis	southern otter	END/THR	END	C1			BI-TH;LE:rare
Felis concolor	puma	END	END	C1/2			
Felis jaguarounadi	jaguaroundi	END/THR	END	C2	I	END	C1 in C.R. USE
Felis pardalis	ocelot	END	END	C1	V	END	USE?
Felis wiedii	margay	END	END	C1	V	END	USE
Panthera onca	jaguar	END	END	C1	V	END	USE
PERISSODACTYLA							
Tapirus bairdii	Baird's tapir	END	END	C2		END	USE
ARTIODACTYLA							
Tayassu tajacu	collared peccary	END/THR	END	C2			
Tayassu pecari	white-lipped peccary	END	END	C2			
Mazama americana	brocket deer	END/THR	END				
Odocoileus virginianus	white-tailed deer	END/THR	END				C3 IN GUAT
SIRENIA							
Trichechus manatus	manatee	END	END	C1	V	END	USE
Totals:		35	29	23	8		

CODES:

INRENARE: Resolution DIR-002-88 declared these mammals in danger of extinction, and bans the hunting and illegal sale of these species.

IUCN:

E = ENDANGERED: In danger of extinction if action not taken

V = VULNERABLE: Likely to move into endangered category soon if action not taken

R = RARE: Taxa with small world populations, and that are at risk

I = INDETERMINATE: Known to be one of above 3 categories, but insufficient information to say which category is appropriate.

CITES: 1 = ENDANGERED; 2 = THREATENED; 3= LOCALLY THREATENED

US Endangered Species Act: E=ENDANGERED, T=THREATENED

Table A.49 Reptiles and Amphibians of the Panama Canal region, with notes on distribution by habitat, and species of special interest.

TAXONOMIC GROUP	HABITATS					STATUS			
	HUM	MAN	BVI	BSY	HRB	CUL	Th	En	Ec	ME
CLASS AMPHIBIA										
CAECILIDAE: caecilians										
Oscaecilia ochrocephala	0		+	+	0	0	+			
PLETHODONTIDAE: salamanders										
Bolitoglossa biseriata	0		+	0	0	0	+		+	
Oedipina parvipes	0		+	+	0	0			+	
BUFONIDAE: toads										
Atelopus sp.	0		+	+	0	0				
Bufo coniferus	0		+	+	0	0				
Bufo haematiticus	0		+	+	+	+				
Bufo marinus	+		+	+	+	+				+
Bufo thyphonius	0		+	+	+	0	+			
CENTROLENIDAE: glass frogs										
Centrolenella colymbiphyllum	0		+	+	0	0			+	
Centrolenella fleishmanni	0		+	+	0	0			+	
Centrolenella granulosa	0		+	+	0	0	+		+	
Centrolenella ilex	0		+	+	0	0			+	
Centrolenella pulverata	0		+	+	0	0	+		+	
Centrolenella spinosa	0		+	0	0	0	+		+	
DENTROBATIDAE: poison dart frogs										
Colostethus flotator	0		+	+	0	0				+
Colostethus inguinalis	0		+	+	0	0				+
Colostethus talamancae	0		+	+	0	0	+			+
Dendrobates auratus	0		+	+	+	+				+
Minyobates fulguritus	0		+	+	0	0				+
HYLIDAE: tree frogs										
Agalychnis callidryas	+		+	+	+	+	+			
Hyla crepitans	0		0	0	+	0			+	
Hyla ebraccata	0		0	0	+	0			+	
Hyla microcephala	+		0	0	+	+			+	
? *Hyla palmeri*	0		+	+	0	0	+		+	
Hyla phlebodes	0		0	0	+	0			+	
Hyla rosenbergi	0		+	0	+	0			+	
Hyla rufitela	0		+	0	0	0	+		+	
Ololygon boulengeri (=Hyla)	0		+	0	0	0			+	
Ololygon rubra (=Hyla)	+		0	0	0	0			+	
Ololygon staufferi (=Hyla altae)	0		0	0	+	0			+	

Table A.49 Cont...

TAXONOMIC GROUP	HABITATS						STATUS			
	HUM	MAN	BVI	BSY	HRB	CUL	Th	En	Ec	ME
HYLIDAE (continued)										
? *Phrynohyas venulosa*	0		+	0	0	0			+	
Smilisca phaeota	0		+	+	+	0			+	
? *Smilisca sila*	0		+	0	0	0			+	
LEPTODACTYLIDAE: frogs										
Eleutherodactylus biporcatus	0		+	+	0	0	+		+	
Eleutherodactylus bransfordii	0		+	+	0	0			+	
Eleutherodactylus bufoniformis	0		+	+	0	0			+	
? *Eleutherodactylus cerasinus*	0		+	+	0	0	+		+	
Eleutherodactylus crassidigitus	0		+	+	+	0			+	
Eleutherodactylus diastema	0		+	+	0	0			+	
Eleutherodactylus fitzingeri	0		+	+	0	0			+	
Eleutherodactylus gaigeae	0		+	+	0	0			+	
Eleutherodactylus gollmeri	0		+	+	0	0			+	
Eleutherodactylus taeniatus	0		+	0	0	0			+	
Leptodactylus insularum	+		0	0	+	+			+	
Leptodactylus labialis	+		0	0	+	0			+	
Leptodactylus melanonotus	0		+	0	0	0			+	
Leptodactylus pentadactylus	+		+	+	+	0				+
Physalaemus pustulosus	+		+	+	+	+				
RANIDAE: frogs										
Rana vaillanti	0		0	0	+	0			+	
Rana warschewitschii	0		0	+	0	0			+	
CLASS REPTILIA										
CROCODILIA: caimans, crocodiles										
Caiman crocodilus	+	+	+	0	+	0		+	+	+
Crocodylus acutus	+		0	0	0			+	+	+
TESTUDINES: turtles										
Chelydra serpentina	+		0	0	0	0		+	+	+
? *Rhinoclemmys annulata*			+							+
? *Rhinoclemmys funerea*	+		+							+
Kinosternon leucostomum	0	+	+	+	+				+	+
Trachemys scripta	+		0	0	+	0			+	+
GEKKONIDAE: geckos										
Gonatodes albogularis	0	+	+	0	+	0				
Lepidoblepharis sanctaemartae	0		+	+	+	0	+			
Lepidoblepharis xanthostigma	0		+	+	0	0	+			
Thecadactylus rapicauda	0		+	+	0	0				

Table A.49 Cont...

TAXONOMIC GROUP	HABITATS						STATUS			
	HUM	MAN	BVI	BSY	HRB	CUL	Th	En	Ec	ME
IGUANIDAE: iguanid lizards										
Anolis auratus	+	+	0	0	+	+			+	
Anolis frenatus	0		+	0	0	0	+		+	
Anolis humilis	0		+	+	0	0	+		+	
Anolis limifrons	0	+	+	+	+	0			+	
Anolis lionotus	0		+	0	0	0			+	
Anolis poecilopus	0		+	+	0	0	+		+	
Anolis sp. (no descrita)	0		+	0	0	0				
Anolis tropidogaster	+		0	0	+	+			+	
Basiliscus basiliscus	+	+	+	+	+	+			+	
Corytophanes cristatus	0		0	+	0	0	+			
Ctenosaura similis	+	+	0	0	0	0				
Iguana iguana	0	+	0	+	+	0		+	+	+
SCINCIDAE: skinks (lizards)										
Mabuya unimarginata	0		+	+	0	0				
TEIIDAE: teiid lizards										
Ameiva ameiva	+	+	+	+	+	+			+	
Ameiva festiva	0		+	+	+	0			+	
Ameiva leptophrys	0		+	+	+	0			+	
Leposoma rugiceps	0		+	0	0	0				
Ptychoglossus festae	0		+	+	0	0	+			
BOIDAE: boas										
Boa constrictor	+	+	+	+	0	+		+	+	+
? *Epicrates cenchria*	0		+	+	0	0				
COLUBRIDAE: colubrid snakes										
? *Chironius carinatus*	0		+	+	0	0	+			
Dipsas articulata	0		+	+	0	0				
Dryadophis melanolomus	0		+	+	+	0				
Drymarchon corais	0	+	+	+	0	0	+			
Enulius sclateri	0		0	+	0	0	+			
Imantodes cenchoa	0		0	+	0	0				
Leptodeira annulata	+	+	0	0	+	+				
Leptophis ahaetulla	0		+	0	0	0	+			
Oxybelis aeneus	0		+	+	0	+				
Pliocercus euryzonus	0		0	+	0	0	+			
Pseustes poecilonotus	0		+	+	0	0	+			
Xenodon rabdocephalus	0		0	0	+	+				+

Table A.49 Cont...

TAXONOMIC GROUP	HABITATS						STATUS			
	HUM	MAN	BVI	BSY	HRB	CUL	Th	En	Ec	ME
VIPERIDAE: pit-vipers										
Bothrops atrox asper	+	+	+	+	+	+			+	+
? *Bothrops lansbergii*	0		+	+	+	+	+		+	+
? *Bothrops nasuta*	+		+	+	+	+	+		+	+
? *Bothrops schlegelii*	0		+	+	0	0			+	+
? *Bothrops nummifer*	0		+	+	0	0			+	+
? *Lachesis muta*	0		+	+	0	0				+
ELAPIDAE: coral snakes										
Micrurus multifasciatus	0		+	+	+	+	+			+
Micrurus nigrocinctus	0		+	+	0	+				+
Micrurus stewarti	0		0	0	+	0				+
TOTAL (Reptiles & amphibians)	22	13	78	66	39	20	28	5	59	26
TOTAL AMPHIBIANS	8	0	40	32	18	7	12	0	36	7
Frogs and toads	8	0	37	30	18	7	10	0	34	7
salamanders, caecilians	0	0	3	2	0	0	2	0	2	0
TOTAL REPTILES	14	13	38	34	21	13	16	5	23	19
snakes	4	4	17	19	8	9	9	1	6	11
lizards	5	7	17	14	10	4	7	1	12	1
turtles, crocodilians	5	2	4	1	3		0	0	0	0

HABITAT TYPES:

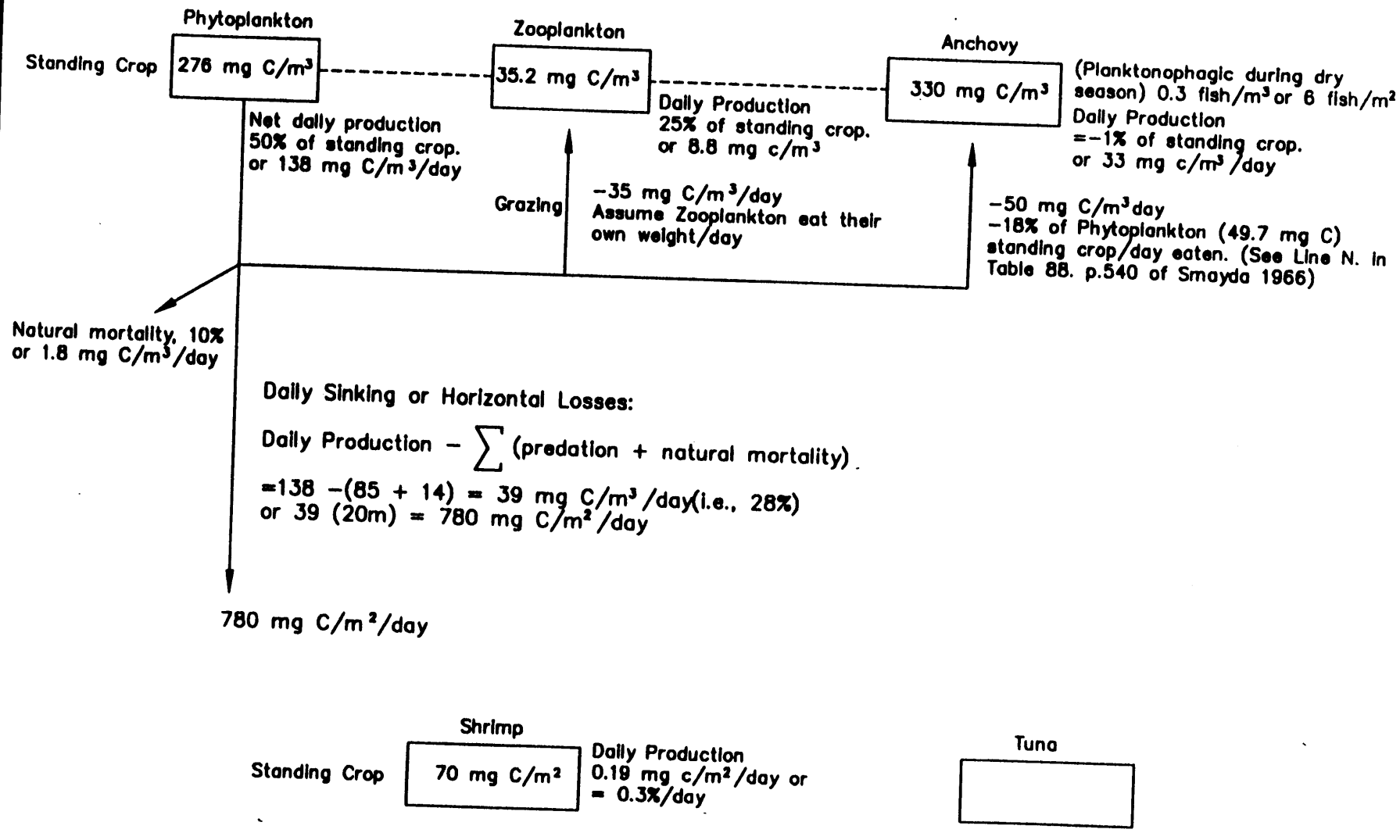
HRB = grasslands, pastures, herbazal
CUL = agricultural areas other than pastures
BSY = young successional forest
BVI = old successional & mature forest
HUM = wetlands
MAN = mangroves

CODES FOR SPECIES OF SPECIAL INTEREST/STATUS:

T Ec = Species of ecological importance
E ME = Species of economic/medical use

? = Species not recorded by the Biological Inventory, but expected or known to occur, based on experience of V. Martinez

UPWELLING (DRY SEASON)

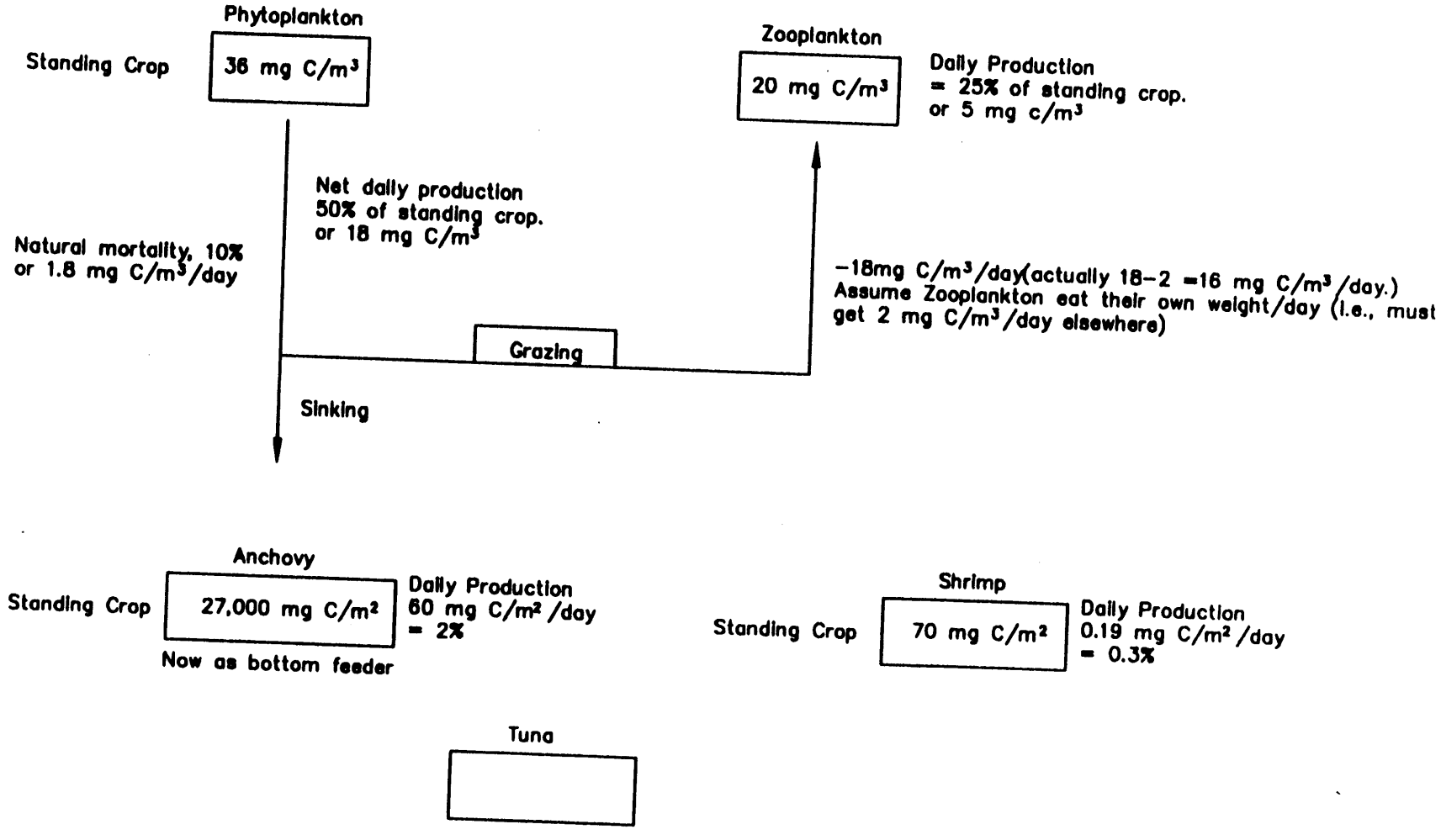


REFEENCE: LOWMAN et.al., 1970

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	STANDING CROPS/ PRODUCTION RATES GULF OF PANAMA DRY SEASON	DAMES & MOORE FIGURE A.1

BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE

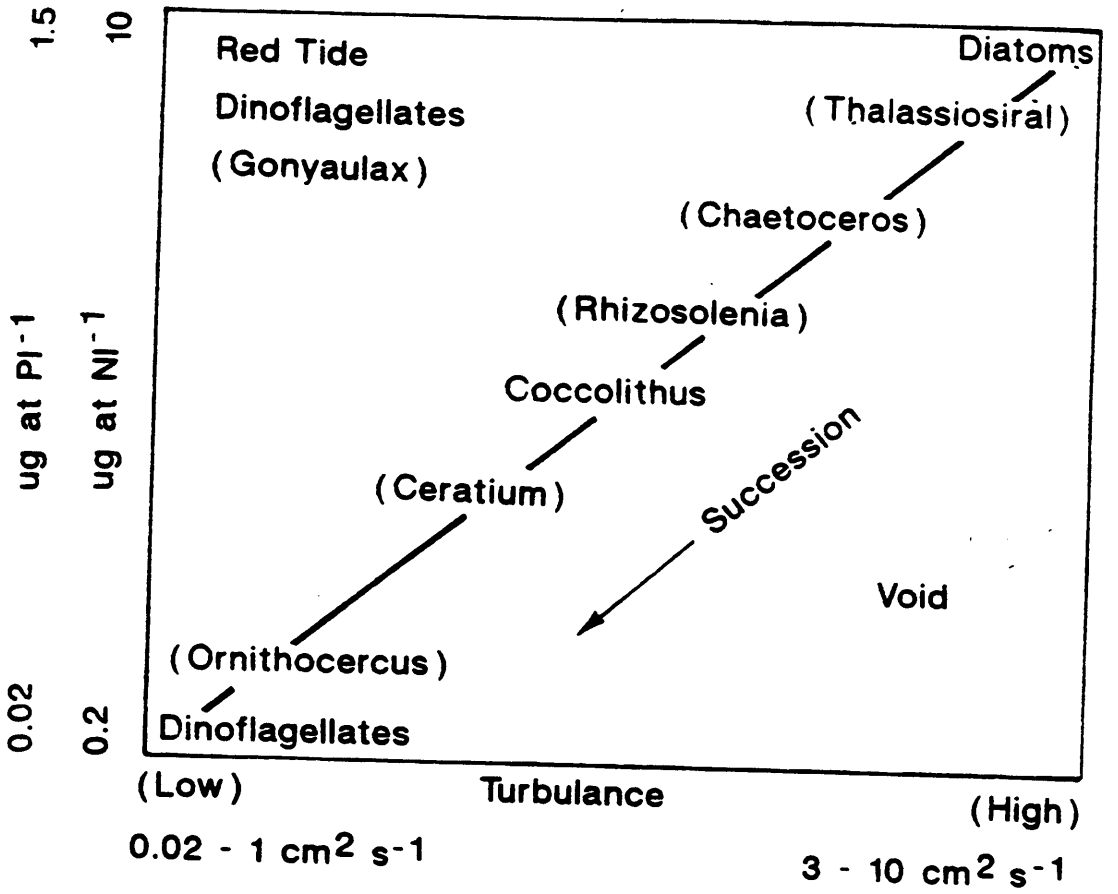
WET SEASON



REFERENCE: LOWMAN et.al., 1970

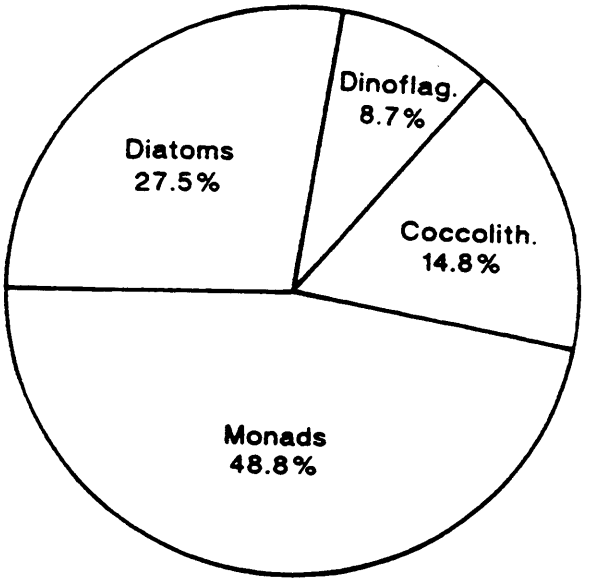
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	STANDING CROPS/ PRODUCTION RATES GULF OF PANAMA WET SEASON	DAMES & MOORE
		FIGURE A.2

BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5662 REVISIONS BY DATE



Reference: Smetacek, 1988

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	PHYTOPLANKTON SUCCESSION AS DETERMINED BY NUTRIENT CONCENTRATION AND TURBULENCE	DAMES & MOORE FIGURE A.3



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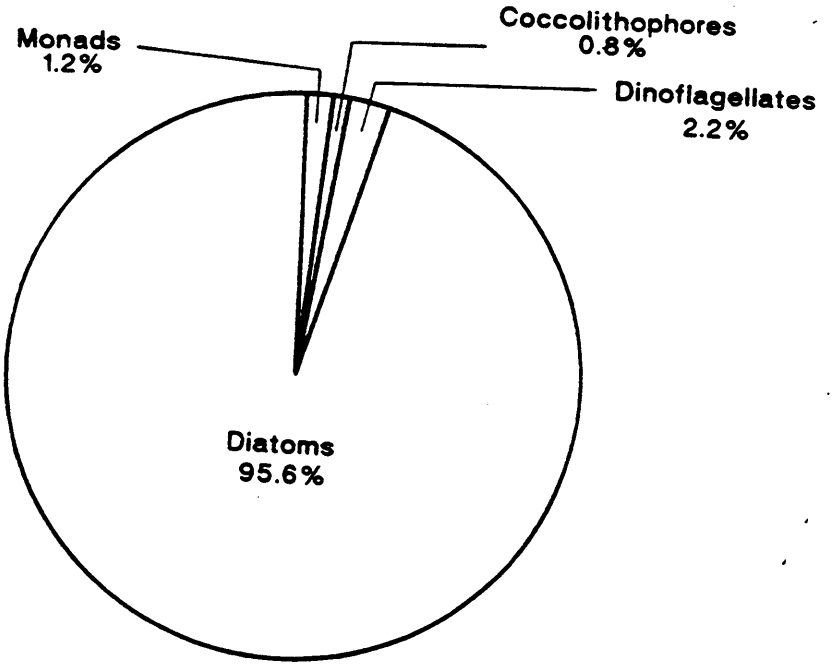


Cell Volume

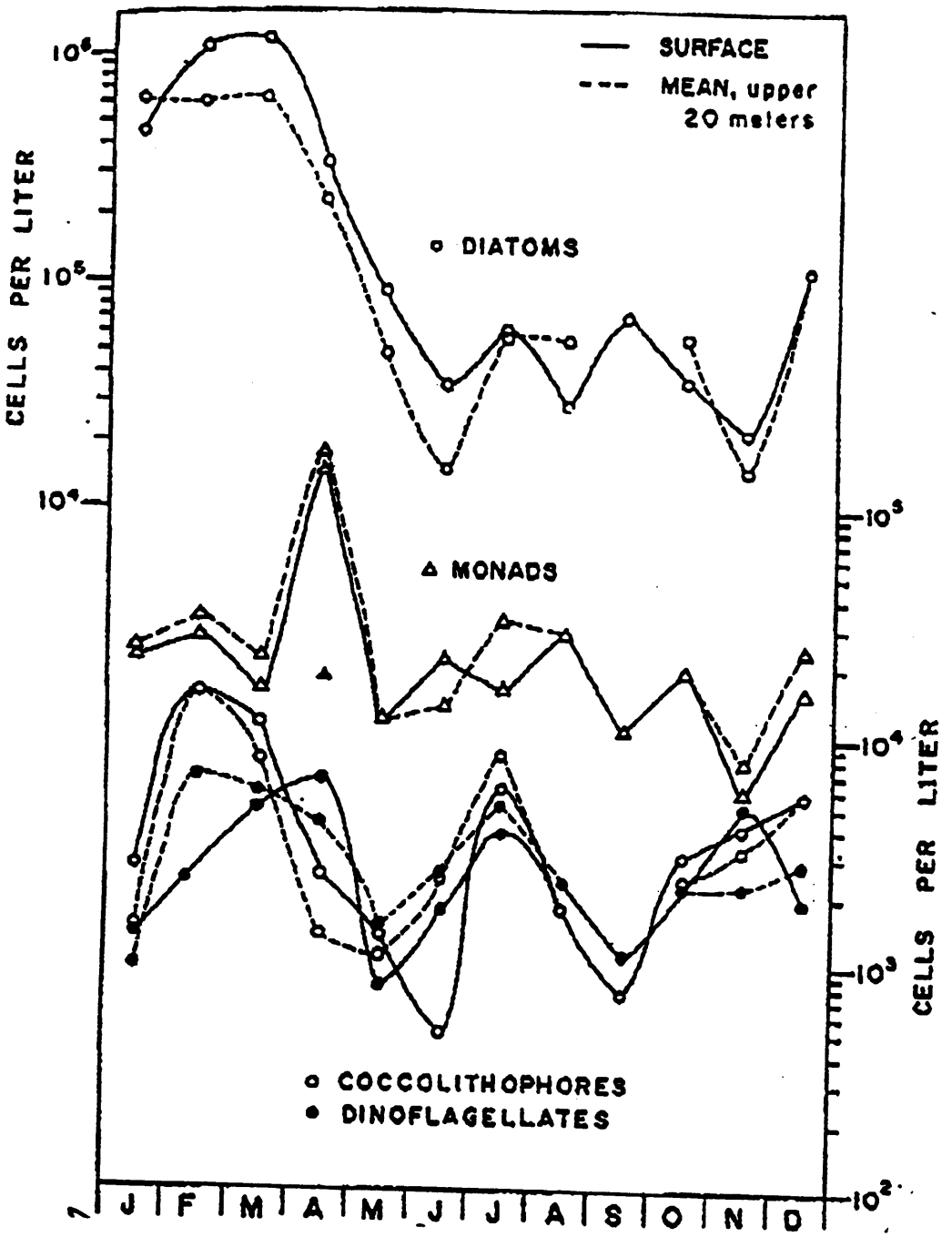
Reference: Smayda. 1966

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

PHYTOPLANKTON RELATIVE PROPORTION

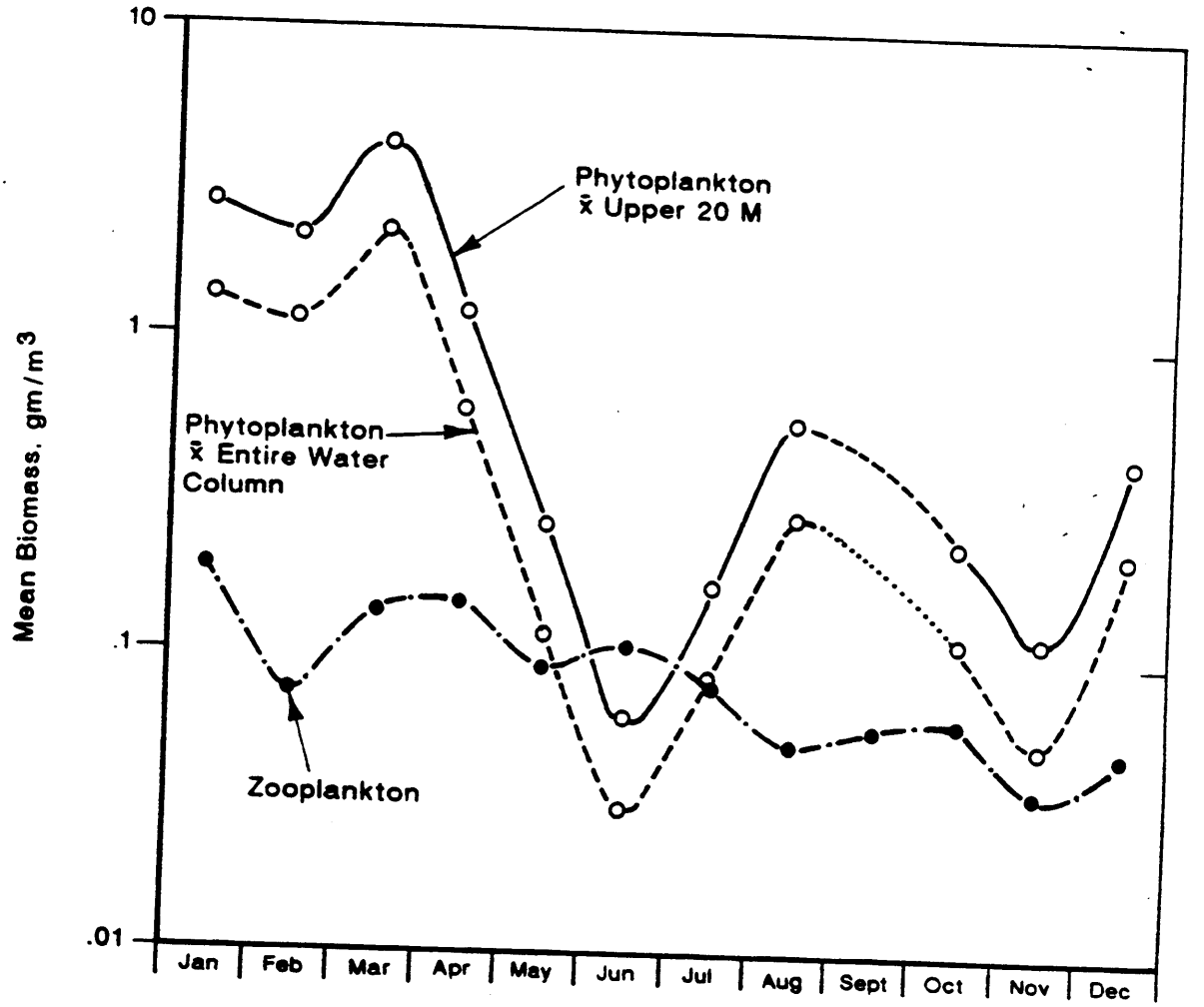
DAMES & MOORE

FIGURE A.4



Reference. Smayda, 1968

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	MEAN MONTHLY DIATOM, COCCOLITHOPHORE, DINOFLAGELLATE AND MONAD POPULATION HYDROBIOLOGICAL STATION, 1954-1957	DAMES & MOORE FIGURE A.5



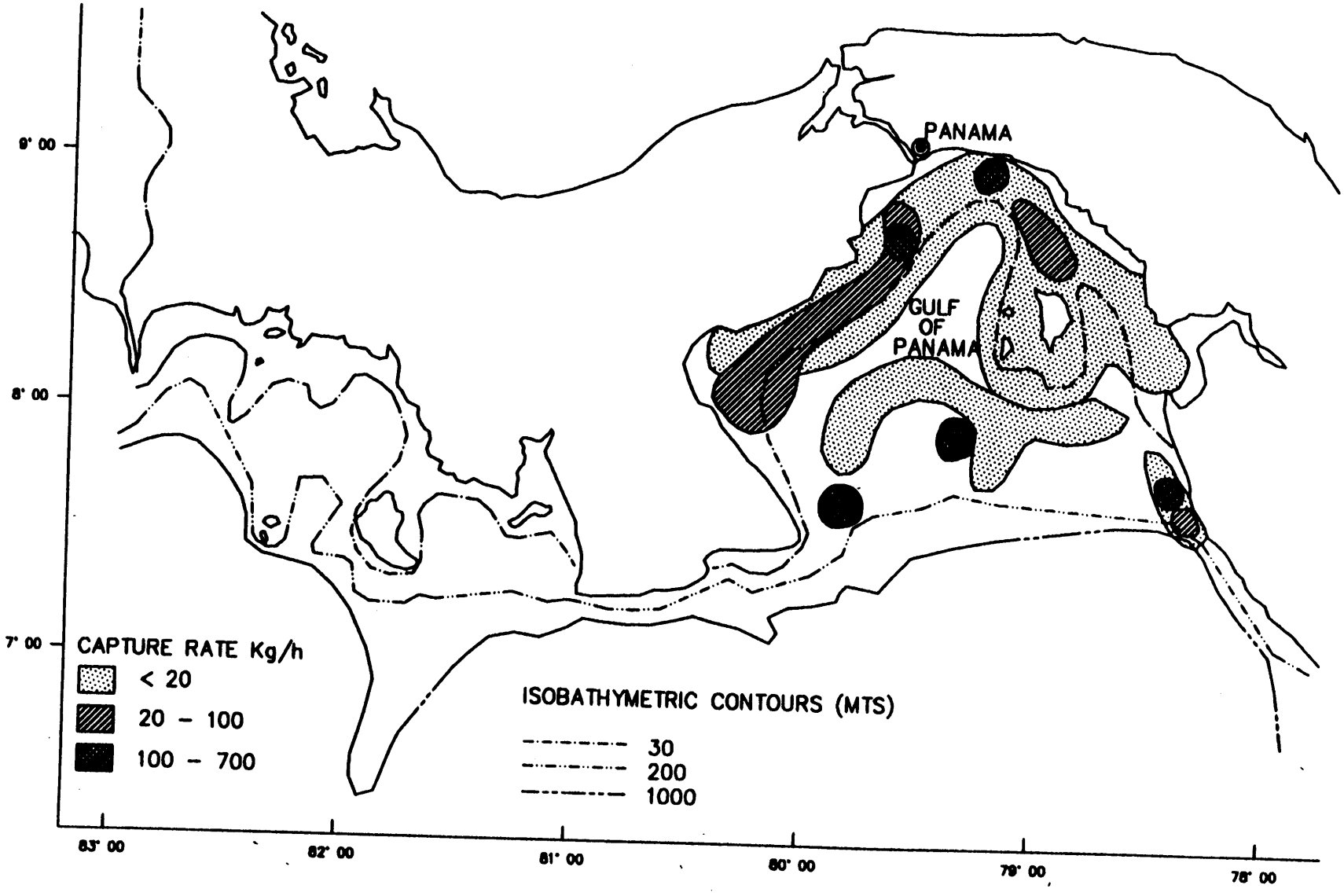
Reference: Smayda, 1966

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

ZOOPLANKTON / PHYTOPLANKTON CYCLES
NOVEMBER 1954 / MAY 1957

DAMES & MOORE

FIGURE A.6



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	CLUPEIDAE DISTRIBUTION GULF OF PANAMA	DAMES & MOORE FIGURE A.7

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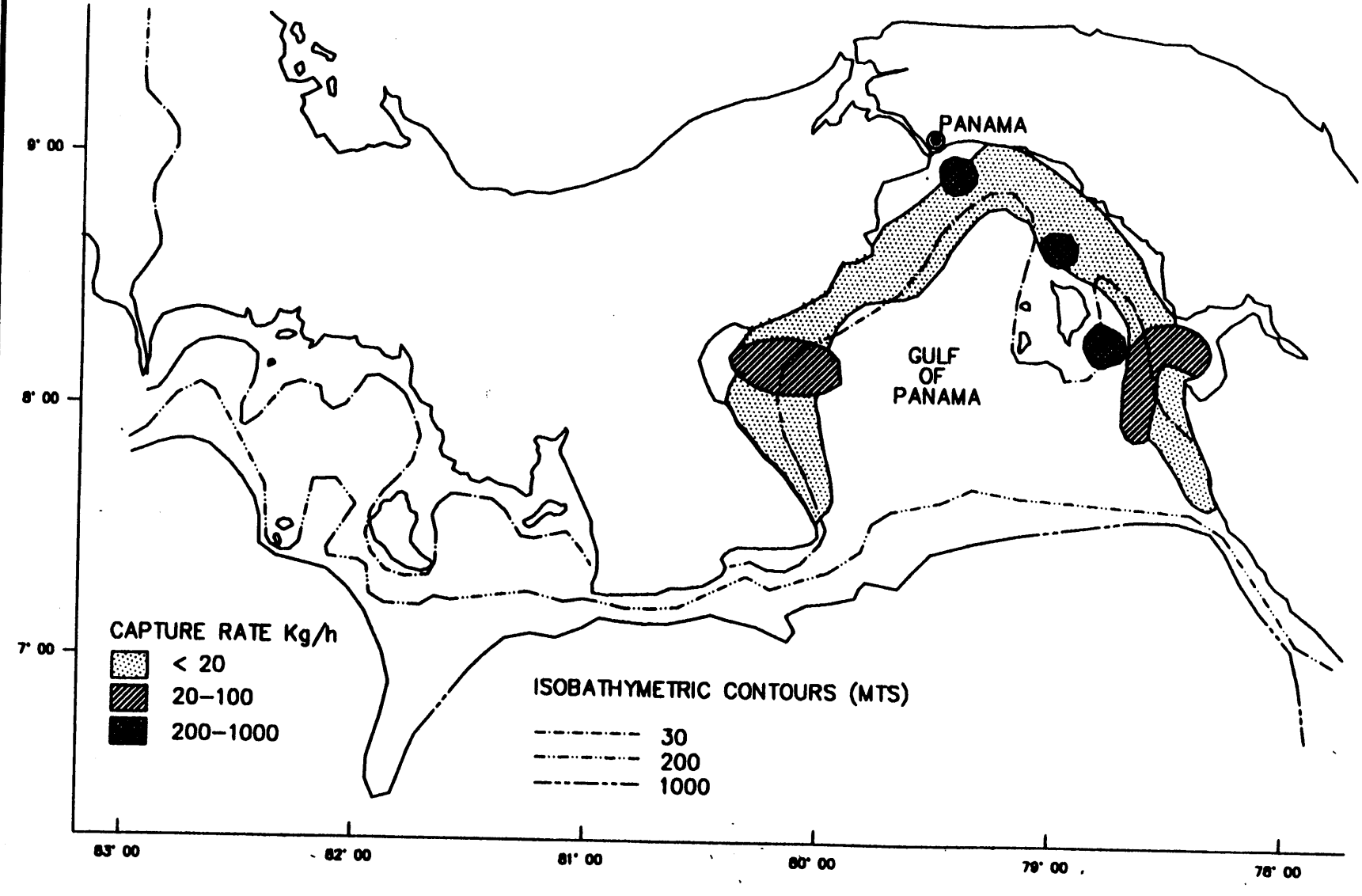
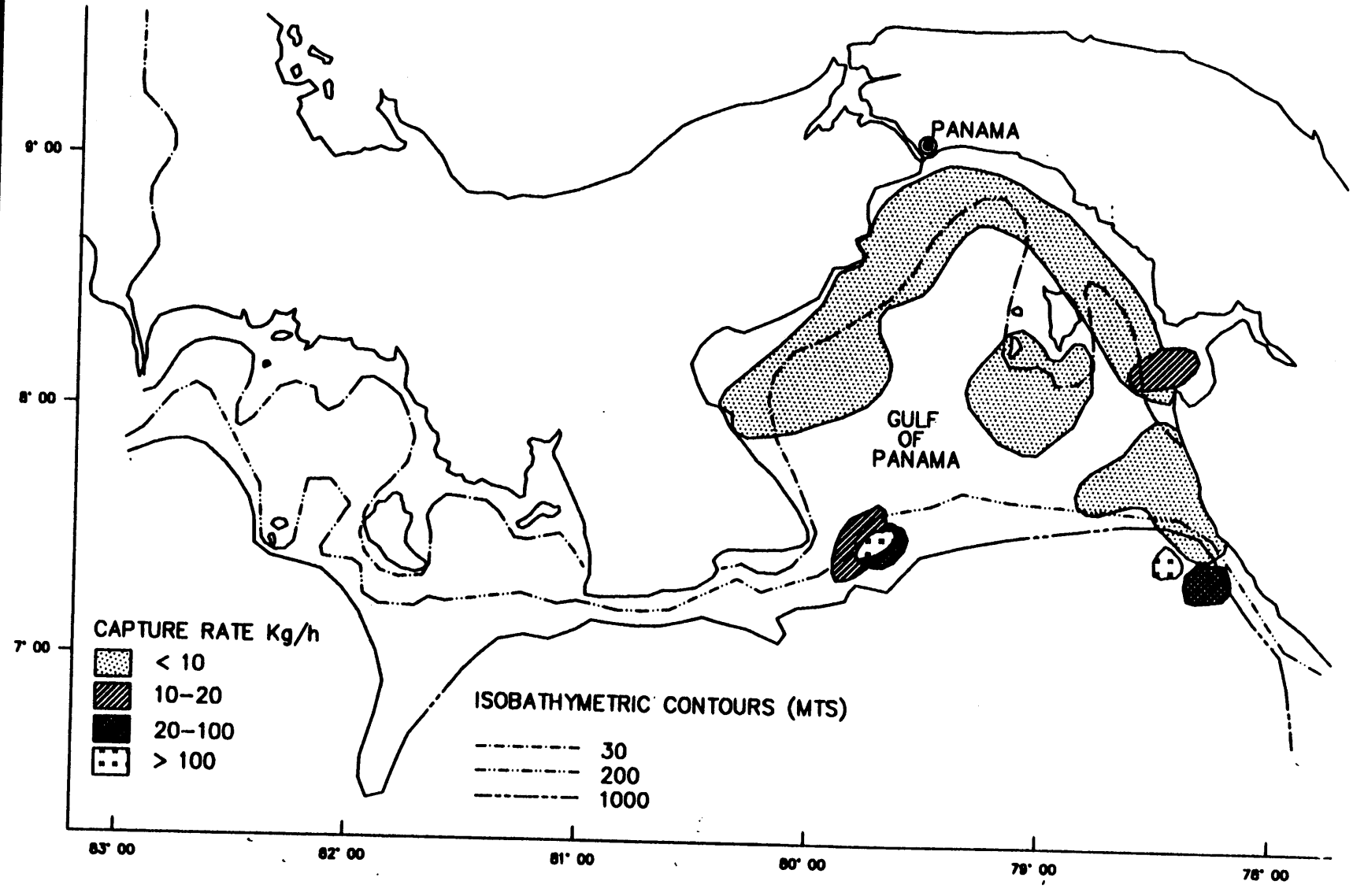


ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	ENGRAULIDIDAE DISTRIBUTION GULF OF PANAMA	DAMES & MOORE FIGURE A 8

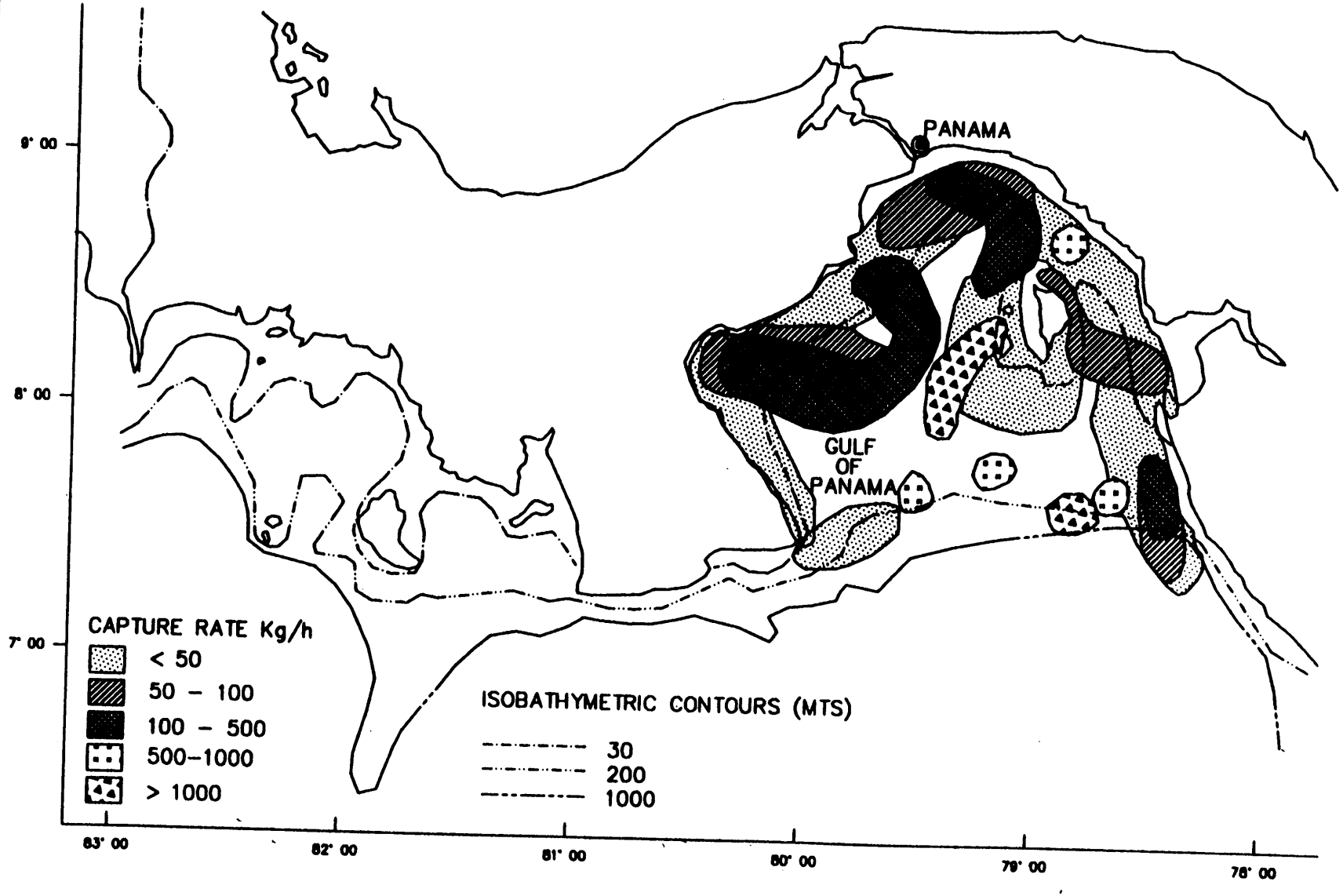
BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 BY DATE REVISIONS



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL	SHRIMP DISTRIBUTION GULF OF PANAMA	DAMES & MOORE FIGURE A.9

BY BEHAR DATE 05-21-93 D & M JOB NO. 26437-001-5552 REVISIONS BY DATE

CHECKED BY



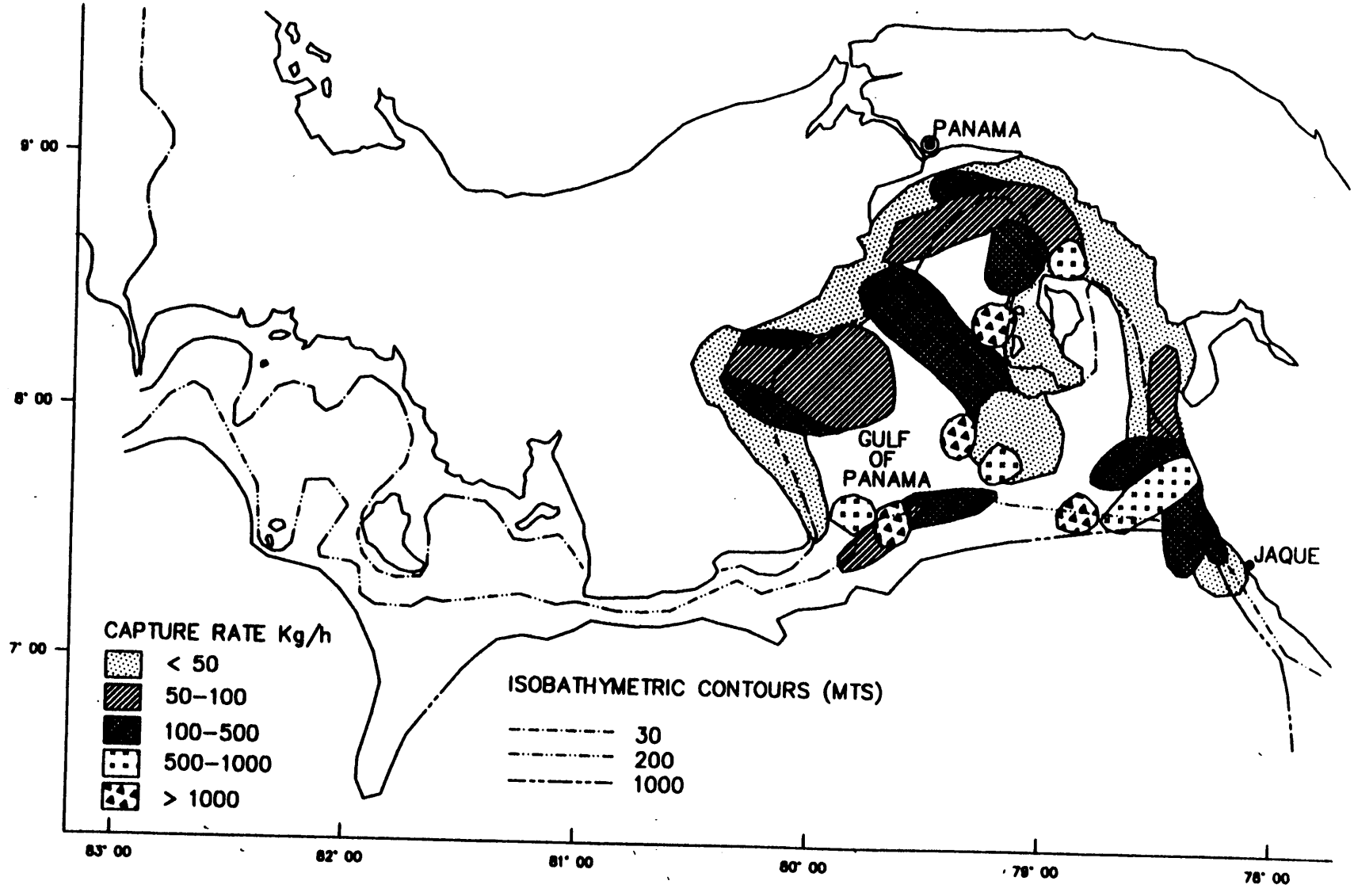
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

COMMERCIAL FISH GULF OF PANAMA

DAMES & MOORE

FIGURE A-40

BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 28437-001-5552 REVISIONS BY DATE



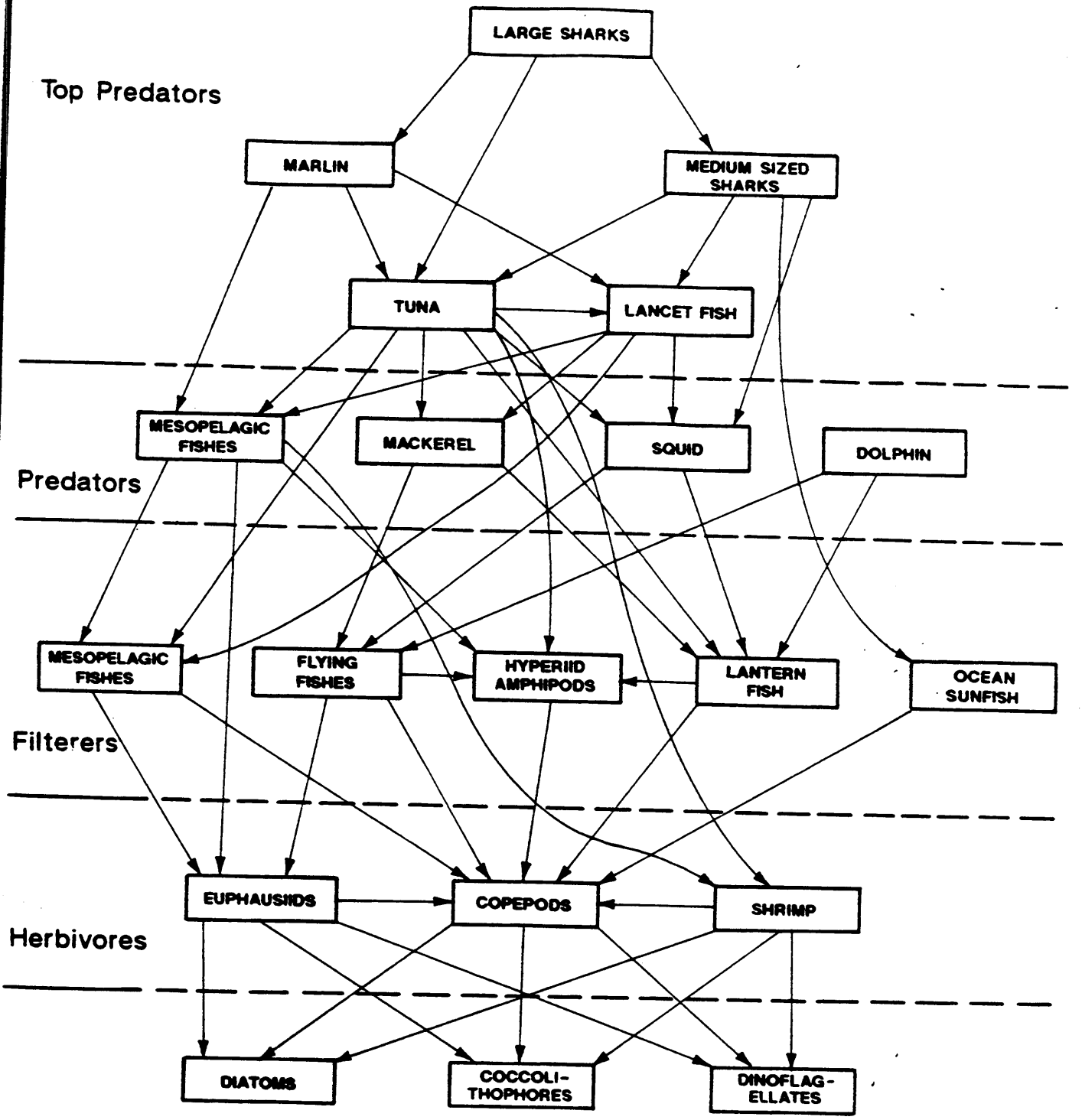
ENVIRONMENTAL ANALYSIS
STUDY OF THE ALTERNATIVES
TO THE PANAMA CANAL

COMMERCIAL SPECIES
GULF OF PANAMA
(FISH, CRUSTACEANS, SQUID)

DAMES & MOORE

FIGURE A 11

BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE

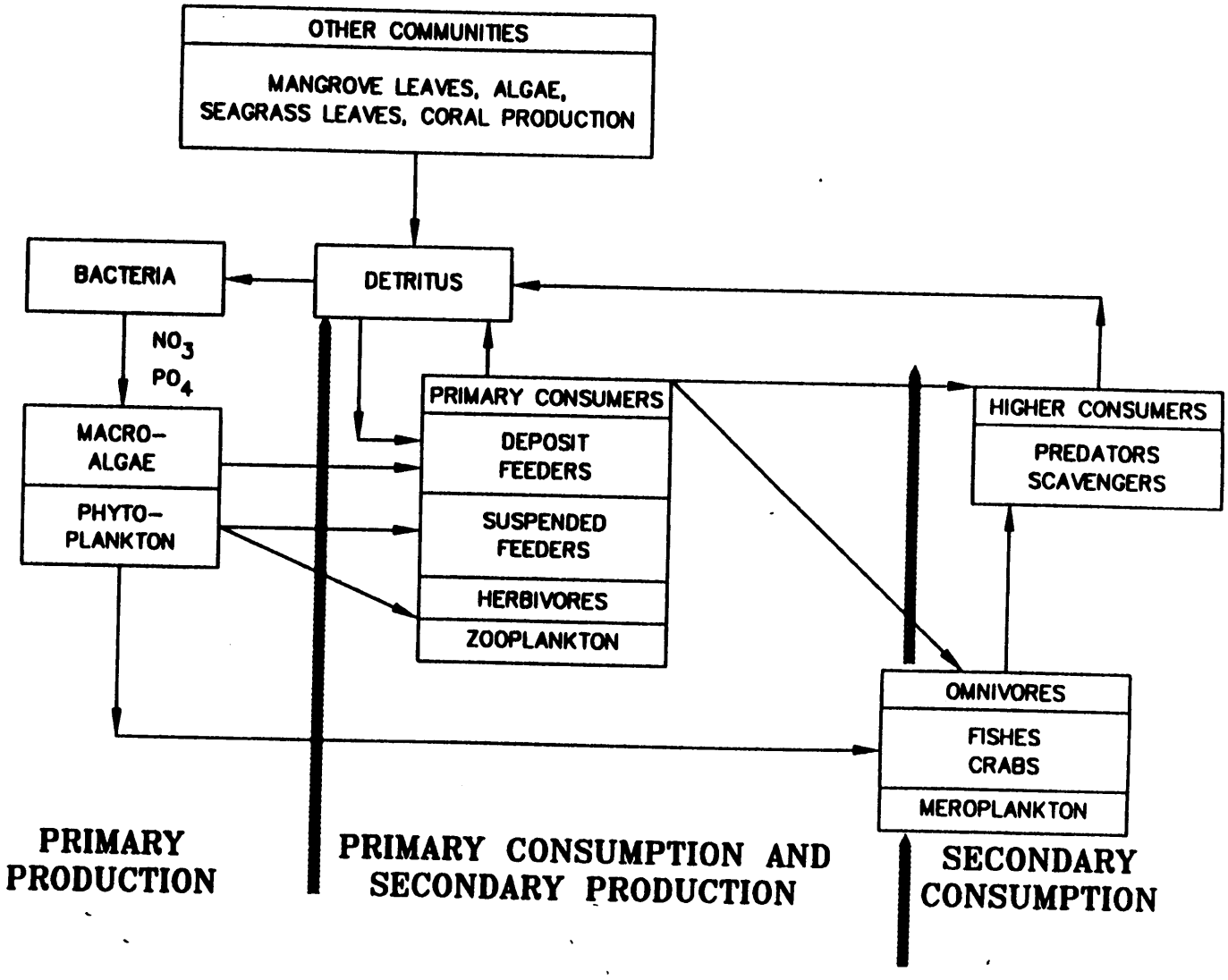


ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

FOOD WEB - TROPICAL MARINE PELAGIC COMMUNITY

DAMES & MOORE

FIGURE A.12



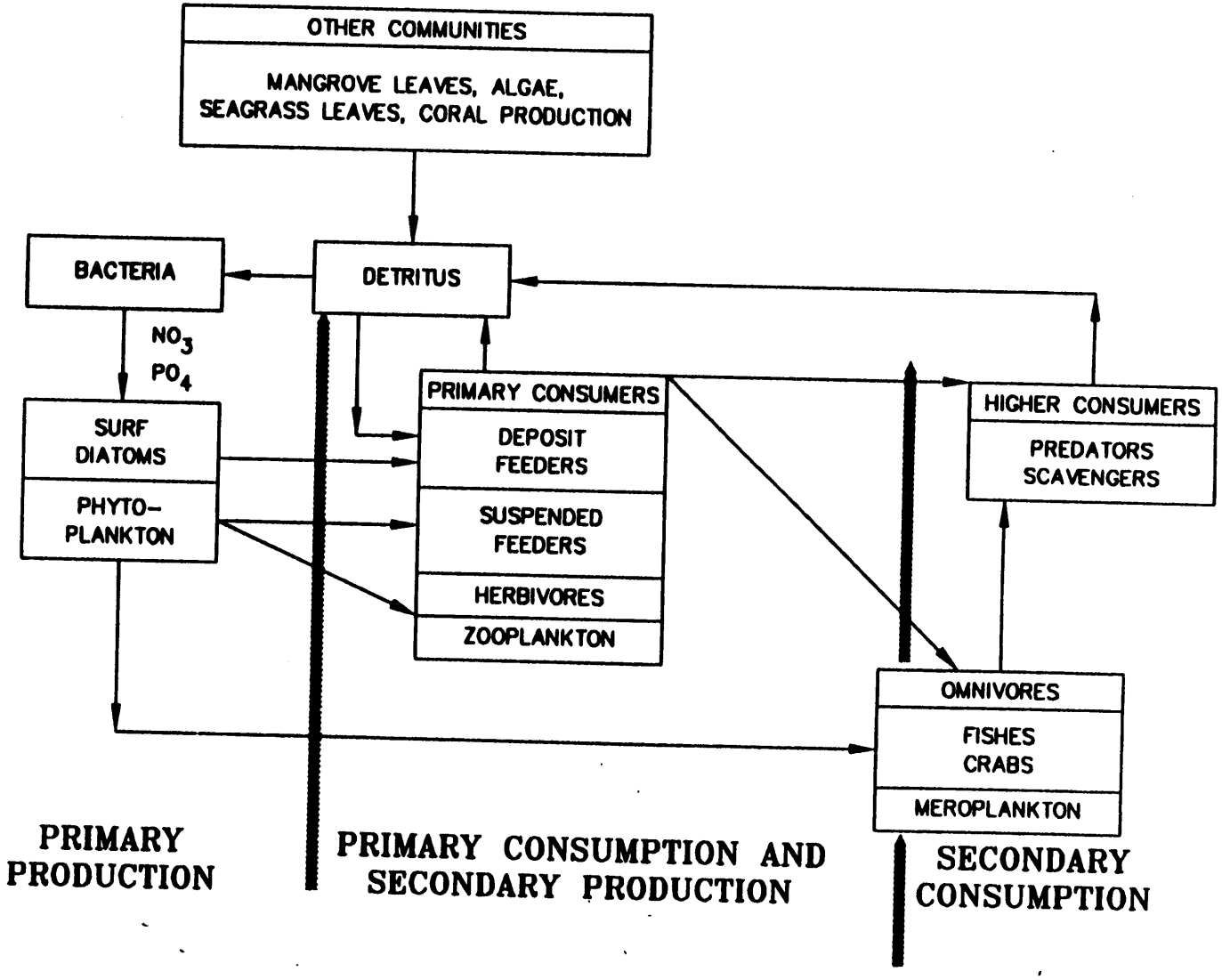
ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

TROPHIC CHAIN OF ROCKEY SHORES GULF OF PANAMA

DAMES & MOORE

FIGURE A.13

BY REHAR DATE 06-21-93 CHECKED BY D & M JOB NO. 26437-001-5552 REVISIONS BY DATE

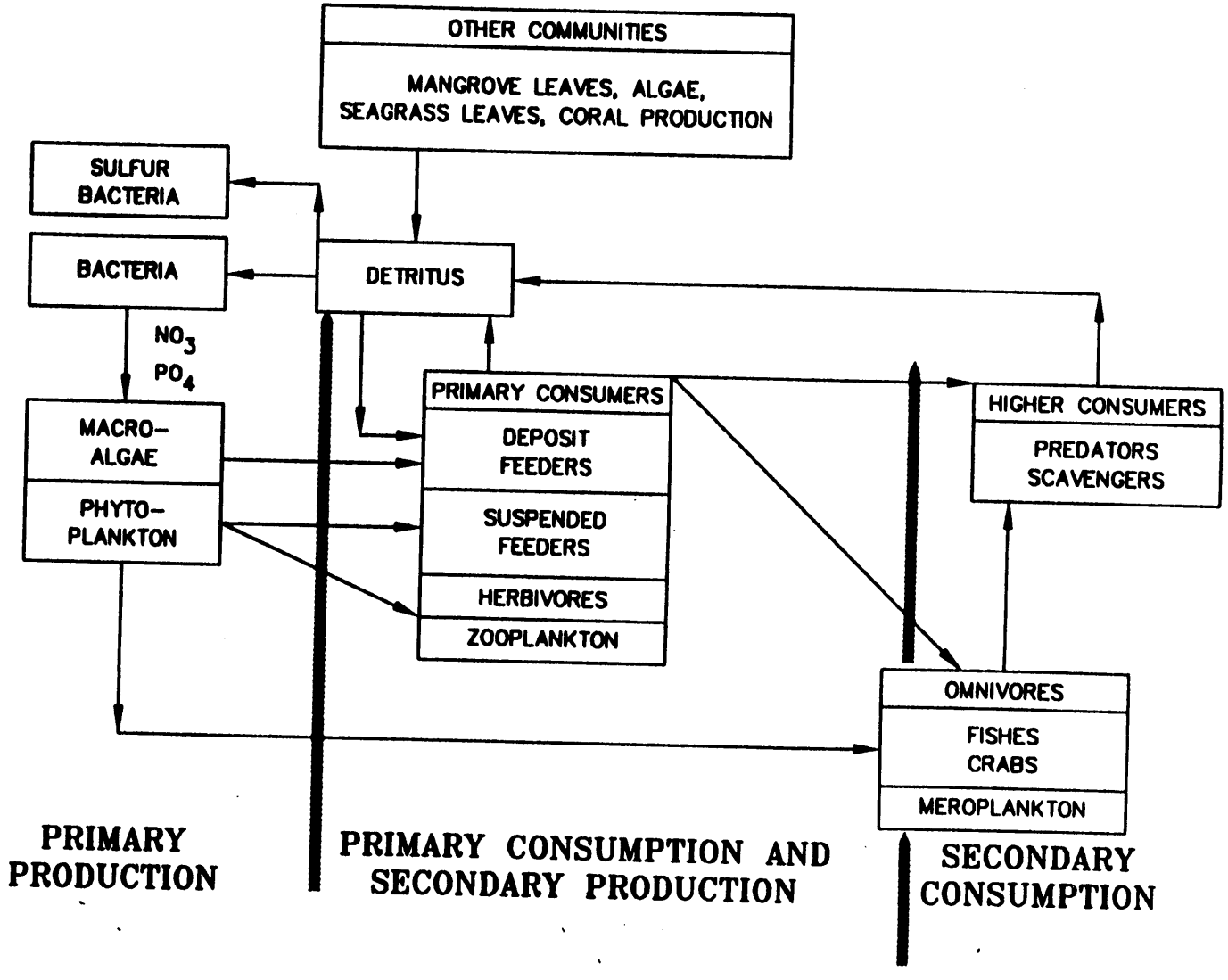


ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

TROPHIC CHAIN OF SANDY BEACHES GULF OF PANAMA

DAMES & MOORE

BY BEHAR DATE 05-21-93 CHECKED BY D & M JOB NO. 28437-001-5562 REVISIONS BY DATE



ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

TROPHIC CHAIN OF MUDFLATS GULF OF PANAMA

DAMES & MOORE

FIGURE A-15

REVISIONS BY DATE

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BY DATE 05-21-93

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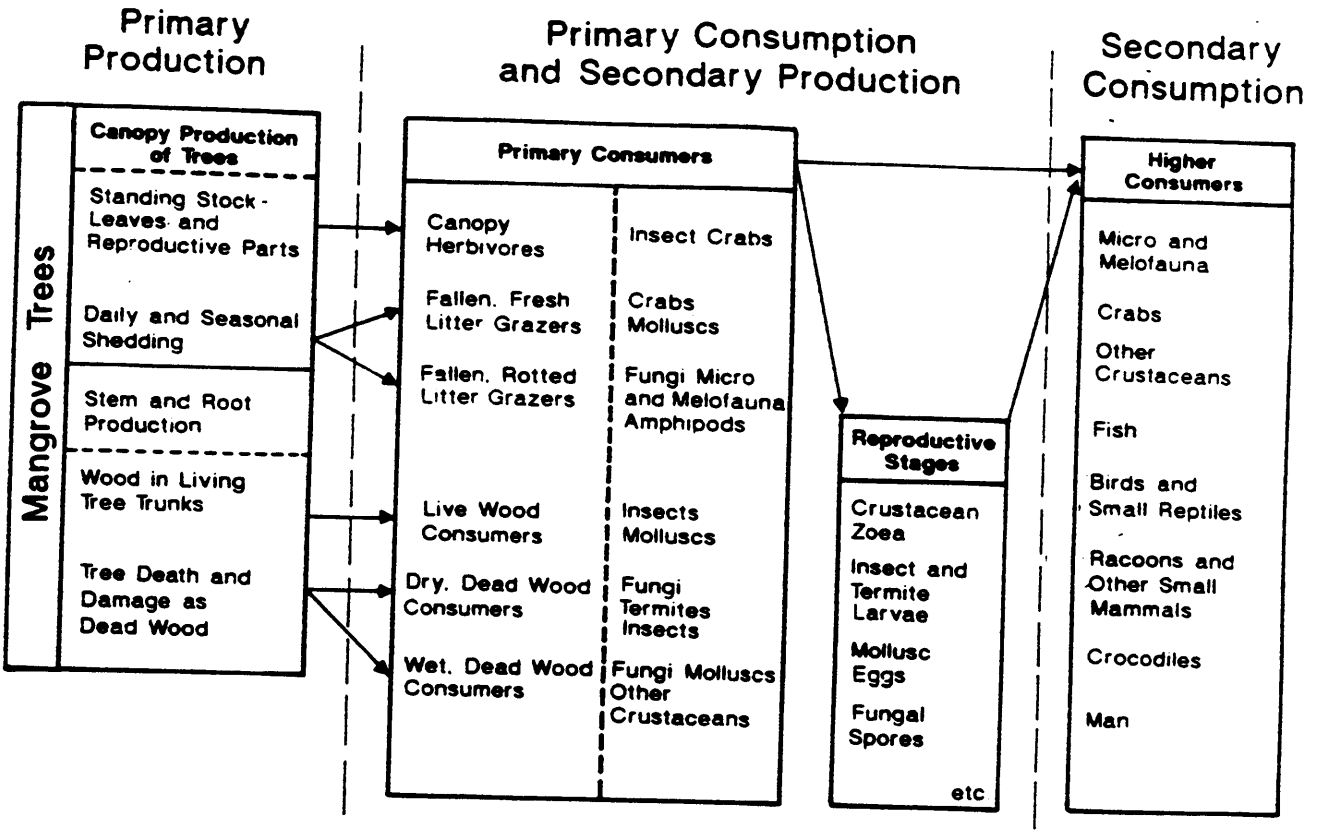

Reference: Duke and Pinzon, 1991

ENVIRONMENTAL ANALYSIS STUDY OF THE ALTERNATIVES TO THE PANAMA CANAL

MAJOR TROPHIC PATHWAYS IN TROPICAL MANGROVE FORESTS

DAMES & MOOR

FIGURE A.16