CELL - OB2 PRESENTS A LIMNOLOGICAL SURVEY OF THE RIO ESPIRITU SANTO WATERSHED, PUERTO RICO (1976-1977) BY Witao R. Bhajan, Miguel Canals, Jose A. Colen, Arthur M. Block, Richard G. Clements. CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, UNIVERSITY OF PUERTO RICO - U.S DEPARTMENT OF ENERGY.

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ABSTRACT: This study constitutes the first complete limnological survey in Puerto Rico. It was

conducted over several years and examined the flora and fauna distribution. It studied the geology and chemistry of water and sediments and identifies the potential sources of pollution and their effects on the environment. Laboratory experiments were also conducted to shed light on some of the problems encountered during the investigation. Lastly, possible areas for future studies are identified.

LIST OF TABLES

Technological Survey of the Rico Espiritu Santo River Drainage System & Previous Limnological Research in Puerto Rico.

While some noteworthy and useful limnological studies have been done in Puerto Rico, these have been, on the whole, fragmentary. Examples of such studies cited by Candelas and Candelas (1963) include Willie (1915) and Tiffany (1963, 1964) on freshwater algae; Gardner (1932) on Myxophyceae; Garcia-Diaz (1938) on insects; Hagelstein (1939) on Diatomaceae; Osborn (1940) on bryozoans; Tressler (1942) on Ostracoda from bromeliads and Candelas (1956) on plankton.

Other studies done recently include those of Candelas and Candelas (1964) on the physical and chemical nature of eight lakes; Hart (1964) and Jones (1964) on contributions to the Limnology of Puerto Rico; Chase and Hobbs (1969) on decapod crustacean; Erdman (1972) on fishes; Wolfe (1972) and Wolfe and Rice (1972) on trace element studies in the Aflasco River; Montgomery (1973) on trace metal chelators of ane/auanasibe, Magee and Culés Rivers.

Previous Limnological Research on The Rico Espiritu Santo River Drainage System.

Maguire (1970) studied aquatic communities in bromeliads; Gifford and Cole (1971) and Vill and crustaceans, Cuevas and Clements (1975) and Clene: (1976) studied stream water chemistry. Accordingly, at the time of preparation, this was the state of the existing research.

Preparing this manuscript, it was found that no complete limnological study of an entire watershed has been done, as far as can be established. This might be a result of the fear of bilharzia, inaccessibility of certain areas, and possibly the whole question of priority. Despite some limitations, this study can be considered a first attempt to undertake a full study of the Limnological aspects of a watershed.

Objectives of the Survey

Primary objectives: The primary objectives of this study are to (a) define the geology of the system

(b) identify the most important and common species of flora and fauna (c) study the distribution of the species (d) examine the water chemistry and some selected physical characteristics as they vary from an elevation of about 950 M to sea level (e) discuss some of the obvious problems related to this survey through laboratory experiments and (f) suggest future investigations.

Secondary Object: The overall objectives of the Rio Espiritu Santo survey are to (a) identify areas for future watershed studies with specific and regional reference (b) create a unified approach with the hope of ensuring the best use of the environment and its resources and (c) finally and hopefully be able to set up a working model for other systems in Puerto Rico as well as other tropical areas.

In Northeast Puerto Rico, the river originates in the El Yunque mountain at an elevation of 950 M. It flows about 20.5 Km and discharges into the Atlantic Ocean. In the upper watershed, there are two main tributaries, namely, Quebrada Grande and Quebrada Sonadora. Quebrada Jimenez unites with Rio Espiritu Santo in the middle portion of the watershed and Rio Grande, Castañon Creek, Quebrada Juan Gonzalez, and Cafe San Luis are the principal tributaries of the estuary situated in the lower watershed. A profile of distance to sea level of the main tributaries of the river is shown in Figure X. The lengths and drainage areas of the principal tributaries are summarized in Table Y. Quebrada Grande has a length of 6.47 km.

The text has an average gradient of 13.6 and drains an area of about 1.9 Km^2. It joins the Rio Espiritu Santo at 10.9 km from its origin. Quebrada Sonadéra is 1.5 km in length, with an average gradient of 21, and drains an area. It joins the main river at 6.2 km. The geological formation consists of granite. Quebrada Jiménez is 7.68 km long with an average gradient of 12.6 and has a drainage area. It joins the main river at 13.2 km.

Quebrada Sonadora is located entirely in the El Yunque forest while the upper and lower halves of both Quebrada Grande and Quebrada Jiménez are located in the forest and grasslands, respectively. The upper part of the main river traverses four distinct types of forest: the Dwarf or Mossy, Palm, Colorado and Tabonuco. In its middle course, it passes through grasslands and some cultivated areas. The lower portion includes some grassland, agricultural, and mangrove communities.

At an elevation of 17.5 m, the geologic form at the confluence is composed of mafic dikes and sheets. The estuary is about 15.6 river km away. It receives the Rio Grande river which flows adjacent to the town of Rio Grande and is the recipient of various types of the town's wastewater. At 17.4 river km, the Castañón Creek merges with the estuary and discharges sewage effluent from Rio Grande. The confluences of both the Rio Grande and Castañón Creek are usually abundant with water hyacinths. Quebrada Juan González stream flows into the estuary at 18.1 river km. It traverses through impenetrable thickets of predominantly...

Red mangrove (Rhizophora mangle) and a well-developed cattle egret (Bubulcus ibis) rookery. Caio San Luis Creek joins the estuary at river kilometer. It flows through swamp lands and mangrove.

Fig. II-2 depicts the Ric Espiritu Santo River system.

Selvarede forest type. Geoplan; minor cultivars corner, plant species include the common: Cyathea arborea (giant fern, tree fern, trumpet tree), Psychotria berteriana (cachimbo common). Palma forest type (above 450m): common plant species include Prestoea montana (sierra palm, mountain palm). The type (below 600m); common plant species include Dacryodes excelsa (tabonuco), Piper aduncum (spiked pepper), Cyathea arborea (giant fern, tree fern), Casearia arborea (wood rat tail), 2. desandre (toasted, wild honey tree), C. sylvestris (coffee), Citharexylum fruticosum (fiddlewood), Pelicoures riparia (yellow pelicoures), Ocotea leucoxylon (white laurel), Guarea guidonia (American muskwood).

Mountains (Little and Wadsworth 1976) in the above four forest types present as the upper watershed are Micropholis chrysophylloides (caimitillo) and Cyrilla racemiflora (swamp cyrilla). The middle watershed located approximately between 25m and 200m above sea level consists of 'transitional moist forest'. Common plant species include Nectandra patens (colorado laurel), Ocotea leucoxylon (white laurel), Guarea guidonia (quarume), Casearia arborea (wood rat tail), C. sylvestris (coffee), and Solanum torvum (turkey berry). This includes typical crops such as breadfruit (pana), banana, plantain, and mango (mango).

Mangrove forests almost cover Panta, 200m south of the mouth of it was destroyed by Coco 5 in development. The red mangrove, Rhizophora mangle, flanks both banks to about 600m below the confluence of Castation Creek. The white mangrove, Laguncularia racemosa, was observed around Caio San Luis and was more abundant on the.

Eastern side of the estuary, especially at the lower reaches of the mangrove forest.

Geography and Features: 'The Rio Espiritu Santo River' is one of the main watersheds of the island of Puerto Rico. The area is nominally located between 30" and 28°27" 25" north latitudes and 16" west longitudes. In general, the river, but one of several rivers, drains the Sierra de Luquillo mountains. The physiography of the region can be described in technical terms as follows: The highest sources of the system begin in mountain uplands which dissolve successively into the St. John peneplain and then onto alluvial, giving way to the Caguana peneplain, with a river basin (Witchelet, 1958).

3.2 Geological History: Most of the rock formations in the drainage system date from the Upper Cretaceous period, although the late Upper Cretaceous period, lasting between 50 and 70 million years ago, formed the Sierra de Luquillo, exposing much which has been observed (Witchelet, 1958). East-west folding also has exposed different formations, the principal period of activity having occurred in the post-middle Oligocene (about 25 to 45 million years ago) (Ferrazano, 1960). The completion of this activity virtually concluded the mountain formation and left the recognizable zones to which reference can be made in today's context.

However, igneous activity and pyroclastic deposits apparently took place during the Laramide orogeny (60-75 million years ago). The intrusive rocks associated with this episode are largely granodiorite, quartz diorite, and minor quantities of quartz porphyry and gabbro. There are also extensive formations (volcanic) in the Sierra de Luquillo cut by numerous vertical dikes, most of which are diorite porphyry. Andesite, the extrusive equivalent of diorite, shows stratification because of ejection in a submarine environment: pyroclastics thus formed are the tuffs which abound in sections.

"Puerco Formation describes a thick sequence of primarily massive tuffs and volcanic breccia (Meyerhoff and Smith, 1921). Breccia refers to the sharp, angled stone fragments bound together with sand or clay. The Formation is exposed throughout the El Yunque quadrangle and consists of thick bedded volcanic sandstone and breccia of andesitic to basaltic composition. Subordinate rock types include thick bedded volcanic and calcareous mudstone and these features are indicative of the submarine environment in which this Formation was likely formed (Sedders, n.d). The Tabonuco Formation is the name applied to conspicuously exposed dark gray, medium bedded mudstone (principally) and less well-exposed volcanic sandstone. The formation is partially conformably overlain by the Hato Puerco Formation. The formation predominantly consists of mudstone, and volcanic sandstone, which is probably andesitic. The volcanic sandstone grades into fine and then coarse volcanic breccia. The dikes and sheets refer to the very dark iron-and-magnesium rich plutonic formations which cut the andesitic or volcanic extrusive formations. They are composed of diabase and porphyry stocks. The plutonic formations also include chlorite and quartz of the Sierra Luquillo and Caguana peneplains. Alluvium deposits are sedimentary features more closely associated with the flood plain than with either the monadnocks or the peneplains. The composition of these deposits is a reflection of the weathering which has occurred both to the tuffs and volcanic sandstone of the Hato Puerco Formation and the Tabonuco Formation respectively. The deposits are rich in silt and some of the most fertile agricultural land in Puerto Rico is derived from the same weathering and transport which gave rise to the deposits. The Riverine System's substrate characteristics can be conveniently subdivided into separate drainage systems. These are the Rio Espiritu Santo River and Quebrada Sonadora Creek."

"Quebrada and its three main triutaries: Grande, Moca and Quebrada Stones, form the geological substrate with the Rio confluence. The characteristic of each tributary to the Espiritu Santo River is shown in Table II-1. The size of the drainage area of the Rio Espiritu Santo River includes the area of each tributary and its size. The U.S. Geological Survey has performed substrate analysis of the principal rock formation in the Rio Espiritu Santo River drainage basin. Tables III-1 and III-2 summarize USGS data (Seiders, 1971) on the chemical analysis of Quartz Diorite and Volcanic Vent Breccia of the Puerco Formation. Both formations are prominent in the area.

TABLE III-1 CHEMICAL ANALYSIS OF EL YUNQUE QUADRANGLE FORMATIONS Hato Puerco Formation

Major Quartz Diorite	Fragment Fragment	Oxides Gray-Green	Oxidized
SiO_2: 67.1%	49.2%	47.9%	
Al_2O_3: 15.8%	17.2%	17.0%	
Fe_2O_3: 2.2%	4.8%	8.0%	
FeO: 2.0%	5.4%	3.8%	

MgO: 1.7% | 7.5% | 6.7%
CaO: 5.1% | 8.4% | 8.0%
Na2O: 3.3% | 2.8% | 3.3%
K2O: 0.92% | 0.12% | 0.31%
TiO2: 0.25% | 0.78% | 0.75%
P2O5: 0.07% | 0.09% | 0.09%
Mn: 0.12% | 0.10% | 0.17%
CO2: <0.05% | <0.05% | <0.05%

Note: Some of the samples contained above 3% water.

TABLE III-2 CHEMICAL TRACE ANALYSIS OF EL YUNQUE QUADRANGLE FORMATIONS Hato Puerco Formation

Minor Quartz Diorite | Fragment Fragment | Elements Gray-Green | Oxidized
Ba: 0.03% | 0.007% | 0.007%
Co: 0.001% | 0.003% | 0.003%
Cr: 0.0005% | 0.005% | 0.007%
Cu: 0.0015% | 0.015% | 0.005%
Ga: 0.001% | 0.001% | 0.0015%
Ni: - | 0.003% | 0.003%
Pb: 0.0007% | - | 0.002%
Se: 0.001% | 0.003% | 0.003%
Sn: - | - | 0.002%
Sr: 0.03% | 0.05% | 0.05%
V: 0.007% | 0.015% | 0.02%
Y: 0.0015% | 0.002% | 0.002%
Zn: 0.00015% | 0.0002% | 0.0002%
Zr: 0.007% | 0.005% | 0.005%

The following elements were looked for, but not found: Ag, As, Au, B, Bi, Cd, Ce, Ge, Hf, Hg, In, Ir, Li, Pt, Re, Sb, Ta, Te, Th, Tl, U, W, Zn, and Eu.

2.1 Rio Espiritu Santo River Geological formation and substrate information for the drainage area of the Rio Espiritu Santo River are summarized in Table IV. Of the actual area examined, more than 89% is Hato Puerco Formation."

More than half of the formation is composed of Quartz diorite and diorite, with the actual quartz diorite in areas where the earth is primarily composed of Svaxp deposits and Alluvium (Table 1). Between these points, subtraces composed of each of the other possible geological strata are found.

a. Hato Puerco Formation 6.28
b. Terrace deposits 0.88
c. Alluvium 0.2

d. Mafic dikes and sheets 3.01
e. Quartz diorite & diorite 1.80
f. Location Origin 1.20

Key:

Tq - Quartz diorite and diorite
xt - Tabomice Formation
Kp - Hato Puerco Formation
Qa - Alluvium
Tmi - Mafic dikes and sheets
Qt - Terrace deposits
Qe - Svaxp deposits

Relatively small areas of Terrace deposits (2.36), Alluvium (0.2), and Mafic dikes (less than 1) comprise the remaining strata drained by the Quebrada Sinénes tributary. Riverine substrates begin in the Hato Puerco at the origin (Table G). Terrace and Alluvium deposits are interspersed with Hato Puerco formations at relatively high altitudes. Dikes are found from 70 to 55%, and at 29.5 and 28m with sections of Hato Puerco, Terrace, and Alluvium interspersed.

Terrace deposits 0.090
Alluvium 0.200
Mafic dikes and sheets 2.58

Table II. Geologic formation of Jiménez streambed

TTT Location (2) Geological Formation Origin:
a. 2.60 km.
b. 2.80 - 1.95 km.
c. 2.92 - 1.75 km.
d. 3.10 - 1.60 km.
e. 3.20 - 3.58 km.
f. 3.98 - 2.00 km.
g. 4.28 - 0.95 km.
h. 4.49 - 0.83 km.
i. 4.76 - 0.70 km.
j. 4.92 - 0.55 km.
k. 5.13 - 0.50 km.
l. 5.33 - 4.95 km.
m. 5.32 - 6.43 km.
n. 6.43 - 6.63 km.
o. 6.71 km.

The text appears to be a technical geological document. It's difficult to correct without additional context, but here is an attempt:

Title: A-WS Sep 6.7m = 6.96 He. 19.5.- 19.0 Ga 5.9682 = 7.02 Fa 19.0 - 18.5
Theat 7.0LKm - 7.53 Ka. 38.5 - 18.0 a 7.53Km - 7.68 Xe. 18.0 - 37.5

Details: Specific ferrace deposits: a - Alluvius 20 Puerco Formation: @t - SSin Aven and sheets

Geological form and substrate information for the watershed area drained by Jueteria Grande Swaok are given in Table T. Of the sector drained, nearly 88% is composed of Hato Puerco, while a minority consists of Terrace and Alluvium deposits with minor sectors of Matic Dikes and sheets (3.91%) and Tebonuco formation (0.2%). Riverine substrates begin on the Hato Puerco formation at the origin and then alternate between Terrace and Alluvium deposits down to 50 meters elevation where the Hato Puerco is re-exposed. After a short drop of about 10 meters in Alluvium, an exposed Maric dike is found at about 10 meters elevation. Thereafter substrate between sections of the exposed Hato Puerco formation are Alluvial deposits. This data can be summarized in Table II.

Geological Formation: 87% Hato Puerco Formation, 10% Terrace deposits, 2.5% Alluvium, 0.2% Magic dikes and sheets, 0.02% Tabonuco Formation

Table III: Geologic formation of Grande stream-bed.

Location: Elevation (z): Geologic Formation

Origin - 3.60 f= 850-90 3.60
tm 90-70 ae 3.95 Ym 70-68
ee was Se 66-62 ae 4.0 Km = 4.60 Hs 62-50
ee 4.60 Hm - 4.80 He 50-48 Kap 4.80
we = 5.2 Kn 48-40 a 5.22 Km = 5. tn 0-38 Tmt 5.
Ka = 5.59 Ra 38-37 Rp 5.59 Km = 5.69 Ke 37-35
ee 5.89 Xm - 6.09 tie ip 6.09 Km - 6.29 Ke 2.5-3
ae 6.29 Hie - 6.29 Hn 3-30 kp 6.39 Ke = 6.47 a 30-26

Key:
Hp - Hato Puerco Formation
Qt - Terrace
Gs - Dikes and sheets
Ga - Alluvium

Gustrae Sonaiora © - a tributary of the Rio Espiritu Santo that drains into the Quebrada Sonadora. Geological Formation and substrate information for the area drained by Quebrada Sonadora Stream are shown. Only 2 formations are exposed in the drainage sector of the Quebrada Sonadora Stream. They are the Hato Puerco formation comprising 90% of exposed formations and the Tabonuco formation.

Comprising the remainder, the riverine substrate begins in the Tabonuco formation at the origin and the Hato Puerco exposition occurs at about 930 m. A summary of altitudes and distances at which the change occurs is given in Table IITA.

Table IIE-7. Geological Formation of Quebrada Sonadora Drainage Area Aves:

- Celeste Formation: 2.35
- Hato Puerco Formation: 0.35
- Tabonuco Formation

Variation of Sonadora Stream-bed. Location Geological Formation origin - 9.2:

- Tabonuco Formation: 0.2
- Hato Puerco Formation: 2.8

Methodology Sampling Station Criteria:

The Rio Espiritu Santo River system was traversed on foot from its origin including the three main high gradient tributaries to the head of the estuary. A boat was used for the estuary survey. In total, 101 sampling stations were examined. These were comprised of shaded and unshaded pools and riffles, weak and fast current areas, confluent sites, areas near or at suspected contaminated spots such as poultry and dairy farms, sanitary landfill and domestic wastes, within each of the four types of forest recognized as Dwarf or Mossy, Palm, Colorado and Tabonuco; grassland, agricultural land and mangrove areas. The stations were distributed in five areas as follows: Quebrada Sonadora 13, Quebrada Grande 13, Quebrada Jiménez 34, freshwater of Rio Espiritu Santo proper 27 and the estuary 14. The upper limit of the estuary is located above Highway No. 3 at sampling station No. J.

Field Methods Decaped Crustaceans

22. The following methods were used:

a) Rocks and stones were disturbed in riffle areas and the animals collected in a net held across the stream.

b) Conical wire mesh traps with baits such as raw meat, codfish, and coconut were used for luring crustaceans in pools.

c) Dip nets

d) Visual observation

e) Diving

f) To observe nocturnal activities, conical wire mesh traps were left overnight at certain stations and animals collected the following day.

g) Conversations with people who frequently visit some of the areas.

h) A

A Ponar grab dredge was used for some estuarine benthic organisms.

Plankton and Drifting Invertebrate Larvae:
a) A plankton net of bolting silk No. 25 was used for both freshwater and estuarine collections.
b) In freshwater, the plankton net was lowered just below riffles for a period of 15 minutes and surface and subsurface hauls were implemented in pools.
c) In the estuary, surface and subsurface collections were conducted for 15 minutes at each station.

Benthic Organisms and Bottom Sediments in the Estuary:
a) A Ponar grab dredge, which encloses an area of 0.05 m^2, was used.
b) One of the triplicate samples was preserved for microscopic examination and benthic organisms were extracted.
c) Detailed observations on Neritina reclivata were restricted to sampling stations No. 15 through 21 of the Rio Espiritu Santo proper, since this part of the river has large populations of the snail, many with extensive shell damage.

Algae Collection:
a) Rock and soil substrates were examined.
b) Attached algae were scraped off and preserved for identification.

Fish Study:
a) Visual observation.
b) Communication with local fishermen.
c) Use of throw nets.

Physicochemical Measurement:
Freshwater:
a) In situ measurements for dissolved oxygen and temperature were determined with a YSI Dissolved Oxygen Meter, Model SIA, equipped with a YSI Oxygen temperature probe.
b) pH was measured with an Orion Specific Ion Meter Model 404 having pH glass and calomel reference electrode.

Estuary:
a) Dissolved oxygen concentrations were determined using the Winkler method (Azide modification) as specified in APHA, 1971.
b) During the latter part of the study, a Martex Water Quality Analyzer equipped with pH, conductivity, dissolved oxygen, and temperature probes was used.

In both freshwater and estuary, visibility measurements were taken with a 20 cm. Secchi disc and water samples were collected for chemical analysis.

Sample Handling and Preservation:
All organisms were preserved in 10% formaldehyde or 70% alcohol for further investigation.

Individuals of Neritin 2 were relocated and taken to the laboratory for experiments and observations on shell erosion.

Laboratory Methods Identification Procedures:

Decapod Crustaceans:

a) Identification keys of Chase and Hicbbs (1969).

b) Confirmation of some species by Dr. Vélez of the Biology Department, University of Puerto Rico and others by the Smithsonian Institute, Washington, D.C.

Plankton and Drifting Invertebrate Larvae:

a) Freshwater phytoplankton identification was confirmed by Dr. H. Duthie of the University of Waterloo, Ontario, Canada.

b) Keys of Pennak (1953), Traver (1938), Edmondson (1966), Mutt (1976), Chu (1949), and Jacques (1947) were used to identify invertebrate larvae.

Benthic Organisms:

a) Identified by Miss Charlene D. Long of Arlington, Massachusetts.

b) Confirmed by Dr. H.C. Duthie, University of Waterloo.

Fish:

a) Confirmed by keys of Erdman (1972).

Mollusks and Tutors:

a) Identification keys of Warmke, (1961) and Emerson and Jacobson (1976).

Estuarine Bottom Sediment Analysis:

The method used by Cunnins (1962) and accepted by EPA (1973) was used to determine particle size. The bottom sediments of the estuary were sifted through U.S. sieve numbers 10, 18, 35, 60, 120 and 230 and the percentage of particle remaining in each sieve was classified as gravel, very coarse sand, coarse sand, medium sand, fine sand and very fine sand. The silt and clay, which passed through sieve number 230, were calculated from the original amount of sediment.

For chemical analysis, sediment samples from 16 stations (Fig. 1V-2) were sieved to remove sand, ground, and further sieved through 170 mesh screening. Further grinding with equal weights of

Lithium carbonate flux and spectroscopic grade graphite powder for 30 minutes in a high-speed ball mill was necessary before.

Samples were analyzed in a Jarrell Ash 1.5 M Wadsworth grating arc-emission spectrograph.

The surface temperature ranged between 5290 and 6400 degrees. The temperature was set at 600 degrees for the evaluation of the G2t-S290 mixture. The pressure was set at 16. The samples were then subjected to a temperature of 900 degrees for 19 hours to induce resistance. The experiment was repeated under similar conditions at temperatures of 610 and 290 degrees respectively. Subsequent measurements and data recording were carried out.

An atomic absorption spectrophotometer, Model 303, was used to obtain Ce and Me concentrations. The standard cadmium reduction method with diazo color development (APHA "Standard Methods for Analysis of Water and Wastewater, 1976) was used to derive the NO3 and NO2 nitrogen concentrations. Sulfate was analyzed using turbidity measurements of barium precipitated standards in the presence of glycerol (Hach Chemical Co., Ame: 50010).

Fresh shells from which the living animal had been removed were digested with Worthington enzymes at pH 8 in the presence of calcium ion and stabilization conditions described by Sipos and Merkel (1970). The digestion was carried out overnight (24 hours) at 25°C. Fresh snail shells processed as described above were also digested with Sigma Scientific Co. papain enzyme in the presence of cysteine and EDTA according to procedures outlined by de Jersey (1970). The digestion was carried out overnight (24 hours) at 10°C. Fresh snail shells were washed with detergent and some were treated for 90 seconds with chlorine bleach (nominal concentration of 5% sodium hypochlorite). The treated shells were subjected to continuous stream water rinsing for some 6 weeks with visual inspection of the shells made every two weeks. The rinsing was carried out in a series of constant...

Row A, Sania WA affiliate enters from a meandering stream. By Binte, System.

Fico Nuclear Center has had to be guided mainly due to the difficulty of fungi and temperature. At the El Verde Field Station, a series of constant flow aquarium systems were set up. PVC tubes were used to transport clear water from a stream nearby. From the main transport tube, connections of flexible tubes with hose clamps were made to allow water to enter the aquariums (Fig. IV-3). In order to maintain a constant level, a siphon consisting of a sieve and attached to a level-controlled bottle was used to allow the outflow of excess water through a drain hose. Inside the aquariums, sand, pebbles, and large stones were placed to simulate stream conditions. Shrimps were collected from the freshwater streams and brought to the laboratory. They were then identified, separated into various aquariums, and fed with detritus, brine shrimps, and bits of meat and coconut. The temperature was about 19°C to 20°C. Bioassay experiments on salinity tolerance were conducted when zoea or larvae were available. When gravid or berried females were observed, they were removed from the aquariums and transferred to wide-mouth gallon glass jars. Aeration was provided by means of a manifold system consisting of two piston air pumps which sent air through

a connecting tube to a Pasteur, providing the necessary aeration. Dilution of filtered sea and stream water to achieve salinity concentrations of 10%, 15%, 25%, 50%, 60%, 70%, 80%, and 90% seawater, including 100% seawater and stream water, was prepared. Four zoea or larvae of the same species were then placed in 50 ml. beakers in triplicates at the various salinity concentrations. No food was supplied during the experiment which lasted 96 hours. Observations on survival and molting were made every 12 hours and the results recorded. Additional data appears to be irrelevant or incoherent and may require more context to accurately interpret and correct.

In Sea Arms, one sees a story 6 when hens 3.

BUNLIND SdWIYHS HOS W3LSAS WNINVNDY MOT4 LNVLSNOD © aUNNdI4 & = _Nivaa on 3SOH NIVEG. Onions 37@1x313 = Wvauis Nous — USivVM — CyvADV USHi0 OL ONIGVS) Adid DSVIS

5.12 Results

The results consist of some selected physico-chemical characteristics including water chemistry, fauna comprising of decapod crustaceans, plankton and drifting invertebrate larvae, benthic organisms and bottom sediments, molluscs, and fish, and flora consisting of periphyton and acres. In addition, laboratory experiments on shell erosion in Neritina reclivata have been examined.

Field Work

Decapod Crustaceans

Twenty seven species of decapod crustaceans were observed in the Rio Espiritu Santo system and are listed as follows:

Order Decapoda
Suborder NATANTIA
Section Penaeidea
Family Penaeidae
Subfamily Penaeinae
Penaeus schmittd
Section Caridea
Crangon sp.
Section Caridea
Family Atyidae
Atya innocuous
Atya Lanji
Atya poeyi
Typroesris stongata

Section Caride
Family Palaemonidae
Subfamily Palaemoninae
Macrobrachium acanthurus
Macrobrachium carcinus
Macrobrachium crenulatum
Macrobrachium faustinum
Macrobrachium heterochirus
Suborder REPTANTIA
Section Anomura
Family Paguridae
Clibanarius cubensis
Section Anomura
Family Coenobitidae
Coenobita clypeatus
Section Brachyura
Family Portunidae
Subfamily Portuninae
Callinectes sapidus
Callinectes sp.

Section Brachyura
Family Pseudothelphusidae
Subfamily Epilobocerinae
Epilobocera sinuatifrons
Section Brachyura
Family Grapsidae
Subfamily Grapsinae
Goniopsis cruentata
Pachygrapsus gracilis
Section Brachyura
Family Grepsidae
Subfamily Sesarminae
Aratus pisonii
Sesarma ricordi
Sesarma roberti

Section Brachyura
Family Gecarcinidae
Cardisoma guanhumi
Section Brachyura
Family Ocypodidae
Subfamily Ocypodinae
Uca leptodactyla

Uca sp. 1
Uca sp. 2
Ucides cordatus

In a shaded pool with weak currents, A. scabra, although not reported in the forthcoming tables, was only observed.

In the fast-flowing feeder brooks of Quebrada Sonadora, individuals measuring about 70cm were collected in March. Out of the 10 species of freshwater decapod crustaceans, 9 were observed in Q. Sonadora, with M. acanthurus missing. Seven species were observed in Quebrada Grande, including 20 others in Quebrada. The least abundant species was crenulatum, and the unobserved species were Atya innocous, A. scabra, Micratya poeyi, Macrobrachium heterochirus, and M. acanthurus. In the Rio Ca Espiritu Santo freshwater mainstream, several species were observed with M. crenulatum being the least abundant.

In the estuary, the aforementioned freshwater crustaceans were restricted to the upper limit. Atya lanipes, dominant in all freshwater habitats, was scarce here. Similarly, Kishocaris elongata and M. carcinus were not as abundant as in freshwater. However, M. acanthurus increased in population size and was distributed almost throughout the length of the estuary. The most abundant estuarine species observed was Uca sp. 1, compared to M. faustinum, which was quite scarce.

The altitudinal distribution of decapod crustaceans was quite conspicuous. A. lanipes and K. elongata exhibited the widest altitudinal range (5-780m) followed by E. sinuatifrons (18-750m) and M. carcinus (5-523m). A. innocous was restricted between 295 and 440m, M. crenulatum between 39-440m, M. heterochirus between 150-550m, and M. acanthurus between 0-30m.

The longitudinal zonation along the estuary was also quite pronounced. M. acanthuri and Uca sp. 1 showed the widest distribution, whereas M. faustinum, P. Schnitti, C. cubensis, and Crangon sp. exhibited limited zonation patterns.

Of the 10 orders of plankton observed in the system, seven were composed of Insecta, two of Crustacea, and one of Arachnida. Five species were noted within the Order Diptera.

Ante Eyer: Upper Interval: 20.05, Sive Fanaa = 4
City Sainte: Freshwater Stream (Table 1)
Orders were observed: O. Jiménez 6, O. Sonadora 6, O. Ciable U-8 (Cable 0-Grande 4) and the estuary €.

In O. Jiménez and O. Sonadoza, the same number of orders and species was observed but it was noted that the following were not observed: Hydracarina, Hemiptera, Coleoptera, Amphipoda and Decapoda.

In Quebrada Walle (Grande 7), in addition to these, there were also missing Diptera, Ephemeroptera and Plecoptera. Not observed in the estuary were Diptera, Trichoptera, Hydracarina and Ephemeroptera. However, the appearance of Hemiptera and Amphipoda marked an increase of decapod crustacean in the estuary (Table U-1e).

The average number of individuals observed in a 15-minute collection per sampling station was:

estuary 14, Q. Sonadora 7, Q. Grande 9, Q. Jiménez 4 and the Rio Espiritu Santo main stream 22.

5.1.3 Benthic organisms and bottom sediments in the estuary:
Five hundred and forty-six polychaetes were collected during a 2-month survey and were grouped into 11 species in 9 families as follows:

Tharyx sp. was the dominant species and made up 68%. Capitellidae sp. 1 and Sigambra tentaculata constitute 19% and 8% respectively. The remaining eight species each represented less than 1% of the total.

The two major, as well as two of the less common species, had a pattern of delimited distribution by navigation. Tharyx sp. and Sigambra tentaculata were observed.

Family Cerrratulidae: Tharyx sp.
Family Capitellidae: Species 1
Family Pilargidae: Sigambra tentaculata (Readwell, 1941)
Family Nereidae: Stenoninereis martini, Redicira belgica (Fauvel, 1936)
Family Capitellidae: Species 2
Family Glyceridae
Family Capitellidae: Species 3
Family Funicidae: Maxs P-
Family Phyllodocidae: Species 1
Family Terebellidae: Species 2

Total individuals: 102 a 546 as

Invertebrate larvae in the estuary were also observed.

Table 8. Continuation: Distribution of Drifting Invertebrate Larvae

Page Break

Drifting Invertebrate Larvae

Page Break

In the sewage, Gigambra Pentaculate constituted 19% and 6% respectively. The remaining eight species each represented less than 1% of the total. The two major species, Tharyx sp. and Sigembra Tentaculata, were found from the sewage outlet (station #7) to the Atlantic Ocean. Stenoninereis Martin and Capitellidae species were found from the outfall south to the head of the estuary. The particle size analysis of estuarine substrate showed that very coarse sand and gravel decreased in quantity from the head to the mouth, whereas very fine sand, silt, and clay tended to increase (Table 1).

5.1.4 Mollusc

Ten species of molluscs were observed in the Rio Espiritu Santo system:

Page Break

Class: Gastropoda

Sub-class: Pulmonata
Order: Basomnatophora
Sub-order: Actophila
Family: Ellobiidae
Species: Melampus coffeus

Sub-class: Prosobranchiata
Order: Archaeogastropoda
Family: Nericidae
Species: Neritina virginea

Order: Neogastropoda
Family: Littorinidae
Species: Littorina angulifera

Family: Thiaridae
Species: Terebia granifera

Family: Pilidae
Species: Maris cornuarietis

Class: Pelecypoda
Order: Filibranchia
Family: Ostreidae
Species: Crassostrea rhizophorae

Family: Dreissenidae
Species: Mytilopsis domingensis

Family: Lucinidae
Species: Lucina pectinatus

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The mollusc species were distributed between the lower and upper estuarine habitats. It was found up to an elevation of 85M. Apart from Q. Son, which has an altitudinal range of 180M - 945M, it was scarce elsewhere. Shell erosion has been noted for these species. The scarcity of M. cornuarietis was quite noticeable.

The text was marked and noted only in the shaded pool (station No. 17) in Q. Jimenez. The species 1. granifera was found to be abundant in the freshwater habitat, especially in shaded rifles. A fascinating array of life is supported by the tangle of arching roots and branches of the red mangrove, Rhizophora mangle. Molluscs such as Neritina vireinea, ¢. rhizophorae, and 1. alatus were fairly abundant. Species like ¥. coffeus and L. aguilifera were restricted to the mouth of the estuary. The periphyton consisted mainly of mosses and ferns. Diatoms attached to mosses were composed of Navicula sp., Pinnularia sp. Eight species of fishes were common in the Rio Bopiritu Santo System:

Order Anguilliformes
Family Anguillidae: Anguilla rostrata

Order Beloniformes
Family Belonidae: Belone sp.

Order Mugiliformes
Family Mugilidae: Agonostomus monticola, Mugil curema

Order Perciformes
Family Eleotridae: Gobiomorus dormitor
Family Gobiidae: Sicydium plumieri
Family Centropomidae: Centropomus ensiferus, Centropomus undecimalis

§. plumieri, A. monticola, and A. rostrata are freshwater species although they were also observed at the upper limits of the estuary. S. plumieri was found to be the most abundant, with an altitudinal range of 5-600 m, while A. rostrata, with an altitudinal range of 5-200 m, was the least abundant. The remaining 5 species are strictly estuarine. However, their presence, except for Belone sp., was also observed just above the upper limits of the estuary (station No. 27). M. curema was noted as the dominant species and was distributed throughout the length of the estuary; the others were restricted to the upper three-quarters of the estuary.

Table 7-1

In situ measurements of pH indicated a general tendency to increase downstream. The exception being Q. Jimenez, which showed a negligible decrease. The general picture for...

This decrease downstream, again -Qv-dimensions which showed, was one of a gradual negative decrease. The general picture for dissolved oxygen was one of a gradual decrease downstream. Again, a slight variation was displayed, that is, there was a slight increase to the sampling station No. 8, followed by a tendency to decrease beyond this point. In the estuary, two average low readings of dissolved oxygen were recorded. At station No. 7, an average of 4.25 mg/l at the surface and 3.0 mg/l at the bottom were noted and most likely attributable to the sewage discharge from the town of Rio Grande. At station No. 9 in Juan Gonzalez, the low dissolved oxygen concentration observed averaged 3.7 mg/l at the surface and 2.05 mg/l at the bottom and was probably caused by the rich deposit of organic detritus produced by the exuberant mangrove and cattle egret rookery nearby. Secchi disc readings showed that the water transparency was noticeably high in the freshwater and in most cases corresponded to the depth of the sampling stations. In the estuary, visibility was high in most cases, at times extending to the bottom up to about 2.5 meters. Occasionally, due to heavy rains, water transparency was rather low.

With respect to Ca and Mg concentration in Table V-2, with the exception of station No. 9 values, Ca and Mg concentrations are low indicating that this tributary contributes little to the metal ion burden at the confluence with the Rio Espiritu Santo River. Quebrada Grande and Quebrada Sonadora were also analyzed with respect to calcium and magnesium concentrations at the sampling stations for this survey. Results are shown in Tables V-20 and V-19 respectively. The lowest metal ion burden contributed by any of the tributaries comes from Quebrada Sonadora. This is consistent with observations of Cuevas and Clements (1975) that land use patterns influence stream burdens, since Quebrada Sonadora courses through undeveloped forest. Some 10 estuarine stations were surveyed to determine the NO3 + NO2.

Nitrogen and sulfate loads. The results for the sampling period of low flow conditions are given in Table V-23. These measurements tend to confirm a marine-type chemical environment at the bottom of the estuary, such as that associated with a variable tidal wedge of high salinity (salt wedge).

Summary of the Results (mg/2) for Sodium, Potassium, Calcium, Magnesium, and Chloride in Stream Water According to Vegetation Types (Cuevas & Clements, 1975).

Vegetation Type - Sodium - Potassium - Calcium - Magnesium - Chloride

Forest 5.624 - 0.06 - 0.304 - 0.00 - 1.048 - 0.01 - 2.084 - 0.04 - 15.754 - 0.96

Grassland 8.184 - 0.22 - 0.394 - 0.00 - 1.884 - 0.07 - 4.200 - 0.20 - 21.074 - 1.36

Upper Estuary 8.144 - 23.03 - 3.294 - 0.84 - 2.344 - 0.23 - 14.864 - 3.33 - 34.274 - 97.83

Concentrations of Calcium and Magnesium in Quebrada Sonadora (mg/1)

Station No. - Ca - Mg

East Branch 1 - 0.65 - 2.33

West Branch 2 - 0.80 - 1.08

Main Stream 6 - 1.08 - 2.62

Main Stream 8 - 1.06 - 1.54

Main Stream 9 - 0.74 - 2.13

5.3 Chemistry of estuarine sediments

Semi-quantitative analysis showed that the following elements were found to be above 100 ppm concentrations in all sediments examined: Al, Ca, Cu, Fe, Mg, Mn, K, Na, and Ti whereas concentration levels below detectable limits were noted for Sb, As, Ba, Ce, Cs, Co, Ge, Hf, Mo, W, U, Zn, and Zr. Furthermore, Cr, Ni, Sr, and V were detected above 100 ppm concentrations at certain stations (Table V-24) and Tl with concentrations below 10 ppm was observed at all stations (Block et al., 1978).

5.4 Laboratory Experiments

Shell erosion in Neritina reclivata was dominant in both freshwater and upper estuarine habitats. Polymorphism of variations in color pattern were evident among all of the populations of N. reclivata, presumably owing to variations in deposition of calcium carbonate in the form of calcite and aragonite influenced by specific properties of the conchiolin overlayer (Watabe and Wilbur, 1960). The conchiolin overlayer appears to be formed during the denaturation of a mucoscleroprotein.

However, the rest of the text seems to be a series of numbers and does not form a coherent sentence or paragraph. It may be helpful to provide more context or details to better assist in correcting the text.

In the final section, the text could be corrected to:

Shell erosion in X. reclivata was dominant in both freshwater and upper estuarine habitats. Polymorphism or variations in color pattern were evident among all of the populations of N. reclivata, presumably owing to variations in the deposition of calcium carbonate in the form of calcite and aragonite, influenced by specific properties of the conchiolin overlayer (fatabe and Wilbur, 1960). The conchiolin overlayer appears to be formed during the denaturation of a mucoscleroprotein secreted by the snail and contains a significant amount of mucopolysaccharides (Kaga, 1966). Digestion of the fresh shell with trypsin and papain or detergents did little to dissolve or lyse the conchiolin layer.

The conchiolin layer, which was soluble in chlorine bleach, was found in Ehyoush 4. The layer at the shell apex tended to dissolve sooner than the rest of the shell. Prolonged rinsing of the apex and the ending shell revealed no further shell damage. In general, smaller snails were undamaged or less damaged than larger, older snails. Erosion of shells of younger snails was confined to the shell apex. A typical temporal sequence of the shell erosion is shown in the following section.

The specimens on the new visible erosion. The pair of shells, second from the left, show apex erosion, more pronounced in the bottom specimen. The pairs second from the right are of badly eroded shells showing exposed layers of calcite and aragonite with conchiolin layers interspersed. The whitish sections shown in the photographs occasionally have a blue or bluish-green hue. The shell on the extreme right shows how severe shell erosion can develop, virtually the entire surface of the shell lacks the fresh shiny conchiolin layer. Direct observation of predation in progress was not uncommon with as many as 4 snails stacked one upon the other in 3 instances of some 59 observations.

Photograph A

Bioassay on Salt Crustacean Larvae

M. acanthurus eggs did not survive at all in freshwater whereas those of A. lanipes seemed to have done very poorly under similar conditions. All zoea of A. innocuous survived between 25% and 100% sea water during the experiment of 96 hours. I. erenulatum zoea survived for the first 24 hours in freshwater and 10% sea water. They also survived between 25% and 70% sea water but did best at 50% sea water. M. heterochirus zoea died after 48 hours in freshwater, but the survival rate fluctuated between 10% sea water and 100% sea water, with 50% to 60% sea water showing 100% survival. X. elongata zoea did poorly in freshwater, 10% sea water. Hundred percent survival was observed between 50% and 80% sea water.

The rest of the text is incoherent and cannot be fixed without further context.

Onansanue Wessessses - Naneasena eg: Erenaeus Masznaas Canazane Senate Sonanasacs Agreement Pomepaed Committed Love Lovers' Onmense:

Decapod Crustaceans

In this study, thirty-seven species of decapod crustacean were identified in the Rio Espiritu Santo system, inclusive of the estuary. Gigford and Cole (1972), failing to find any A. innocous in the Sonadora and Rio Espiritu Santo, concluded that this was a result of steep, turbulent waterfalls, some of noticeable height, and swift currents. A. innocous showed a preference for slow flowing streams. Chace and Hobbs (1969) claim that the animal shows very little restriction in terms of its ecological and geographic distribution, being found in the mouth of the Layou River (Dominica) 100 feet from the Caribbean Sea and in other freshwater regions. It seems to be at home in mountains and cascading streams, upland pools and in waters of lowlands. In our study, contrary to Gigford and Cole (1973), the species was observed at Q. Sonadora, common in circles and at an altitudinal range of 295-440 meters. A. innocous exhibits the peculiar trait of facing the current and procuring food by the constant movement of the bristled first and second pereopods of the chelae to and from the current and mouth. In constant flow aquaria, they are usually found where the water is in constant movement. Chace and Hobbs noted that ovigerous females were present throughout the year in Dominica while Gifford and Cole (1971) indicated an early winter to early spring breeding season.

The breeding season lasts from the end of March to the end of July. The postulate of Chace and Hobbs (1969) that a marine phase for the family Atyidae agrees with our results on A. innocous. The other species will be discussed later. The zoae of A. innocous exposed to salinity concentrations from freshwater to sea water showed that while the larvae seemed to thrive exceedingly well from 10% to 20% sea water, they were appreciably affected in freshwater. A. lanipes was found in every stream where shrimp were present.

The text is present (Gifford and Cole, 1971) and is considered to be the most widely distributed of the decapod crustaceans throughout Puerto Rico (Chace and Hobbs, 1969). Results of this study clearly indicate that it is the dominant species which abounds in all the freshwater Rio Espiritu Santo system but is quite scarce in the upper estuarine waters. Its altitudinal distribution is adapted between 5 and 780M. Gifford and Cole (1971) stated that A. lanipes is found in those waters where A. innocuous cannot survive, but this study shows that this is not true since both species are found in common habitats. A. lanipes prefers to feed just below riffles entering pools, whereas A. innocuous is usually found at the edge of riffles entering pools. A. lanipes feeds on detritus and its method of feeding is quite similar to that of A. innocuous. When not feeding, A. lanipes moves to a shaded area where the water current is quite low. Gifford and Cole (1971) indicated that it is probably the most important species for the recycling of detritus and nutrient input into the streams. A marine phase is postulated (see above) and our salinity tolerance bioassay analysis accords with this view. Most of the zoca thrived in freshwater and did not do well in either 10% or 15% seawater.

A. scabra is found in some areas but is not as widely distributed in Dominica (Chace and Hobbs, 1969). Results of this study in respect of distribution showed that the species was not observed. However, subsequent examinations of fast-flowing feeder brooks of Quebrada Sonadora confirmed the reports of Gifford and Cole (1971). They also noted a difference in the habitat of the male and female adults; the former are usually located in crevices between rocks, while the latter are found only in rocky riffles. The method of feeding is most likely quite similar to that of A. innocuous because of the presence of bristles on the chelae. Chace and Hobbs (1969) found gravid females of A. scabra at the end of January and Gifford and Cole (1971) reported their findings.

The presence in December suggests that breeding occurs around this time. Gifford and Cole (1971) reported that M. poeyi, the smallest of the decapod crustaceans, was restricted to one stream. However, our study shows that this species was found in Q. Sonadora at an elevation of 380 meters, in a shaded pool with weak currents. Chace and Hobbs (1969) noted at least two quite different habitats: rivers and cascading brooks, and drainage ditches with strong currents among roots of aquatic plants. They also found that by using Pronox, the animal showed greater sensitivity to this poison than other crustaceans. Gifford and Cole (1971) inferred that the presence of tufted pereiopods could well indicate filter feeding. Chace and Hobbs (1969) mentioned that although the species M. poeyi breeds throughout the year, most of the eggs are swept downstream and out to sea.

Our study indicates that the adults are usually found at a higher elevation than juveniles. Furthermore, juveniles are always abundant in the upper estuary. The species is second in abundance to Aylanipes and contributes significantly to the biomass of the system. It was observed that its feeding method is particle-picking rather than filter feeding, and that it shows a preference for sunlit areas. Gravid females were quite abundant during November and December. The zoea of X. elongata thrived best between 50 and 80% seawater, whereas it was noted that they did very poorly in fresh and salt water. This result essentially agrees with the postulate of Chace and Hobbs (1969), and our field observations indicate that the young juveniles moved upstream from the estuary. In the Palaemonidae family, M. carcinus is the largest species of the genus and is known to occur in fresh and brackish waters. Its food consists of both animal and vegetable matter such as aquatic insects, fish, mollusks, algae, leaves, and parts of aquatic plants (Lewis, Ward, and Metver, 1966). The mature males...

The animals are equipped with massive claws, which make them deadly predators. Their feeding pattern involves lying in wait for their victims. Observations of heavy populations in areas where garbage was dumped indicate that the animal, while omnivorous, also scavenges (Lewis, 1961). Ovigerous females were noted between May and October, with the highest fertility observed in August (Lewis, Ward, and McIver, 1966). Our study showed that they were common from the end of March to the end of July.

Bougan et al. (1875) provide an excellent review of the life cycle of Macrobrachium. Mating follows the female's premating molt, with the male standing over the freshly molted female and implanting the sperm mass near the female genital pore. Within 24 hours, as the female deposits eggs into her brood chamber, they are fertilized by sperm. At 28°C, the development of fertilized eggs takes 16 to 20 days. M. carcinus carries 120,000 to 140,000 eggs, while M. acanthurus may have 8,000 to 18,000 eggs. Stage I larvae of M. carcinus (Lewis and Ward, 1965) and M. acanthurus (Choudhury, 1970) are 1.44 mm and 2.25 - 2.35 mm in length respectively.

Stage I larvae of M. carcinus are free-swimming, while those of M. acanthurus usually cling to vegetation and become planktonic at Stage II. Planktonic larvae are then carried by the current to brackish water, where they remain during their larval development (usually 30-50 days). Larvae that remain in freshwater or 100% seawater do not survive (Lewis, 1961; Choudhury, 1970). First-stage larvae do not feed and after passing through ten larval stages, they metamorphose into juveniles, settle to the bottom, and migrate toward freshwater. Sexual maturity is reached by the seventh month.

M. acanthurus, as observed, lives in brackish and freshwater at low altitudes (Choudhury, 1970). During the day, according to Chace and Hobbs (1969), the animals can be found along the shoreline among aquatic plants and tend to be active at night, moving debris accumulation to the surface. They relish both animal and plant materials.

They are both omnivorous scavengers and cannibalistic (Eldred, 1960). The cannibalistic tendency was observed during the laboratory culture of our study. The lack of food soon made the adults aggressive and cannibalistic towards the newly molted individuals. Dugan and Frakes (1972) indicated that the larvae of M. acanthurus need a salinity phase.

Dobkin (1971) noted that out of 655 larvae reared between 26-30°C, only 4 and 5 reached metamorphosis at salinity concentrations of 35% and 23.5% respectively, whereas no larvae reared at 12% reached metamorphosis. Choudhury's work (1970) showed that larvae reared in salinity concentrations higher or lower than 60% sea water failed to metamorphose.

Choudhury (1971) showed that larvae reared at 33.8% salinity perished within 11 days and that the maximum survival and development took place at salinities between 15% and 20% at a temperature range of 23-27°C. Dugan et. al, (1975) and Hughes and Richard (1973) observed that M. acanthurus larvae remained at the bottom of an experimental canal with running waters during a decrease in salinity. They moved through this behavior prevents the larvae from moving to the sea and maintains their position in the estuary.

In our bioassay study, we found that the larvae of M. acanthurus died in freshwater and did not thrive well in 10% sea water. Therefore, the importance of a salinity phase, which coincides with the above-cited studies, is beyond dispute.

H. cronulatum abounds in well as in shallow rocky areas of larger streams. It is also common in drainage ditches (Chace and Hobbs, 1969). This study showed that they were also present throughout the freshwater system, especially in pools at an elevation of 30-440 meters. Like other members of this genus, the larger individuals are usually found concealed beneath rocks and stones where they lie in wait for food. They are known to be always in search of food and a fragment of any meat stimulates them to action. Collections of ovigerous females were made.

In February, March, April, May, August, and September (Chace and Hobbs, 1969), they were common from the end of March to the end of July in our study area. It appears that this species was not recorded previously in Puerto Rico. From the bioassay salinity tolerance experiments, the larvae of M. crenulatum did not survive well in either extremes of fresh water or sea water. Twenty-five to seventy percent sea water was best suited. According to Chace and Hobbs (1969), both young and adult M. heterochirus were found to be restricted in riffle areas and low cascades. Our study indicates the importance of riffles where they were found to be common at an altitudinal range of 150-500 meters. The presence of claws, though not as massive as M. carcin and M. crenulatum, would suggest that a similar type of feeding pattern was replicated.

Chace and Hobbs (1969) noted ovigerous females. Our study established that they were the bioassay experiments showed that the species did not thrive well in freshwater and died. E. sinuatifrons, the only crab with a freshwater life cycle in Puerto Rico, is restricted to fresh water habitats and they are known to live on land where they burrow along stream banks. However, the young are restricted to an aquatic habitat. They feed on any kind of decaying material and are thus considered sanitary engineers of the forest (Gifford and Cole, 1971). Very little is known of their life cycle. Our work shows that E. sinuatifrons are found throughout reaches of the estuary. U. cordatus was found in burrows between mangrove roots and similar observations were noted for Yea sp. 1. The distribution of both species was limited to areas periodically inundated by the tides.

G. cruentata was always observed wandering among mangrove roots of Rhizophora and Laguncularia racemosa. Occasionally, the golden tern, Acrocephalus aureus, was observed crawling on mangrove roots and branches but never on the forest floor. P. gracilis inhabits submerged mangrove roots.

Roots and decaying tree stumps are found in the area. Other species of brachyuran crabs such as Uca leptodactyla, Sesarma ricordi, Callinectes bocourti (referred to as sp. 1 in the tables), and the two species of anomuran crabs, Clibanarius cubensis and Coenobita clypeatus were also observed in the lower reaches of the estuary. U. leptodactyla and S. ricordi inhabit sandy shores. However, the latter species and C. clypeatus are often found among grasses and in areas where beach debris accumulates.

Aquatic crabs such as C. cubensis and C. bocourti were observed in the mangrove forest, but the latter species was also present in grassland areas located in the upper half of the estuary. Other brachyuran crabs such as Cardisoma guanhumi, Sesarma roberti, Callinectes sapidus and Uca sp. 2 were very common in the grassland areas, that is, the upper half of the estuary. C. guanhumi lives in burrows along the river banks where the vegetation consists of grasses and bamboo. It has also been observed behind mangrove forests and the adults may establish populations in cane fields or grasslands quite a distance from the river or sea shore. S. roberti was observed under river bank debris and among grasses. Although C. sapidus is aquatic and quite common in the upper reaches of the estuary, it was also collected in the mangrove area. However, it was not as common as C. bocourti which also shares both mangrove and grassland habitats.

The caridean shrimps Atya lanipes, Xiphocaris elongata and Macrobrachium carcinus, although few in numbers, were collected in the upper reaches of the estuary. Mature adults of these species were observed only in freshwater habitats but do have an estuarine phase in their life cycle. M. acanthurus was present throughout most of the estuary except close to the river mouth. It is typically an estuarine species and was the most abundant shrimp.

Very rare were M. faustinus, Crangon sp. and Penaeus schmitti which were limited to the mangrove areas. It was discovered that invertebrate growth was a normal occurrence.

The process, even in the presence of strong currents, was discussed. Muller (1951) accounted for the drift on the basis of competition for food and space, and further saw it as an agent in population dispersal. Waters (1965) spoke of "behavioural drift" to indicate a difference between constant and catastrophic types. He also seemed to agree with earlier studies in respect of the control and regulation of population densities. Elliott (1967) advanced another reason for the drifting phenomena, namely, that organisms lost footing or were dislodged in the competitive struggle for food and space. Hynes (1972), citing Muller (1954) and Waters (1961), put forward the view that drifting resulted through population explosion in areas and that the process replaced lost specimens further downstream, while others in the drift provide food or are simply lost. Hynes (1972) also noted that many organisms rely on the current for the process of respiration and will perish in still water, even though the oxygen content is high. In a very interesting work in Ghana, Hynes (1975) showed that drifting fauna is normally the result of mechanical dislodgment of individual organisms and exposure to the risk of being carried away into the drift is affected by behaviour, especially responses to light. It was stated that there is no evidence that the drifting pattern of the invertebrate, as observed in the Rio Reptrith Santo system, varies. In the main river's freshwater habitat, it was observed that the movement of Diptera, Odonata, and Trichoptera were about the same. The other species were more or less irregular. In the work of Imer and G. Sonadore, the spectrum of a situation was observed. In Grande, on the other hand, all species except for Hydracarina showed an almost equitable distribution. In the same habitat, Decapod larvae exhibited a rather regular distribution (except for sampling station No. 35 where two were collected) as compared to the other species, especially Amphipoda, Hemiptera, Coleoptera, Monatu, and Ephemeroptera. The average number of...

The number of individuals per sampling station showed 22, 4, 9, 7, and 14 for Rio Espiritu Santo proper freshwater, Q. Jiménez, Q. Crane, Q. Sonadora, and the estuary respectively. From this, one can conclude that the Rio Espiritu Santo proper freshwater habitat is more productive within the test. The large number of species in the terminus of the Rio Espiritu Santo proper seems to reflect less environmental interference than the Grande, with fewer species and consequently a higher probability of greater environmental stress.

6.3 Benthic Annelids Siganbre tentaculata and Thalax sp. were distributed from the Rio Grande Sewage Treatment Plant outfall (station No. 7) north to the Atlantic Ocean, whereas the CAPITELLIDAE species and Stenoninereis martini were found from the outfall south to the head of the estuary. The 7 specimens of S. martini were all collected at the headwaters of the estuary in February, 1977. Three of the specimens contained large eggs and another appeared to indicate that this is an established breeding population. S. martini is a Caribbean biological indicator of a stressed environmental situation (natural or man-induced). The presence of S. tentaculata is also indicative of stressed conditions (Charlene Long, personal communication).

While Y. comuaretis was observed to be the least dominant, this species and Tarebia granifera were restricted to fresh water. Y. comuaretis, an ampullariid snail, is a control agent for Biomphalaria glabrata, the intermediate host of schistosomiasis. Its presence in a large pool (Station No. 17) in Q. Jiménez at an altitude of 70 meters needs investigating. T. granifera, a thiarid snail, is also used as a biological control for B. glabrata. It sometimes forms heavy mats on the bottom and sides of streams and rivers. It is believed that this snail outcompetes B. glabrata for space and food and also eats its egg masses. M. coffeus and L. angulifera were restricted to the mouth of the estuary; the former species was quite abundant and commonly observed on mud flats and mangrove areas.

Roots, while the population of the latter species was quite small and occupied exposed mangrove roots. Y. douingensis was found almost throughout the estuary, more abundant in the upper portion and frequently on river rocks. It sometimes shares its mangrove root habitat with C. rhizophorae in the lower reaches of the estuary. The quite scarce edible clams, P. pectinatus and I. alatus, occupied mudflats in the middle and lower reaches of the estuary. A dense population of N. virginea was established at station No. 8 among mangrove roots and on mudflats whereas N. 2 was quite abundant on rocks and bottom sediments in both freshwater and upper estuary. The dominance of N. xeclivata can be explained by its wide range of tolerance from fresh to brackish waters. In freshwater, it thrives on rocks where periphyton is usually abundant; in brackish environments, it is commonly found in the mud between mangrove roots and occasionally attached to mangrove roots. There seems to be a correlation between size and spatial distribution. Smaller snails are found in brackish waters and the lower parts of the Rio Espiritu Santo, whereas larger sizes are observed at their upper limit of distribution.

It was observed that shell erosion was common in freshwater for this species, while in estuarine conditions the phenomenon was quite rare and only in the form of a tiny hole in the apex. Ferguson (1959) suggested that shell erosion might well be a condition which results from a craving for calcium. The experiments undertaken with eroded shells are additional indications that predation is responsible for the erosion. That this predation is intraspecific could be inferred from several other observations. First, at least two other Neritina species exhibit shell erosion. N. punctulata undergoes this response to calcium deficiency (Aguayo, 1976) and N. virginea observed in the Rio Espiritu Santo estuary. The only other potential competitors such as Tarebia granifera or Biomphalaria glabrata were never.

Observed attached to the external shell of a living specimen of N. recliva. Secondly, only shells of living snails were observed to be attacked, indicating that the particular conchiolin resulting from the mucoid secretion is specifically necessary for calcium uptake by other individuals of the species. As well, water erosion of intentionally damaged shells did not show erosion patterns conventionally observed. Finally, under the dissecting microscope, apex erosion features appeared as small caves, occasionally with shiny green diamond-shaped crystals inside. On the whole, however, they most resembled holes created by continued dissolution of the calcitic or aragonitic layers below the outer conchiolin shield. This may be a dissolution phenomenon dependent on metabolic enzymes for calcium carbonate secreted by the individuals of the species. Hynes (1972) also noted that even in soft waters where there is very little calcium the umba of the shell of the mollusk, Margaritifera margaritifera, is often dissolved away and replaced by white nacre.

In the R.E.S. system, eight species belong to six orders. Three of these, (S. plusieri, A.monticola and A. rostrata) are known to be native to freshwater habitats though they have been observed in the region of the upper limits of the estuary. S. plumieri showed a preference for an altitudinal range of 5-600 M, while A. rostrata was found within the altitudinal range of 5-200 M. Five species (Belone sp., M. curema, G. dormitor, C. enciferus and C. undecimalis) are exclusively estuarine and, except for Belone sp., they were found in the upper limits of the estuary where the region overlaps with freshwater. The dominant species in the estuary was M. curema, being found throughout the length of the estuary while the others showed a limitation to the upper three quarters of the estuary. It is of particular relevance here to report that graduate work is being undertaken by Iris Corujo on the distribution and behavior of fish populations in the estuary. It is hoped.

At the completion of this research, many interesting and useful details will come to hand, shedding more light on this subject.

Physicochemical characteristics, data of pH and temperature, showed a tendency to increase downstream in the freshwater system. Generally, dissolved oxygen was invariably high except in the estuary where marked variations were observed. Low oxygen concentrations at certain sampling stations were possibly a result of the sewage outfall, bottom detritus, water hyacinth, and a well-established cattle egret rookery. In Quebrada Juan González, it was observed that the depth was 0.25 m and the substrate consisted mainly of mangrove detritus. Phosphate concentration was also noticeably high (2.2), and this is attributable to the presence of the nearby cattle egret rookery. Except for the sewage outfall and tannin produced by mangrove, light penetration was usually high and in some cases extended up to 2 meters.

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Thallium forms soluble compounds when exposed to both air and water, and many serious or fatal incidents have resulted from accidental ingestion of thallium (Encyclopedia of the Chemical Elements, 1968). In the United States, thallium sulfate...

The text was recently cited: usage of rodenticides was banned (Phousen, 1976). It would be interesting to know the status of thallium sulfate in Puerto Rico. In the RES estuary, copper was found in concentrations of over 100 ppm in the sediments for all 18 stations. The EPA (1973) suggested that concentrations of copper equal to or exceeding 0.05 mg/l constitute a hazard in the marine environment. The paper further states that the polychaete, Hervea vireus, was affected by copper at concentrations of approximately 0.1 mg/l. It had been observed that copper was concentrated by various organisms with concentration factors of 30,000 in phytoplankton; 5,000 in the soft tissues of molluscs and 1,000 in fish muscle (Lowman et. al., 1971). Another interesting report (Bryan and Hummerstone, 1971) stated that the polychaete Nereis diversicolor developed a high tolerance of copper and speculated that predators feeding on this species could receive doses toxic to themselves or accumulate concentrations that would be toxic to higher trophic levels. Synergistic effects in the presence of zinc and cadmium have been documented. The concentration of vanadium in the RES estuary sediments was below detectable limits in 2 stations and above 100 ppm in 16 stations. Roshchin (1967) noted that alloys of vanadium.

Chemistry of Estuarine Sediments: Thallium (Ti) concentrations showed that 11 stations were below detectable limits while the remaining 7 stations were less than 10 ppm. The EPA “Ecological Research Series, Water Quality Criteria” (1973) stated that thallium salts are cumulative poison and are used as poison for rats, dyes, pigments in fireworks, optical glass and as depilatory. Adverse effects of thallium nitrate within 3 days were reported for rainbow trout (S. gairdneri) at levels of 10-15 mg/l, for Daphnia sp. at levels of 2.4 mg/l, and Gammarus sp. at levels of 4 mg/l. It was also suggested that concentration of thallium equal to or exceeding 0.1 mg/l constitutes a

Hazards exist in the marine environment. In fact, the Army Corps of Engineers Regulations on wastewater collection and treatment policy specifically mentioned that the constituent thallium constitutes a potential environmental and hygienic risk such that its absence is desirable (Federal Regulations; November 3, 1975). In the RES estuary, it was noted that polychaetes from all stations tend to concentrate Al and Tl by a factor of at least 10, while a concentration of as much as 50-fold may occur in worms from 3 of the stations (Block et. al. 1978). The implications and possible bioaccumulated concentrations of such elements in the food web should be investigated. In fact, the Encyclopedia Americana (1967) noted that all thallium compounds are very toxic and can produce loss of hair, gastrointestinal disturbances, and ultimately, death. Also, thallium concentrations in marine environments can reach up to 15,000 times in algae, 10,000 times in plankton, 9,000 times in the soft parts of mollusks, 12,000 times in crustacean muscles, and 10,000 times in fish muscles.

Lowman et al. (1971) reported a concentration factor of 1,000 for cadmium in fish muscle and the EPA (1973) suggested that the concentration of this element exceeding 0.01 mg/l in the marine environment constitutes a hazard. Cadmium also acts synergistically in the presence of 1 mg/l or more of copper and zinc (La Roche, 1972 cited by EPA, 1973). Raymont and Shields (1964, cited by EPA, 1973) reported threshold toxicity levels of 1 mg/l chromium for the polychaete Nereis virens, 5 mg/l for small prawns (Leander souilla), 20 mg/l in the form of 2'Cx0, for the shore crab Carcinus maenas. Marine chromium concentration factors of 1,600 in benthic algae, 2,300 in phytoplankton, 1,900 in zooplankton, 440 in molluscan soft parts, and 70 in fish muscle have been reported by Lowman et al. (1971). The EPA (1973) pointed out that concentrations of chromium equal to or exceeding 0.1 mg/l constitute a hazard to the marine environment. Most of the cited elements discussed above indicate this.

"Bicaceumslated concentrations at various trophic levels reveal a serious ecological problem. Efforts should be made to study the accumulative effects in the food web of the RES estuary.

This information is found in the Encyclopedia of Chemical Elements, 1968. In the United States, face was recently banned from usage in rodenticides (Thomson, 1876). It would be interesting to know the status of thallium sulfate in Puerto Rico. In the RES estuary, copper was found in concentrations of over 100 ppm in the sediments for all 18 stations. EPA (1973) suggested that concentrations of copper equal to or exceeding 0.05 mg/l constitute a hazard in the marine environment. The paper further states that the polychaete Nereis virens is affected by copper at concentrations of approximately 0.1 ng/1 (Iver, Shields).

On the shore, copper is also concentrated by marine organisms with concentration factors of 30,000 in phytoplankton; 5,000 in the soft tissues of molluscs, and 1,000 in fish muscle (Lowman et. al., 1971). Another interesting report (Bryan and Hummerstone, 1971) stated that the polychaete Nereis diversicolor developed a high tolerance of copper and speculated that predators feeding on this species could receive doses toxic to themselves or accumulate concentrations that would be toxic to higher trophic levels.

Synergistic effects in the presence of zinc and cadmium have been documented. The concentration of vanadium in the RES estuary sediments was below detectable limits in 2 stations and above 100 ppm. in 16 stations. Roshchin (1967) noted that alloys of vanadium were found.

The Academy of Sciences (1967) reviewed the medical and biological effects of vanadium and noted the following lethal doses of vanadium compounds:

- Colloidal vanadium pentoxide: Rabbit (1-2), Guinea Pig (20-28)
- Ammonium metavanadate: Rabbit (1.5-2.0), Guinea Pig (12), Rat (20-30), Mouse (25-30)
- Sodium orthovanadate: Rabbit (23), Guinea Pig (2), Rat (50-60)
- Sodium pyrovanadate: Rabbit (4), Guinea Pig (2), Rat (4-50), Mouse (4-50)"

Cetravanadate: 18-20, 30-40. Sodium Hexavanadate: 30-40, 40-50, 40-50, 100-150. Sodium Vanadate: 30-40, 10-20, 190-250. Vanadium Sulphate: 18-20, 35-45, 156-190, 125-150. Derived from Faulkner Hudson. It is also stated that the sources of vanadium include welding of vanadium-containing steel, coating of some welding rods, and industrial processing of various vanadium compounds. Besides, vanadium is used in chemical and electronics industries. Its presence in the atmosphere may be caused by the combustion of coal and processing of crude and heavy fuel oil.

A glance at the other elements observed in the sediments shows that some, for example, beryllium, aluminium, cadmium, and chromium can bioaccumulate in various trophic levels. EPA (1973) suggested that concentrations of beryllium and aluminum concentrate 15.01 times in plankton, 9,000 to 12,000 times in crustacean muscles, and 10,000 times in fish muscles. Lowman et al. (1971) reported a concentration factor of 1,000 for cadmium in fish muscle. EPA (1973) suggested that the concentration of this element exceeding 0.01 mg/l in the marine environment constitutes a hazard.

Cadmium also acts synergistically in the presence of 1 mg/l or more of copper and zinc (La Roche, 1972 cited by EPA, 1973). Raymond and Shields (1964, cited by EPA, 1973) reported threshold toxicity levels of 1 mg/l chromium for the polychaete Nereis virens, 5 mg/l for small prawns (Leander squilla), 20 mg/l in the form of Na2CrO4 for the shore crab Carcinus maenas. Marine chromium concentration factors of 1,600 in benthic algae, 2,200 in phytoplankton, 1,900 in zooplankton, 440 in molluscan soft parts, and 70 in fish muscle have been reported by Lowman et al. (1971).

EPA (1973) pointed out that a concentration of chromium equal to or exceeding 0.1 mg/l constitutes a hazard to the marine environment. Most of the cited elements discussed above indicate bioaccumulated concentrations at various trophic levels. Realizing this as a serious ecological problem, efforts should be made to study the accumulative effects in more detail.

The Espiritu Santo River drainage is based on its scheme in which precipitation varies from 500 cm to 150 cm per year. With gradients extending but a few kilometers, one might expect differential weathering characteristics to be pronounced. Soils will likely be in various stages of formation through heavy leaching; very dense vegetation will tend to impede soil erosion, but can lead to a net export of nutrients because of plant mobilization followed by vegetable material decay and mineralization.

Some of the chemical parameters associated with biological productivity in streams have been measured previously and during this survey. Different utilization of land drained by the Rio Espiritu Santo River appears to profoundly affect the quality of water in the streams. Semi-quantitative analysis of estuarine bottom sediments showed that Al, Ca, Cu, Fe, Mg, Ma, K, Na, and Th were found to be above 100ppm concentration, whereas concentration levels below detectable limits were noted for Sb, As, Ba, Ce, Co, Ge, HF, Mo, W, U, Zn, and Zr. Furthermore, Cr, Ni, Sr, and V were detected above 100 ppm at some sampling stations and Tl with concentrations below 10 ppm was observed at all stations.

There are 7 types of rock formations (Quartz diorite and diorite, Tabonuco formation, Hato Puerto Formation, Alluvium, Mafic dikes and sheets, Terrace deposits and Swamp deposits). The Hato Puerco Formation makes up about 85% of the river basin and is composed of at least 50% volcanic sandstones, 30-40% volcanic breccias and small amounts of calcareous mudstones, conglomerate, and lava flows.

Fauna and flora showed a marked altitudinal distribution in the freshwater system and a pronounced longitudinal zonation along the length of the estuary.

In freshwater habitats, mosses, ferns, diatoms, Elodea sp., and Oscillatoria sp. were dominant, whereas water hyacinths, diatoms, and mangroves were dominant in the estuary. Decapod crustaceans were dominant in the entire system. The freshwater species, except for Epilobocera sinuatifrons, require a brackish water phase for development. This was established through salinity tolerance bioassay experiments. The presence of two benthic polychaetes, namely, Sigambra tentaculata and Stenoninereis zartini, indicated stressed conditions in the estuary. The problem of shell erosion in Neritina reclivata was investigated through laboratory experiments. It was concluded that predation was responsible and only living snails were attacked, indicating that the particular conchiolin resulting from mucoid secretion is specifically necessary for calcium uptake by other individuals of the same species.

The Espiritu Santo River drainage basin cannot be understood on the basis of its geochemistry alone. In a basin in which precipitation varies from 500 cm to 150 cm per year along gradients extending only a few kilometers, one might expect differential weathering characteristics to be pronounced. Soils will likely be in various stages of formation through heavy leaching; very dense vegetation will tend to impede soil erosion but can lead to a net export of nutrients because of plant mobilization followed by vegetable material decay and mineralization. Some of the chemical parameters associated with biological productivity in streams have been measured previously and during this survey. Different utilization of land drained by the Rio Espiritu Santo River appears to profoundly affect the quality of water in the streams. Semi-quantitative analysis of estuarine bottom sediments showed that Al, Ca, Cu, Fe, Mg, Mn, K, Na, and Ti were found to be above 100ppm concentration, whereas concentration levels below detectable limits were noted for Sb, As, Ba, Ce, Cs, Co, Ge, He, Mo, W, U, Zn, and Zr. Furthermore, Cr, Ni,

Sr and V were detected above 100 ppm at some sampling stations, and Tl with concentrations below 10 ppm was observed at all stations. (9) A persistent salt wedge is typical of the estuary. The upper 0.3 M consists of freshwater and the lower portion, salt water. During heavy rainfall in the El Yunque region, the leading edge of the salt wedge is pushed further down; the distance being dependent on the intensity of rainfall. (10) Potential sources of pollution include: livestock wastes, solid waste landfills, runoffs from urbanizations and agricultural lands, Coco Beach Land Development, Rio Grande Sewage Treatment Plant and industrial discharges. An overview and suggestions for future investigations are as follows:

(1) Potential Sources of Pollution These include the following:
- 8 Poultry Farms with 105,000 chickens.
- 4 Pig Farms with 1,650 pigs
- 3 Dairy Farms with 400 heads of cattle
- 1 Dog Kennel with 30 dogs
- 3 Solid Waste Landfills
- Runoffs from Urbanizations and Agriculture
- Rio Grande Sewage Treatment Plant
- Industrial discharge
- Coco Beach Land Development

(a) Livestock waste, especially from poultry farms, is left exposed and quite conspicuous. The result of this practice causes volatilization losses of nitrogen and possibly increases pollution through runoff water. The proper disposal of poultry waste can result in the utilization of this material through anaerobic fermentation. The benefits that can be derived are threefold: (1) a drastic reduction of pollution in the environment (2) the creation of a stabilized residue (sludge) that retains the fertilizing value of the original material and (3) the production of a resource (methane) that can be stored and used efficiently. Some of the oxidation ponds which receive the waste from pigs need improvements, such as volume compatible to number of pigs. Again, the bioconversion of pig waste to methane and fertilizer would significantly reduce potential public health hazards.

(b) Of the three solid waste landfills,

The area located at the confluence of Quebrada Jiménez and the main stem of Rio Espiritu Santo poses a public health hazard and should be relocated. Waste is often left exposed, making the site a breeding ground for rodents and flies. Another potential hazard is the seepage of organic pollutants and bacteria into the river system.

The Rio Grande Sewage Treatment Plant is currently unable to handle the waste generated by the growing population of Rio Grande. During heavy rains, the plant fails to process the volume of waste. Therefore, it's necessary to improve the plant. A more long-term solution would be to install a tertiary treatment plant. This not only reduces the phosphorus concentration but also ensures the reduction of water hyacinth.

Approximately 12 industrial plants are located in the watershed. Many of these plants assemble parts, while two of them carry out complete processing, including the use of large amounts of chromic acid. The acid and other waste are discharged into nearby rivulets, presenting a potential pollution source to the Rio Espiritu Santo system.

The mangrove lining the east side of the estuary, from the confluence of Quebrada Juan González to the Atlantic Ocean, appears to be in danger. Coco Beach Land Development is constructing adjacent to these mangroves, and gradual erosion or filling may eliminate them. There are indications that the mouth of the estuary is gradually filling up. The source of siltation and sedimentation needs to be investigated and corrected.

Bacterial flora in the entire system needs attention. A year's investigation on the total coliform bacteria in the estuary showed a high concentration, often far exceeding 10,000 per 100 ml, which is above the limit specified by the Environmental Quality Board of the Commonwealth of Puerto Rico. A priority for future investigation should be a complete study of the entire system to identify the sources and various strains of fecal coliforms.

The hydrology of the entire system also requires comprehensive study.

Hydrology constitutes a vital area of water resources and management, and its importance can hardly be overemphasized. (4) The food web of the entire system, with particular reference to the estuary, is generally based on either detritus or plankton. In the estuary, it was noted that detritus from mangrove and other allochthonous sources was abundant and probably the main base of the food web. However, subsequent studies revealed that plankton, especially diatoms, shrimp larvae, and copepods, was also quite abundant. The implication is that both detritus and plankton are important in the food web, but the extent of the importance of plankton throughout the year is still unknown.

(5) Sources, transport, fate, and toxicology of pollutants in the entire watershed. A complete study of pollutants should be another priority. This should include: (a) identifying potential point and non-point sources of pollution, (b) establishing sampling stations, (c) conducting chemical analyses of effluents at point sources, water at sampling stations, biota, and suspended and bottom sediments, (d) carrying out laboratory bioassays and field biomonitoring, (e) studying synergistic effects of pollutants and environmental factors, and (f) conducting laboratory experiments on the feedback of some toxic elements found in bottom sediments to the overlying water.

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