CEER-082

1980 -

A LIMNOLOGICAL SURVEY OF THE RIO ESPIRITU SANTO WATERSHED, PUERTO RICO
(1976-1977)

not published

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ACKNOWLEDGEMENTS

We wish to acknowledge with thanks the assistance of Dr. Arthur Ehlmann of the Geology Department, Texas Christian University, Fort Worth, Texas, for his review of the geology and stratigraphy sections of this survey. We also wish to thank José Rodríguez for his help in field monitoring associated with characterization of *Neritina reclivata*.

To Manuel Rivera who assisted in the final stages of this survey and Mrs. Ana J. Correa who painstakingly typed the manuscript, our sincere thanks.

Thanks are also due to Dr. Juan A. Bonnet, Jr. for his moral support and encouragement.

(More names to be added

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ABSTRACT

This study constitues the first complete limnological survey of a watershed in Puerto Rico and was conducted over a period of two years (1976-1977). It examined the flora and fauna and their distribution; it studied the geology and chemistry of water and sediments and identifies the potential sources of pollution and their effects on the environment. Included also are laboratory experiments which were conducted to throw light on some of the problems encountered during the investigation. Finally, possible areas for future studies are identified.

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Limnological Survey of the Rio Espiritu Santo River Drainage System

1. Introduction

1.1 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) are Willie (1915) and Tiffany (1963, 1944) on fresh water algae; Gardner (1932) on Myxophyceae; García-Díaz (1938) on insects; Hagelstein (1939) on Diatomaceae; Osborn (1940) on bryozoans; Tressler (1941) on Ostracoda from bromeliads and Candelas (1956) on plankto Other studies done recently include those of Candelas and Candelas (1964) on 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 crustaceans; Erdman (1972) on fishes; Wolfe (1972) and Wolfe and Rice (1972) on trace element studies in the Añasco River; Montgomery (1973) on trace metal chelators of the Guanajibo, Añasco and Culebrinas Rivers; the ecological surveys of Bhajan (1973) on Las Cucharillas Canal and its estuary Bhajan (1973) on the Corazón, Branderi and Salada streams; Bhajan (1973) on the Manatí River; Bhajan (1974) on Rio Seco; Bhajan (1977) on Los Frailes Creek; Bhajan (1973-1978) on several other smaller water bodies in various terrestrial ecological impact statement; Jobin: (1973, 1978), Jobin et al. (1973, 1977) Bhajan et al (197 on bilharzia in ponds, reservoirs and lakes and Quiñones - Marquez and Fuste (1978) on Tortuguero lake.

1.1.1 Previous Limnological Research on The Rio Espiritu Santo River Drainage System.

Maguire (1970) studied aquatic communities in bromeliads; Gifford and Cole (1971) and Villamil and Clements (1976) on decapod crustaceans and Cuevas and Clements (1975) on stream water chemistry. Accordingly, at the time of preparing this manuscript, no complete limnological study of an entire watershed, as far as can be established, has been done. This might be a result of the fear of bilharzia, inaccessibility of certain areas, and possibly the whole question of priority. This study, ~~for all its limitations~~, can be considered a first attempt ~~to undertake~~ a full study of the limnological aspects of a watershed.

1.2 Objectives of the Survey

1.2.1 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.

1.2.2 Secondary Objectives

The overall objectives of the Rio Espiritu Santo [illegible] River Drainage System will eventually include (a) the interplay of the factors of geology, climate, hydrology, soils, fauna and flora and the human impact in an attempt to determine their individual and combined effects on the entire drainage system (b) to provide pointers and identify areas for future watershed studies with specific and regional reference (c) to create a unified approach with the hope of ensuring the best use of the environment and its resources and (d) finally and hopefully to be able to set up a working model for other systems in Puerto Rico as well as in other tropical areas.

2. The System

2.1 Description and Geography of the Study area.

Situated in northeast Puerto Rico, the Rio Espiritu Santo River originates in the El Yunque mountain at an elevation of 950 M. It courses 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 Jiménez unites with Rio Espiritu Santo in the middle portion of the watershed and Rio Grande, Castañon Creek, Quebrada Juan González and Caño San Luis are the principal tributaries of the estuary situated in the lower watershed. A profile of distance above sea level of the main tributaries of the river is shown in Figure I-1 and the length, average gradient and drainage area of principal tributaries are summarized in Table I-1. Quebrada Grande has a length of 6.47 Km. with an average gradient of 13.6 M/100 M and drains an area of about 1.9 Km^2. It joins the Rio Espiritu Santo at 10.9 river Km. from its origin at an elevation of 26 m. The geologic formation at [illegible] is made up of Alluvium.

Quebrada Sonadora is about 3.8 Km. in length, an average gradient of 21 M/100 M and drains an area of 1.5 Km^2. It joins the main river at 6.2 river Km. at an elevation of 175M. where the geologic formation consists of quartz diorite.

Quebrada Jiménez is 7.68 Km. long with an average gradient of 12.6 M/100 M and has a drainage area of 3.9 Km^2. It joins the main river at 13.2 river Km.

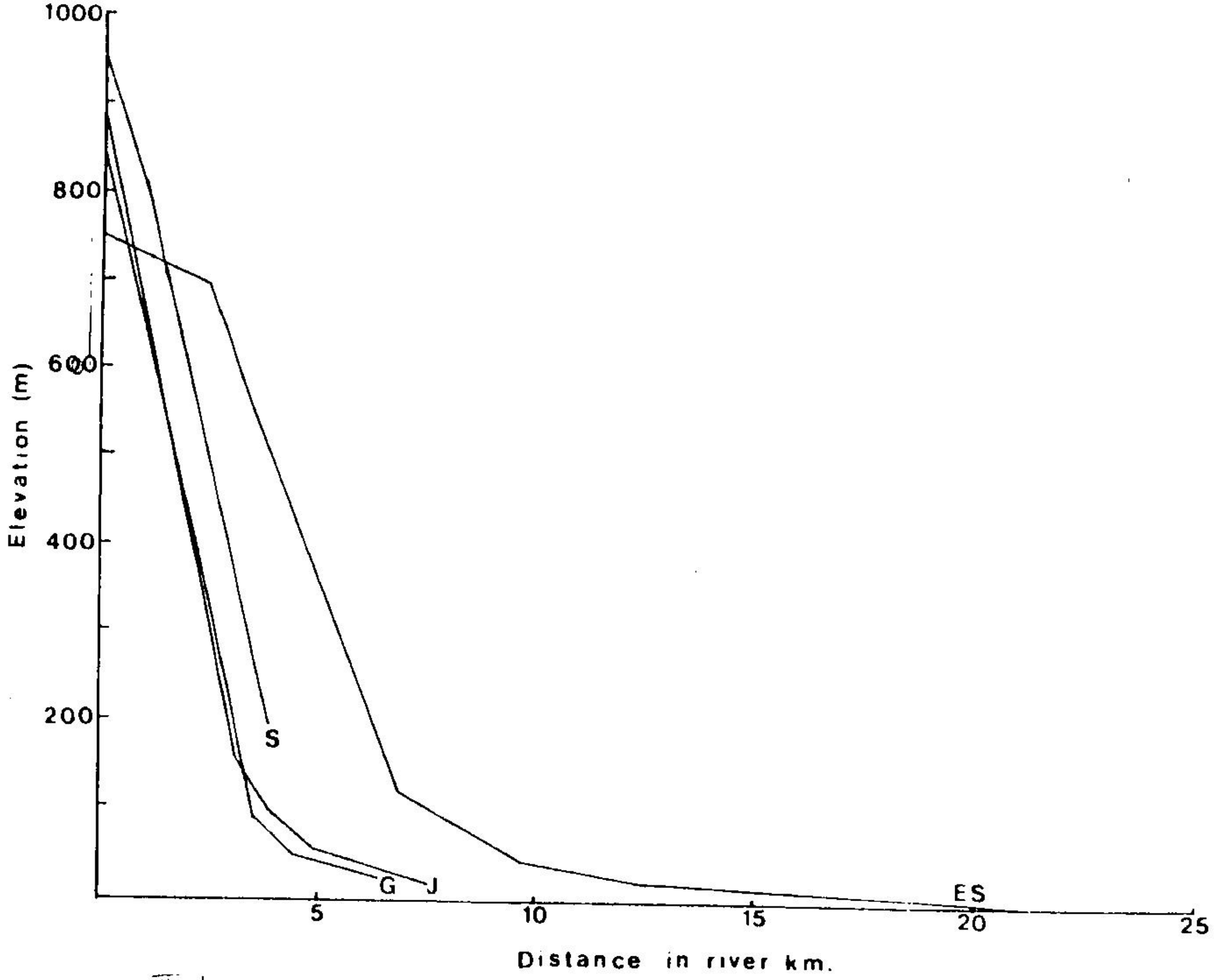


Fig. II-1 Vertical profile of Rio Espiritu Santo and its tributaries.

Table II-1. Some Characteristics of Rio Espiritu Santo (R.E.S) Basin

	Length (Km)	Av. Grad. (M/100 m.)	Drainage Area	Confluent data		
Espiritu Santo	20.45	5.1	20.6			
1000 m. to 50 m. elev.	9.05	10.6				
50 m. to estuary	11.40	0.47				
Tributaries				R.E.S. river Km.	Elevation (m)	Geologic formation
Quebrada Sonadora	3.80	21.0	1.5	6.2	175	Quartz diorite
Quebrada Grande	6.47	13.6	1.9	10.9	26	Alluvium
Quebrada Jiménez	7.68	12.6	3.9	13.2	17.5	Mafic dikes & sheets

at an elevation of 17.5 m. The geologic formation at the confluence is composed of mafic dikes and sheets.

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 and the lower portion includes some grassland, agricultural and mangrove communities.

The estuary ~~runs~~ is about 6 Km long ~~for a distance of about 6 Km~~. At 15.6 river Km. it receives the Rio Grande river which flo 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 Castañon Creek (Fig II-2) unites with the estuary and dischar sewage effluent from Rio Grande. The confluences of both Rio Grande and Castañon Creek are usually abundant with water hyacinth.

Quebrada Juan González stream flows into the estuary at 18.1 river Km. It traverses through inpenetrable thickets of predominantly red mangrove (Rhizophora mangle) and a well developed cattle egret (Bubulcus ibis ibis) rookery.

Caño San Luís Creek joins the estuary at 19.1 river Km. It flows through swamp lands and mangrove forests.

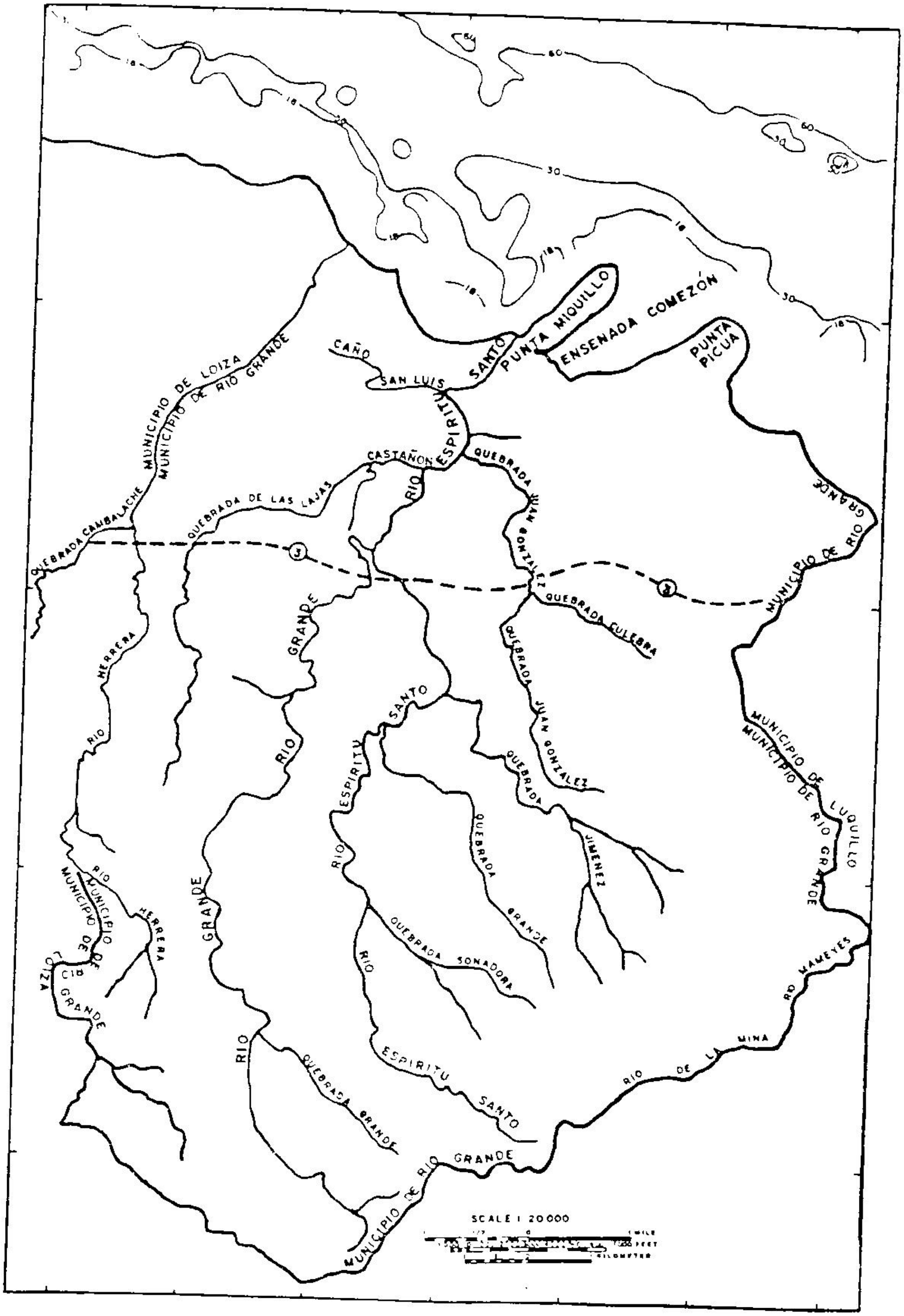


Fig. II-2 Rio Espiritu Santo River System.

2.1 Ecotypical Sections of the Watershed.

1. Dwarf forest type ("elfin woodland"):

   Located above an altitude of 750 M; common plant species include *Psychotria berteriana* (cachimbo común).

2. *Colorado forest type* (above 600 M altitude): common plant species include *Cyathea arborea* (helecho gigante, tree fern), *Cecropia peltata* (Yagrumo hembra, trumpet tree), *Psychotria berteriana* (cachimbo común).

3. *Palm forest type* (above 450 M):

   Common plant species include *Prestoea montana* (palma de Sierra, Sierra palm).

4. *Tabonuco forest type* (below 600 M): common plant species include *Dacryodes excelsa* (tabonuco), *Piper aduncum* (higuillo), *Cyathea arborea* (helecho gigante, tree fern), *Casearia arborea* (rabo ratón), *C. decandra* (tostado, wild honey tree), *C. sylvestris* (cafeillo), *Citharexylum fructicosum* (péndula, pasture fiddlewood), *Palicourea riparia* (cachimbo, yellow palicourea), *Ocotea leucoxylon* (Laurel geo), *Guarea guidonia* (guaraguao, American muskwood)

   Also abundant (Little and Woodbury 1976) in the above four forest types recogniz as the upper watershed are *Micropholis chrysophylloides* (caimitillo) and *Cyrilla racemiflora* (palo colorado, swamp cyrilla).

   The middle watershed located approximately between 25 M and 200 M above sea level consists of:

5. *Transitional moist forest type:*

   Common plant species include *Nectandra patens* (laurel geo colorado), *Ocotea leucoxylon* (laurel geo), *Guarea guidonia* (guaraguao), *Casearia arborea* (rabo ratón), *C. decandra* (tostado), *C. sylvestris* (cafeillo) and *Solanum torvum* (berengena cimarrona, turkey berry).

6. *Cropland:* minor cultivation of typical crops such as breadfruit (pana), banana (guineo), plantain (platano) and mango (mángo).

7. Pasture land: the dominant grass is *Panicum purpurascens* (malojillo).

The lower watershed (below 25 M) consists mainly of pasture land, agriculture, mangrove forests and swamp lands. Sugar cane and coconut are the dominant agricultural plants.

8. *Mangrove*: Previously, the mangrove forest almost covered Punta Miguillo but most of it was destroyed by Coco Beach Development. About 100 M south of the estuary mouth, the red mangrove *Rhizophora mangle* flanks both banks to about 600M below the confluence of Castañon Creek.

The white mangrove, *Laguncularia racemosa*, was observed around Caño San Luis and was more abundant on the eastern side of the estuary especially at the lower reaches of the mangrove forest.

GEOLOGY

3.

3.1. Geography and Physiography

The Rio Espiritu Santo River drainage area is located on the northern faces of the central mountain range, on the eastern side of the island of Puerto Rico. The area is nominally bounded by 18° 17' 30" and 18° 17' 25" north latitudes and 65° 47' and 65° 50' west longitudes. In general, the river with its tributaries, is but one of several rivers draining the Sierra de Luquillo mountains. The physiography of the region can be described in terminus technicus as follows. The highest sources of the system begin in mountain uplands which dominate successively the St. John peneplain giving way to the Caguana peneplain, with a river mouth on alluvial flood plain (Mitchell, 1954).

3.2 Geological History

Most of the rock formations in the drainage system date from the upper Cretaceous period, although the orogeny which began in the late Upper Cretaceous period, lasting through the Paleocene and Eocene (roughly between 50 and 70 million years ago) probably pushed up the Sierra de Luquillo, exposing much of the stratigraphy which has been observed (Mitchell, 1954; Meyerhoff, 1933).. Subsequent east-west folding also has exposed different formations, the principal fold activity having occurred in the post Middle Eocene and pre-Middle Oligocene (about 35 to 45 million years ago) (Pessagno, 1960). The completion of this activity virtually concluded mountain formation and left the recognizable zones to which reference can be made in today's context.

2.1.1 Geological Background

Igneous, sedimentary and metamorphic rocks are all found in Puerto Rico. Volcanic rocks predominate, however, and pyroclastic rocks have been said to give Puerto Rico the appearence of "essentially a heap of volcanic debris" (Beinroth, 1969). Plutonic and volcanic igneous activity apparently took place during the first orogeny (60-75 million years ago). The intrusive rocks associated with this episode are largely granodiorite, quartz-diorite and minor quantities of quartz p~~re~~ORphyry and gabbro.

There are also extrusive formations (volcanic) in the Sierra de Luquillo cut by numerous vertical dikes most of which are diabase and diabase porphyry. Andesite, the extrusive equivalent of diorite, shows stratification because of ejection in a submarine environment. Pyroclasts thus formed are the tuffs which abound in sections of the El Yunque quadrangle (Seiders, 1971).

The term "tuff" conventionally refers to volcanic rock fragments bound together by compaction. The Tuffs are normally of medium grain and may vary from a lose friable consistency to a hard-indurated form. The tuffs may be massive, stratified and may grade into limestone or shales. Unconsolidated tuff is termed "volcanic ash", and when subjected to slight metamorphism during the orogeny, glassy ashes commonly crystallized forming volcanic sandstone or siltstone. The andesitic rock formations tend to weather deeply, particularly in the high rainfall areas of the St. John and Caguana peneplains. Weathering of these rocks in general, produces soils high in clay, medium-low in silt and low in sand with prominent formation of iron oxides and hydroxides. This is because the parent material is low in silica much of which has been dissolved before actual soil has formed.

Although there are not nearly as many sedimentary type rocks in the Sierra de Luquillo, those formed or deposited during the pleistocene era certainly qualify as important since they are well represented in river and stream substrata. These rocks are derived from alluvial deposits, swamp and marsh (largely organic muck) deposits, blanket deposits, beach sands and indurated dunes. In general, the parent materials of the deposits include quartz, calcite, volcanic breccia and plutonic debris, and are, by and large, unconsolidated. Ratios of quartz to other constituents are general indications of the lithology of the watershed from which the deposit is formed, since transport only occurs via wind and water flow.

Most metamorphic rocks are associated with the orogeny and are not considered prominent features of the El Yunque Quadrangle (the Sierra de Luquillo). Rather, true metamorphosis is more prominent in the south-west part of the island, with a zone from Comerio to Humacao of demonstrated metamorphic mineral assemblage (Hildebrand, 1960).

3.3 Stratigraphy

3.3.1 River Bed Substrate Description

Mapping of exposed geological formations in the Río Espiritu Santo drainage area has been carried out by the U.S. Geological survey (Pease and Briggs, 1972 Seiders, 1971). There are 7 principal units identified as both typical of strata in the watershed and represented as substrates in the Río Espiritu Santo River System. ~~The System is~~ shown in Map III - 1, ~~and~~ the appropriate substrata identified from U.S. Geological Survey documents are: Hato Puerco Formation (Khp), Terrace deposit (Qt), Alluvium (Qa), Mafic dikes and sheets (Tkmi), Quartz Diorite and Diorite (Tqd), Tabonuco Formation (Kt) and Swamp deposit (Qs).

The Hato Puerco Formation describes a very thick sequence of dominantly massive tuffs and volcanic breccia (Meyerhoff and Smith, 1931). Breccia refers to sharp, angled stone fragments cemented 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 very likely formed (Seiders, 1971).

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 is chiefly composed of mudstone, and volcanic s~~t~~andstone which is probably andesitic. The volcanic sandstone grades into fine and then (rarely) into coarse volcanic breccia.

Mafic 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 diabase-porphyry stocks.

The plutonic igneous activity and subsequent ejection gave rise to diorite and quartz diorite stocks now found in the monadnocks of the Sierra Luquillo and the St. John and Caguana peneplains.

The Terrace, Alluvium and Swamp deposits are sedimentary features more closely associated with the flood plain than with either the monadnocks or the 2 peneplains. The composition of these deposits is a reflection of the weathering which has ocurred 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 are ~~is~~ derived from the same weathering and transport which gave rise to the deposits.

3.3.2 Substrate Characteristics of the Riverine System

The drainage basin is conveniently sub-divided into 4 separate drainage systems. These are the central Río Espiritu Santo River and its 3 main tributaries: Quebrada Sonadora ~~Brook~~, Quebrada Grande, ~~Brook~~ and Quebrada Jiménez. ~~Brook.~~ The geologic base of the river system was determined by using ... Survey maps of El Yunque and Rio Grande quadrangles. Utilizing a Keuffel + Esser swivel handle map measure, precise measurements of the location of various types of geologic formation was attained. The measurements are given in river kilometers measured downstream from the river's origin. The geological substrate characteristic of the confluence of each tributary with the Río Espiritu Santo River is shown in Table II-1 The size of drainage area of each tributary and that of the Río Espiritu Santo River is included in the table.

The U. S. Geological Survey has performed substrate analysis of the principle rock formation in the Rio Espiritu Santo River drainage basin. The Tables III-1 and III-2 summarizes USGS data (Seiders 1971) on Chemical analysis of Quartz diorite and volcanic vent breccia of the Hato Puerco Formation. Both formations are prominent in the El Yunque quadrangle and the Hato Puerco Formation is conspicuously well represented

TABLE III - 1

CHEMICAL ANALYSIS OF EL YUNQUE QUADRANGLE FORMATIONS

		Hato Puerco Formation	
Major Oxides	Quartz diorite	Fragment Gray-Green	Fragment Oxidized
SiO_2	67.1%	49.2%	47.9%
Al_2O_3	15.8	17.2%	17.0%
Fe_2O_3	2.2	4.5	8.0
FeO	2.1	5.4	3.8
MgO	1.7	7.5	6.7
CaO	5.1	8.4	8.1
Na_2O	3.3	2.9	3.3
K_2O	0.92	0.12	0.31
TiO_2	0.25	0.78	0.75
P_2O_5	0.07	0.09	0.09
MnO	0.12	0.10	0.17
CO_2	<0.05	<0.05	<0.05

*None of the samples contained ~~above~~ over more than 3% water.

TABLE III-2

CHEMICAL TRACE ANALYSIS OF EL YUNQUE QUADRANGLE FORMATIONS

		Hato Puerco Formation	
Minor Elements	Quartz diorite	Fragment Gray-Green	Fragment Oxidized
Ba	0.03%	0.007%	0.007%
Be	-	-	-
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
Mo	-	-	-
Nb	-	-	-
Ni	-	0.003	0.003
Pb	0.0007	-	0.002
Sc	0.001	0.003	0.003
Sn	-	-	0.001
Sr	0.03	0.05	0.05
V	0.007	0.015	0.02
Y	0.0015	0.002	0.002
Yb	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, La, Li, Pt, Re, Sb, Ta, Te, Th, Tl, U, W, Zn, and Eu.

3.3.2.1 Río Espiritu Santo River

Geological formation and substrate information for the drainage area of the Río Espiritu Santo River are summarized in Table ~~3-1.~~ III-3 Of the actual area drained, more than 85% is composed of Hato Puerco Formation, more than 8% is formation of Quartz diorite and diorite, with relatively low areas dominated by exposed alluvium (3.01%) Mafic dikes and sheets (1.78%) and Terrace deposits (<1%).

The actual riverine substrate varies dramatically from the origin on Quartz diorite and diorite to the river mouth, where the bottom is principally composed of Swamp deposits and Alluvium (Table III-4). Between these points substrates composed of each of the other possible geological strata are found.

Table [illegible] Geologic formation of Rio Espiritu Santo Drainage Area.

Area	%	Geologic Formation
17.64 Km^2	85.55	Hato Puerco Formation
0.18 Km^2	0.89	Terrace deposits
0.62 Km^2	3.01	Alluvium
0.36 Km^2	1.78	Mafic dikes and sheets
1.80 Km^2	8.74	Quartz diorite & diorite

Table II-4. Geologic formation of Espiritu Santo River-bed.

Location	Elevation (m)	Geologic Formation
Origin - 1.20 Km.	750-725	Tqd
1.20 Km - 2.30	725-695	Kt
2.30 Km - 6.90	695-120	Khp
6.90 Km - 7.40	120-100	Qa
7.40 Km - 7.80	100-90	Khp
7.80 Km - 8.30	90-70	Qa
8.30 Km - 9.40	70-48	Tkmi
9.40 Km - 9.90	48-40	Khp
9.90 Km -10.85	40-28	Qa
10.85 Km -10.95	28-27.5	Khp
10.95 Km -11.35	27.5-26.5	Qa
11.35 Km -12.15	26.5-22	Khp
12.15 Km -12.35	22-20	Qa
12.35 Km -12.55	20-10.5	Tkmi
12.55 Km -13.15	10.5-10	Qa
13.15 Km -13.80	10-8	Tkmi
13.80 Km -14.65	8-5	Qa
14.65 Km -15.65	5-1.5	Qt
15.65 Km -18.05	1.5-0	Qa
18.05 Km -20.45		Qs

Tqd - Quartz diorite and diorite: Kt - Tabonuco Formation; Khp - Hato Puerco Formation; Qa - Alluvium; Tkmi - Mafic dikes and sheets; Qt-Terrace deposits; Qs - Swamp deposits.

3. .2.1 Quebrada Jimenez ~~[illegible]~~

Geological formation and substrate information for the drainage area of the Quebrada Jiménez ~~Brook~~ are summarized in Table ~~?-III~~ III-5. Of the actual area drained, more than 91% is Hato Puerco Formation. Relatively small zones of Terrace deposits (3.8%), Alluvium (2.3%), Mafic dikes and sheets (2.6%) and Tabonuco Formation (less than 1%) comprise the remaining strata drained by the Quebrada Jiménez tributary.

Riverine substrates begin in the Hato Puerco at the origin (Table III-6). Terrace and Alluvium deposits are interspersed with Hato Puerco formation at relatively high altitudes. Dikes are found at ~~the~~ altitudes of 70 ~~altitudes~~ to 55 m, at ~~5om~~ 50 m, at 19 m and at 18 m with sections of Hato Puerco, Terrace and Alluvium interspersed.

Table III-5. Geologic formation of Quebrada Jiménez Drainage Area

Area	%	Geologic Formation
3.555 Km^2	91.17	Hato Puerco Formation
0.150 Km^2	3.84	Terrace deposits
0.090 Km^2	2.30	Alluvium
0.100 Km^2	2.56	Mafic dikes and sheets
0.005 Km^2	0.13	Tabonuco formation

Table III-~~4~~6. Geologic formation of Jiménez stream-bed

Location	Elevation (m)	Geologic Formation
Origin - 2.80 Km.	880 - 195	Khp
2.80Km - 2.92 Km.	195 - 175	Qt
2.92Km - 3.10 Km.	175 - 160	Khp
3.10Km - 3.58 Km.	160 - 125	Qt
3.58Km - 3.98 Km.	125 - 100	Qa
3.98Km - 4.28 Km.	100 - 95	Khp
4.28Km - 4.49 Km.	95 - 83	Qa
4.49Km - 4.76 Km.	83 - 70	Khp
4.76Km - 4.92 Km.	70 - 55	Tkmi
4.92Km - 5.13 Km.	55 - 50	Khp
5.13Km - 5.33 Km.	50 - 49.5	Tkmi
5.33Km - 6.43 Km.	49.5 - 30	Khp
6.43Km - 6.63 Km.	30 - 21	Qt
6.63Km - 6.71 Km.	21 - 19.5	Khp
6.71Km - 6.96 Km.	19.5 - 19.0	Qa
6.96Km - 7.01 Km.	19.0 - 18.5	Tkmi
7.01Km - 7.53 Km.	18.5 - 18.0	Qa
7.53Km - 7.68 Km.	18.0 - 17.5	Tkmi

Khp - Hato Puerco Formation; Qt - Terrace deposits; Qa - Alluvium
Tkmi - Mafic dikes and sheets.

3.3.2.3. Quebrada Grande ~~Brook~~

Geological formation and substrate information for the watershed area drained by Quebrada Grande ~~Brook~~ are given in Table III-~~8~~7. Of the actual sector drained, nearly 88% is composed of Hato Puerco Formation. Nearly 9% consists of Terrace and Alluvium deposits with minor sectors of Mafic dikes and sheets (3.15%) and Tabonuco formation (.02%).

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 Mafic dike is found at about 40 meters elevation. Thereafter substrate alternates between sections of the exposed Hato Puerco formation and Alluvium deposits. This data ~~is~~ are summarized in Table III-~~6~~8.

Table III-5. Geologic formation of Quebrada Grande Drainage Area

Area	%	Geologic Formation
1.670 Km^2	87.87	Hato Puerco Formation
0.090 Km^2	4.74	Terrace deposits
0.080 Km^2	4.22	Alluvium
0.060 Km^2	3.15	Mafic dikes and sheets
0.005 Km^2	0.02	Tabonuco Formation

Table III-~~6~~?. Geologic formation of Grande stream-bed.

Location	Elevation (m)	Geologic Formation
Origin - 3.60 Km	850-90	Khp
3.60 Km - 3.95 Km	90-70	Qt
3.95 Km - 4.15 Km	70-68	Qa
4.15 Km - 4.40 Km	68-62	Qt
4.40 Km - 4.60 Km	62-50	Qa
4.60 Km - 4.80 Km	50-48	Khp
4.80 Km - 5.21 Km	48-40	Qa
5.21 Km - 5.44 Km	40-38	Tkmi
5.44 Km - 5.59 Km	38-37	Khp
5.59 Km - 5.89 Km	37-35	Qa
5.89 Km - 6.09 Km	35-34.5	Khp
6.09 Km - 6.29 Km	34.5-34	Qa
6.29 Km - 6.39 Km	34-30	Khp
6.39 Km - 6.47 Km	30-26	Qa

Khp - Hato Puerco Formation: Qt - Terrace deposits Qa - Alluvium
Tkmi - Mafic dikes and sheets.

3.3.2.4. Quebrada Sonadora Stream

The highest rising tributary of the Río Espiritu Santo River, with the smallest actual drainage area is the Quebrada Sonadora Stream. Geological formation and substrate information for the watershed sectors drained by Quebrada Sonadora Stream are shown in Table III-~~7~~9. Only 2 formations are exposed in the drainage sector of the Quebrada Sonadora Stream. They are Hato Puerco formation comprising 90% of exposed formations and Tabonuco formation comprising the remainder.

The riverine substrate begins ~~o~~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 III-~~8~~10.

Table III-~~7~~9. Geologic Formation of Quebrada Sonadora Drainage Area

Area	%	Geologic Formation
1.35 Km^2	90	Hato Puerco Formation
0.15 Km^2	10	Tabonuco Formation

Table III-~~8~~10. Geologic Formation of Sonadora Stream-bed.

Location	Elevation (m)	Geologic Formation
Origin - 0.2 Km.	950-930	Tabonuco Formation
0.2 Km - 3.8 Km.	930-175	Hato Puerco Formation

4. Methodology

4.1 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.

A total of 101 sampling stations ~~was~~ were examined (Fig. IV-1). 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. 1.

4.2 Field Methods

4.2.1 Decapod Crustaceans

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, cod fish 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) conversing with persons who frequent some of the areas.

h) a Ponar grab dredge was used for some estuarine benthic organisms.

4.2.2 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 surfac and subsurface hauls were implemented in pools.

c) in the estuary, surface and subsurface tows for 15 minutes at each station.

4.2.3 Benthic annelids and bottom sediments in the estuary

a) Ponar grab dedge which encloses an area of 0.05 m^2 was used.

b) One of the Triplicate samples was preserved for chem and particle size analysis and the other two for benthos.

c) the bottom sediments were collected in a Ponar wash frame (20" x 14" x 4") with a mesh size of 520 microns and benthic organisms sorted using a 3x magni-focuser.

4.2.4 Molluscs

a) wading in freshwater habitats and observing their presence on rock and bottom substrates.

b) observations on mangrove roots, non-living isolated branches and roots of plants and other materials.

c) using a Ponar grab dredge for some benthic mollusc in the estuary.

d) 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.

4.2.5 Algae and Macrophytes

a) Rock and soil substrates were examined

b) attached algae were scraped off and preserved for identification.

4.2. Fish

a) Visual observation

b) communication with local fishermen

c) throw nets

4.2.7 Physicochemical measurements

Fresh water:

a) In situ measurements for dissolved oxygen and temperature were determined with a YSI Dissolved Oxygen Meter, Model 51A 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 collected for chemical analysis.

4.2.6 Sample handling and preservation

All organisms were preserved in either 10% formaldehyde or 70% alcohol except for [illegible] 137 individuals of *Neritina reclivata* which were taken to the laboratory for experiments and observations on shell erosion.

4.3 Laboratory Methods

4.3.1 Identification procedures

4.3.1.1 Decapod Crustaceans

a) Identification keys of Chase and Hobbs (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.

4.3.1.2 Plankton and drifting invertebrates 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.

4.3.1.3 Benthic annelids

a) Identified by Miss Charlene D. Long of Arlington, Massachusetts and Dr. Christer Erseus of the University of Goteborg, Sweden.

4.3.1.6 Algae and Macrophytes

Periphyton

a) Confirmed by Dr. H.C. Duthie Biology department, University of Waterloo, Ontario, Canada.

4.3.1.5 Fish

a) Confirmed by keys of Erdman (1972).

4.3.1.4 Molluscs

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

4.3.3 Estuarine bottom sediment analysis

The method used by Cummins (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 (Table IV-1). The silt and clay, which passed through sieve number 230 were calculated from the original amount of sediment by settling and centrifuging, respectively.

For chemical analysis, sediment samples from 18 stations collected in June 1977 (Fig. IV-2) were sieved to remove sand, ground and further sieved through 170 mesh screening. Further grounding 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 Jarell Ash 1.5 M Wadsworth grating arc-emission spectrograph.

Table IV-1. Suggested terminology, categories, and methods for particle-size analysis. Modified from Cummins (1962) and taken from Hynes (1972).

			Mesh size and methods of measurement			
Name of Particle	Range of Size in mm.	Phi-scale	mm.	Approx. in equivalent	U.S. sieve no.	Tyler sieve no.
Boulder	>256	-8	Direct measurement			
Cobble	64-256	-6-7	Individual wire square			
Pebble	32-64	-5	Individual wire square			
	16-32	-4	16	0.625 (15.9 mm)		
Gravel	8-16	-3	8	0.312 (7.93 mm)		
	4-8	-2	4	0.157	5	5
	2-4	-1	2	0.0787	10	9
Very coarse sand	1-2	0	1	0.0394	18	16
Coarse sand	0.5-1	1	0.5	0.197	35	32
Medium sand	0.25-0.5	2	0.25	0.0098	60	60
Fine sand	0.125-0.25	3	0.125	0.0049	120	115
Very fine sand	0.0625-0.125	4	0.0625	0.0024	230	250
Silt	0.0039-0.0625	5,6,7,8	Separated by settling			
Clay	<0.0039	9	Separated by centrifuge			

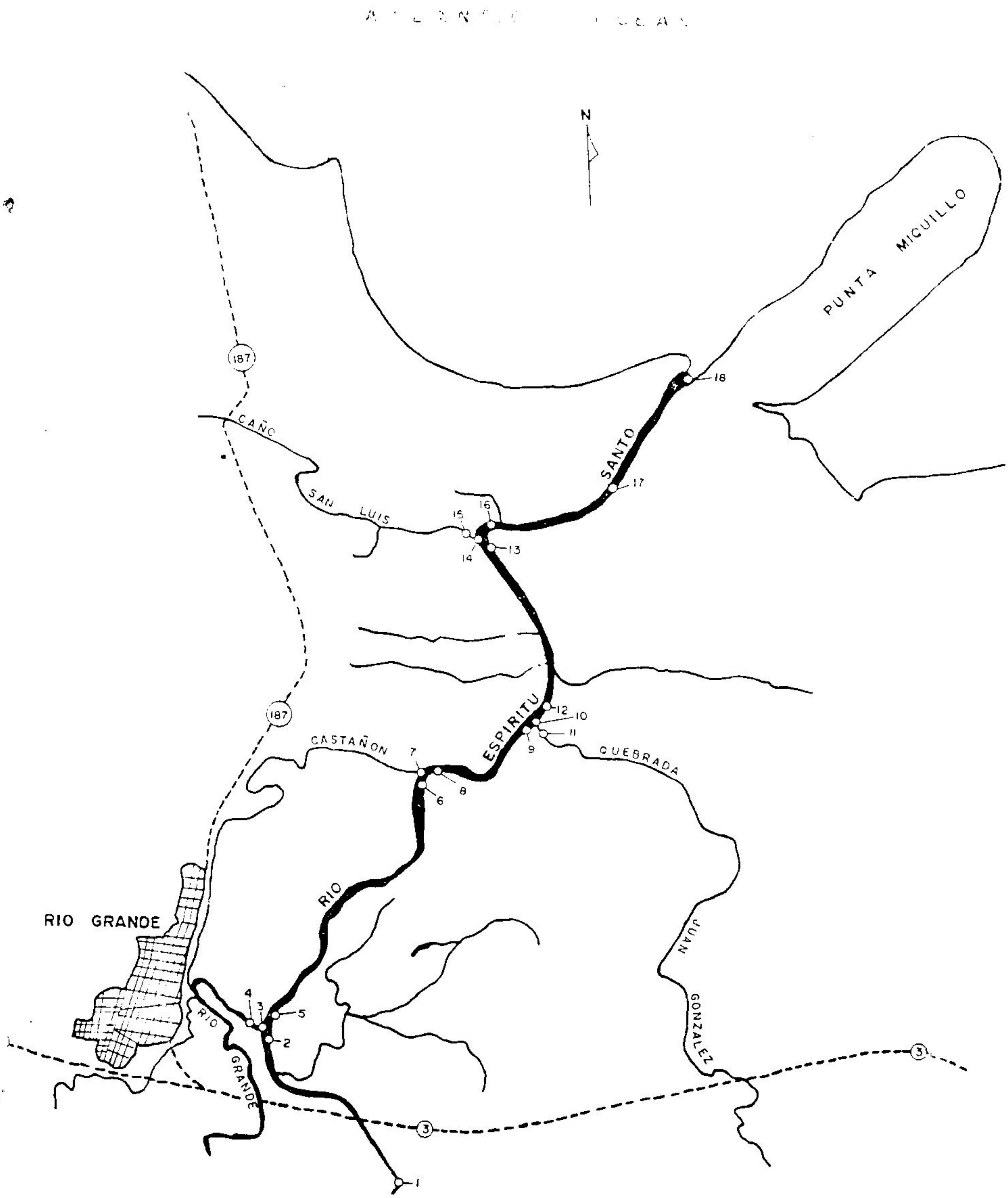


FIGURE 1. RIO ESPIRITU SANTO ESTUARY SHOWING SAMPLING STATIONS

4.3.2. Water-Chemistry

An atomic absorption spectrophotometer, Model 303 was used to obtain Ca and Mg concentrations whereas the standard cadmium reduction method with diazo color development (APHA "Standard Methods for Analysis of Water and Wastewater, 1976) was used to derive the NO_2, NO_3 nitrogen concentrations. Sulfate was analyzed using turbidity measurements of barium precipitated standards in the presence of glycerol (Hach Chemical Co. Ames, IO., 50010).

4.3.2 Shell erosion in *Neritina reclivata*

Fresh shells from which the living animals had been removed were digested with Worthington trypsin 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 flow aquaria system which utilized water from a nearby stream in El Verde.

4.3.5 Bioassay on salinity tolerance of freshwater decapod crustacean larvae.

Laboratory rearing of some decapod crustaceans was started at the Puerto Rico Nuclear Center but had to be discontinued after two months due mainly to the difficulties of fungal infection and temperature. At the El Verde Field Station, a series of constant flow aquaria system was set up. PVC tubes were used to transparent water from a stream nearby. From the main transporting tube, connections of flexible tubes with hose clamps were made to allow water to enter the aquaria (Fig. IV-2). 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 aquaria were placed ~~sand,~~ pebbles and larger stones to simulate stream conditions. Shrimps were collected from the fresh water streams and brought to the laboratory. They were then identified, ~~separated~~ into various aquaria, and fed with detritus, brine shrimps and bits of meat and coconut. 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 aquaria 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 surgical rubber tubing. By means of hypodermic needles air was tapped from this tubing and sent through a connecting tube to a Pasteur pipette which provided 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% sea water and stream water was prepared. Four zoea or larva 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.

This survey ~~[illegible]~~ both of field observations and laboratory studies lasted over a period of two years (January, 1976 - January, 1978). Visits to some of the stations in the upper reaches of the watershed were by necessity limited due to the very steep and dangerous stream gradients. However, other stations were monitored with greater frequency.

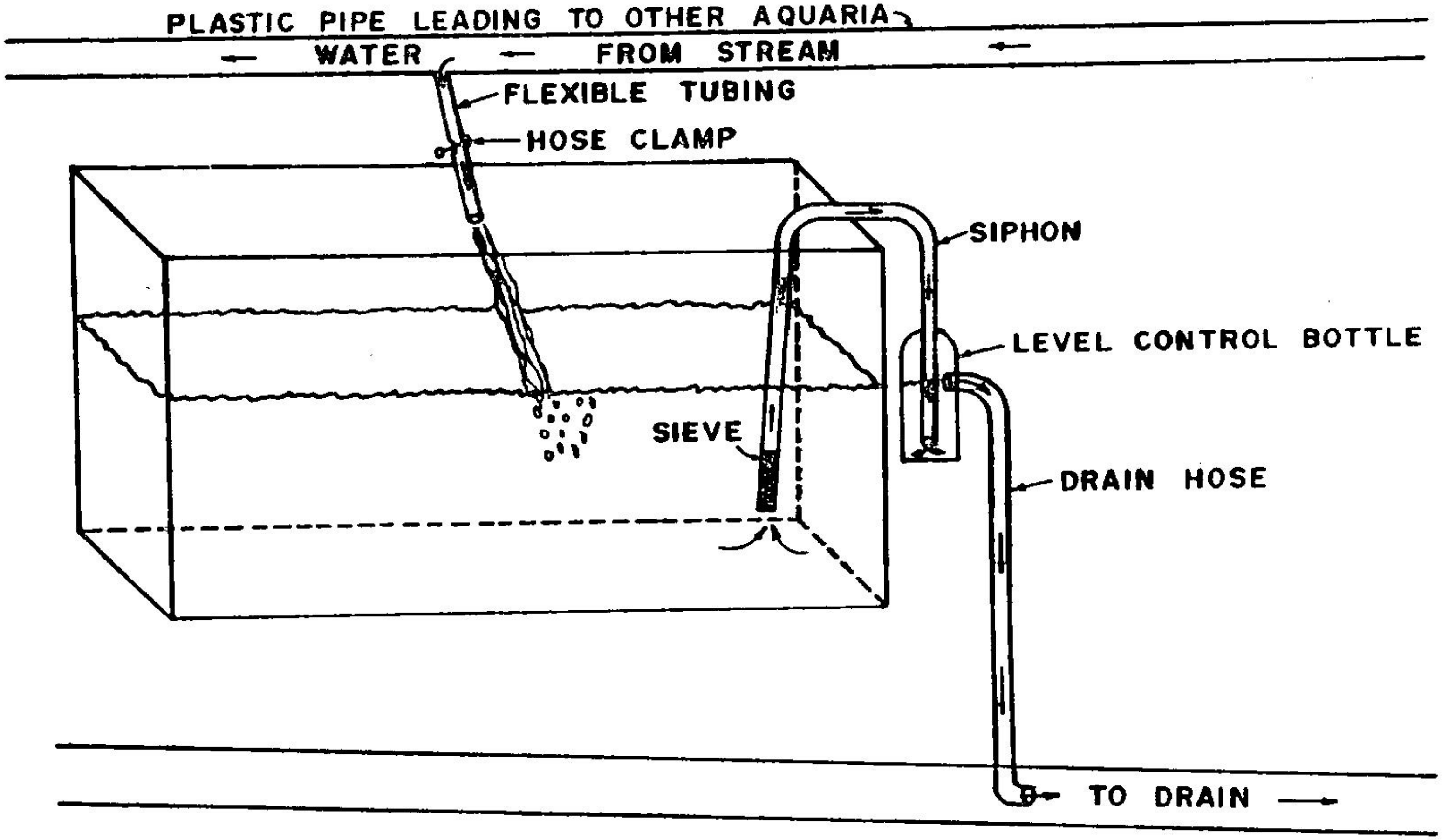


FIGURE 3 . CONSTANT FLOW AQUARIUM SYSTEM FOR SHRIMPS CULTURE

5. Results

The results consist of some selected physico-chemical characteristics including water chemistry; fauna comprising of decapod crustaceans, plankton and drifting ivertebrate larvae, benthic organisms and bottom sediments, mollusc, and fish, and flora consisting of phytoplankton, periphyton and macrophytes.

In addition, laboratory experiments on shell erosion in Neritina reclivata have been examined.

5.1 Field Work

5.1.1 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 schmitti

 Section Caridea
    Crangon sp.

 Section Caridea
  Family Atyideae
   *Atya innocous
   *Atya lanipes
   *Atya scabra
   *Micratya poeyi
   *Xiphocaris elongata

Section Caridea

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. 1

Section Brachyura

Family Pseudothelphusidae

Subfamily Epilobocerinae

*Epilobocera sinuatifrons

Section Brachyura

Family Grapsidae

Subfamily Grapsinae

Goniopsis cruentata
Pachygrapsus gracilis

Section Brachyura

Family Grapsideae

Subfamily Sesarminae

Aratus pisonii
Sesarma ricordi
Sesarma roberti

Section Brachyura
  Family Gecarcinidae
    Cardisoma guanhumi

Section Brachyura
  Family Ocypodidae
    Subfamily Ocypodi~~d~~nae
      Uca leptodactyla
      Uca sp. 1
      Uca sp. 2
      Ucides cordatus

The freshwater species are indicated by asterisks (*). *Macrobrachium acanthurus*, *M. crenulatum* and *M. heterochirus* were not reported previously in the Rio Espiritu Santo freshwater habitats and this is the first study of the common estuarine invertebrates.

Atya lanipes was the dominant species throughout the study area except in the estuary. *Micratya poeyi* was observed only in Quebrada Sonadora (Table V-1) at an elevation of 380M in a shaded pool with weak currents. *A. scabra*, although not reported in the forthcoming tables, was only observed in fast flowing feeder brooks of Quebrada Sonadora. Individuals measuring about 7cm. were collected in March. Of the 10 species of freshwater decapod crustaceans, 9 were observed in *Q. Sonadora* with *M. acanthurus* missing.

In Quebrada Grande (Table V-2) as well as in Quebrada Jiménez (Table V-3), 5 species were observed; *M. crenulatum* was least abundant and not observed were *Atya innocous*, *A. scabra*, *Micratya poeyi*, *Macrobrachium heterochirus* and *M. acanthurus*. In the Rio Espiritu Santo freshwater mainstream (Table V-4), 7 species were observed with *M. crenulatum* the least abundant and *A.* in-

Table [illegible] The biota of Quebrada Sonadora

STATION NUMBER	ELEVATION (M)	POOL OR RIFFLE	PLANKTON		ALGA	CRUSTACEAN										MOLLUSC			FISH							
Quebrada Sonadora			Phytoplankton	Zooplankton	Periphyton	Atya innocous	A. lanipes	A. scabra	Micratya poeyi	Xiphocaris elongata	Macrobrachium carcinus	M. crenulatum	M. heterochirus	M. acanthurus	Epilobocera sinuatifrons	Neritina reclivata	Tarebia granifera	Marisa cornuarietis	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus enciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Belome sp.
East Branch																										
1	945	Shaded Riffle	-	S	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	780	Shaded Riffle	-	C	P	-	A	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	668	Open Pool	-	C	P	-	A	-	-	A	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
4	603	Open Pool	-	C	-	-	C	-	-	C	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
West Branch																										
1	831	Shaded Pool	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	794	Shaded Pool	P	-	P	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
3	677	Open Pool	P	-	P	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	523	Open Pool	P	-	P	-	A	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
5	462	Open Pool	P	-	-	-	A	-	-	C	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Main Stream																										
6	440	Open Riffle	P	S	P	C	A	-	-	A	S	A	-	-	C	-	-	-	C	-	-	-	-	-	-	-
7	380	Shaded Pool	P	C	P	C	A	-	S	A	C	A	S	-	A	-	-	-	A	C	-	-	-	-	-	-
8	295	Shaded Riffle	P	A	-	C	C	-	-	C	C	A	S	-	C	-	-	-	C	S	-	-	-	-	-	-
9	185	Shaded Pool	-	C	-	-	S	-	-	A	S	A	S	-	C	-	S	-	S	S	-	-	-	-	-	-

S equals 1 or 2 specimens; C about 5; A, 10 or more; P, present and - , not observed, in 15 - minute collections.

Table , The biota of Quebrada Grande

STATION NUMBER Quebrada Grande	ELEVATION (M)	POOL OR RIFFLE	PLANKTON		ALGA	CRUSTACEAN										MOLLUSC			FISH							
			Phytoplankton	Zooplankton	Periphyton	Atya innocous	A. lanipes	A. scabra	Micratya poeyi	Xiphocaris elongata	Macrobrachium carcinus	M. crenulatum	M. heterochirus	M. acanthurus	Epilobocera sinuatifrons	Neritina reclivata	Tarebia granifera	Marisa cornuaretis	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus enciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Balome sp.
1	850	Shaded Pool	P	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	700	Open Pool	P	A	-	-	C	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	500	Shaded Pool	P	C	-	-	A	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
4	350	Shaded Pool	P	C	P	-	A	-	-	S	-	-	-	-	-	-	-	-	A	S	-	-	-	-	-	-
5	250	Shaded Riffle	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	150	Open Pool	P	C	P	-	C	-	-	C	S	S	-	-	S	-	-	-	C	S	-	-	-	-	-	-
7	85	Shaded Pool	P	C	P	-	-	-	-	A	S	-	-	-	S	S	-	-	A	S	-	-	-	-	-	-
8	63	Shaded Riffle	-	-	P	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	55	Open Riffle	-	S	P	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	44	Open Pool	P	C	P	-	-	-	-	C	-	-	-	-	C	A	S	-	S	-	-	-	-	-	-	-
11	39	Shaded Pool	P	C	P	-	-	-	-	C	C	S	-	-	C	A	S	-	A	C	-	-	-	-	-	-
12	34.5	Shaded Riffle	-	-	P	-	S	-	-	-	-	-	-	-	-	A	S	-	-	-	-	-	-	-	-	-
13	26	Open Riffle	-	-	P	-	S	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-

S equals 1 or 2 specimens; C, about 5; A, 10 or more; P, present and - , not observed, in 15 - minute collections.

Table [illegible] The biota of Quebrada Jiménez

STATION NUMBER	ELEVATION (M)	POOL OR RIFFLE	PLANKTON		ALGA	CRUSTACEAN										MOLLUSC			FISH							
Quebrada Jiménez			Phytoplankton	Zooplankton	Periphyton	Atya innocous	A. lanipes	A. scabra	Micratya poeyi	Xiphocaris elongata	Mucrobrachium carcinus	M crenulatum	M. heterochirus	M. acanthurus	Epilobocera sinuatifrons	Neritina reclivata	Turbia granifera	Murisa cornuaretis	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus euciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Belome sp.
West Branch West Fork																										
1	800	Shaded Pool	P	S	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	554	Shaded Pool	P	S	P	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	461	Shaded Pool	P	S	P	-	C	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	388	Open Pool	P	C	P	-	S	-	-	C	-	S	-	-	S	-	-	-	-	-	-	-	-	-	-	-
East Fork																										
1	630	Closed Riffle	P	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	523	Shaded Pool	P	S	P	-	-	-	-	A	S	-	-	-	S	-	-	-	S	-	-	-	-	-	-	-
3	431	Open Pool	P	S	P	-	A	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-
4	338	Open Pool	P	S	P	-	A	-	-	S	S	S	-	-	-	-	-	-	S	-	-	-	-	-	-	-
Main West Branch																										
5	280	Open Pool	P	C	P	-	S	-	-	C	S	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
6	225	Shaded Riffle	-	C	P	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	200	Shaded Pool	-	C	P	-	A	-	-	A	S	A	-	-	-	-	-	-	S	-	S	-	-	-	-	-
8	180	Shaded Pool	P	S	P	-	-	-	-	C	-	-	-	-	S	-	-	-	C	-	-	-	-	-	-	-
East Branch West Fork																										
1	585	Open Pool	-	S	P	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	462	Open Pool	P	S	-	-	C	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-

Table V-3 (Continued) - The biota of Quebrada Jiménez

			PLANKTON		ALGA	CRUSTACEAN										MOLLUSC			FISH							
STATION NUMBER Quebrada Jiménez	ELEVATION (M)	POOL OR RIFFLE	Phytoplankton	Zooplankton	Periphyton	Atya innocous	A. lanipes	A. scabra	Micratya poeyi	Xiphocaris elongata	Macrobrachium carcinus	M. crenulatum	M. heterochirus	M. acanthurus	Epilobocera sinuatifrons	Neritina reclivata	Turebia granifera	Marisa cornuarietis	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus enciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Belome sp.
3	431	Open Pool	P	C	P	-	C	-	-	A	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	320	Semi-Open Pool	P	S	P	-	A	-	-	A	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Branch East Fork																										
1	450	Shaded Riffle	P	S	P	-	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
2	400	Shaded Pool	P	S	P	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	320	Shaded Pool	P	S	P	-	A	-	-	-	A	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	295	Shaded Riffle	P	S	P	-	A	-	-	-	-	C	-	-	A	-	-	-	-	-	-	-	-	-	-	-
Main East Branch																										
5	215	Open Pool	P	S	P	-	A	-	-	-	S	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
6	150	Open Riffle	P	S	P	-	A	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Main Stream																										
9	130	Shaded Pool	-	C	P	-	-	-	-	S	S	-	-	-	S	-	-	-	C	-	-	-	-	-	-	-
10	100	Open Riffle	-	C	P	-	S	-	-	-	S	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-
11	96	Open Riffle	-	S	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	90	Open Riffle	-	C	P	-	S	-	-	-	S	-	-	-	-	-	-	-	S	S	-	-	-	-	-	-
13	88	Open Riffle	-	C	P	-	S	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	82	Open Pool	P	A	P	-	S	-	-	A	C	-	-	-	C	-	-	-	C	S	-	-	-	-	-	-
15	76	Open Riffle	-	S	P	-	C	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-
16	74	Open Pool	P	A	P	-	S	-	-	A	-	-	-	-	-	S	-	-	S	S	-	-	-	-	-	-
17	70	Shaded Pool	P	A	P	-	S	-	-	S	S	-	-	-	-	C	S	S	C	A	C	-	-	-	-	-
18	55	Shaded Pool	-	A	P	-	S	-	-	A	S	-	-	-	-	C	S	-	C	C	-	-	-	-	-	-
19	36	Open Pool	P	C	P	-	S	-	-	C	S	-	-	-	-	S	C	-	S	C	-	-	-	-	-	-
20	20	Shaded Riffle	-	C	P	-	-	-	-	S	S	-	-	-	-	A	C	-	S	S	-	-	-	-	-	-

' S equals 1 or 2 specimens; C, about 5; A, 10 or more; P, present and - , not observed, in 15 - minute collections.

Table · The biota of Rio Espiritu Santo

STATION NUMBER	ELEVATION (M)	POOL OR RIFFLE	PLANKTON		ALGA	CRUSTACEAN										MOLLUSC			FISH							
Rio Espiritu Santo			Phytoplankton	Zooplankton	Periphyton	Atya innocous	A. lanipes	A. scabra	Micratya poeyi	Xiphocaris elongata	Macrobrachium carcinus	M. crenulatum	M. heterochirus	M. acanthurus	Epilobocera sinuatifrons	Neritina reclivata	Turbia granifera	Marisa cornuaretis	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus enciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Bulome sp.
1	750	Shaded Riffle	-	-	P	-	S	-	-	S	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
2	730	Shaded Riffle	-	S	P	-	S	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	720	Open Riffle	-	C	P	-	S	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	600	Shaded Pool	-	S	P	-	C	-	-	S	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-
5	550	Open Pool	P	S	P	-	A	-	-	S	-	-	S	-	-	-	-	-	C	-	-	-	-	-	-	-
6	520	Closed Pool	P	S	P	-	A	-	-	C	S	-	S	-	-	-	-	-	C	-	-	-	-	-	-	-
7	450	Open Riffle	P	S	P	-	A	-	-	C	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-
8	400	Open Pool	P	S	P	-	A	-	-	A	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
9	360	Open Pool	P	S	P	-	A	-	-	A	-	-	S	-	-	-	-	-	C	-	-	-	-	-	-	-
10	300	Open Pool	P	S	P	-	C	-	-	A	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
11	200	Open Pool	P	S	P	-	A	-	-	A	S	-	S	-	-	-	-	-	C	-	-	-	-	-	-	-
12	180	Open Pool	P	S	P	-	A	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	150	Open Pool	P	S	P	-	A	-	-	A	S	-	S	-	-	-	-	-	A	-	-	-	-	-	-	-
14	80	Open Riffle	P	C	P	-	A	-	-	C	S	S	-	-	S	-	-	-	S	-	-	-	-	-	-	-
15	70	Shaded Riffle	P	C	P	-	S	-	-	S	-	-	-	-	S	A	-	S	-	-	-	-	-	-	-	-
16	60	Open Pool	P	C	P	-	A	-	-	C	S	-	-	-	S	C	S	A	A	-	-	-	-	-	-	-
17	50	Open Pool	-	-	P	-	S	-	-	S	S	-	-	-	S	C	S	C	A	-	-	-	-	-	-	-
18	43	Open Riffle	-	-	P	-	S	-	-	C	-	-	-	-	-	A	C	S	S	-	-	-	-	-	-	-
19	40.5	Open Riffle	P	-	P	-	S	-	-	S	-	-	-	-	-	A	S	S	-	-	-	-	-	-	-	-
20	36	Open Pool	P	C	P	-	S	-	-	S	C	-	-	-	C	C	-	-	C	-	-	-	-	-	-	-
21	30.5	Shaded Pool	P	A	P	-	S	-	-	S	A	-	-	S	S	A	S	S	C	-	-	-	-	-	-	-
22	27	Open Riffle	-	S	P	-	S	-	-	S	S	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-
23	25	Open Riffle	-	C	P	-	S	-	-	S	-	-	-	-	S	A	A	-	-	-	-	-	-	-	-	-
24	23	Open Pool	P	C	P	-	S	-	-	S	S	-	-	S	C	C	-	S	S	-	-	-	-	-	-	-
25	21	Open Pool	P	C	P	-	S	-	-	S	S	-	-	-	S	S	S	S	S	-	-	-	-	-	-	-
26	18	Open Riffle	-	S	P	-	S	-	-	S	S	-	-	S	S	A	A	-	-	-	-	-	-	-	-	-
27	15	Open Pool	P	A	P	-	S	-	-	S	C	-	-	C	-	C	C	C	C	S	C	S	S	S	S	-

S equals 1 or 2 specimens; C, about 5; A, 10 or more; P, present and - , not observed, in 15 - minute collections.

Table 5-1 Decapod crustaceans of the Rio Espiritu Santo River estuary

STATION NUMBER R. E. S. ESTUARY	DISTANCE FROM ORIGIN (Km)	WIDTH (M)	DEPTH (M)	DECAPOD CRUSTACEANS																				
				Atya lanipes	*Xiphocaris elongata*	*Macrobrachium carcinus*	*M. acanthurus*	*M. faustinum*	*Penaeus schmitti*	*Ucides cordatus*	*Cardisoma guanhumi*	*Aratus pisonii*	*Goniopsis cruentata*	*Uca leptodactyla*	*Uca* sp. 1	*Uca* sp. 2	*Pachygrapsus gracilis*	*Callinectes sapidus*	*Callinectes* sp. 1	*Sesarma ricordi*	*S. roberti*	*Clibanarius cubensis*	*Coenobita clypeatus*	*Crangon* sp.
1	14.30	20	0.25	X	X	X	X				X							X			X			
2	14.90	18	0.60	X	X	X	X				X							X			X			
3	15.30	20	1.80		X		X				X					X		X			X			
4	15.60	14	2.00				X				X				X	X								
5	16.60	24	2.60				X								X	X								
6	16.90	16	3.00				X								X	X								
7	17.40	20	5.00				X								X									
8	18.10	10	4.70				X	X	X	X		X	X		X									
9	QJG	2	0.25				X			X		X	X		X		X		X					
10	18.30	16	4.90				X			X		X	X	X	X		X		X	X			X	
11	18.60	19	6.00				X			X		X	X		X									
12	19.20	20	3.80				X			X		X	X		X									X
13	19.80	24	4.30							X		X	X		X									
14	20.45	10	2.00							X		X	X	X	X					X		X	X	

QJG - Quebrada Juan González; X - present nocous, A. scabra and M. poeyi missing.

Twenty one species were observed in the estuary of which 4 of the aforementioned freshwater crustaceans were restricted to the upper limits of the estuary. Atya lanipes which was found to be dominant in all freshwater habitats was scarce. Similarly, Xiphocaris 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 as compared to M. faustinum which was quite scarce (Table V-1).

The altitudinal distribution of decapod crustaceans was quite conspicuous Fig. V-2). A. lanipes and X. 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 440 M., M. crenulatum 39-440M., M. heterochirus 150-550M. and M. acanthurus 0-30M.

The longitudinal zonation along the estuary Fig V-3) was also quite pronounced. M. acanthurus and Uca sp. 1 showed the widest distribution, whereas M. faustinum, P. schmitti, C. cubensis, and Crangon sp. exhibited limited zonation patterns.

5.1.2 Plankton and drifting invertebrate larvae

Of the 10 orders of plankton observed in the system; 7 were composed of Insecta, 2 of Crustacea, and 1 of Arachnida. Five species were noted within the Order Diptera

Fig. V.

The altitudinal distribution of macro-fauna in the Rio Espiritu Santo freshwater system.

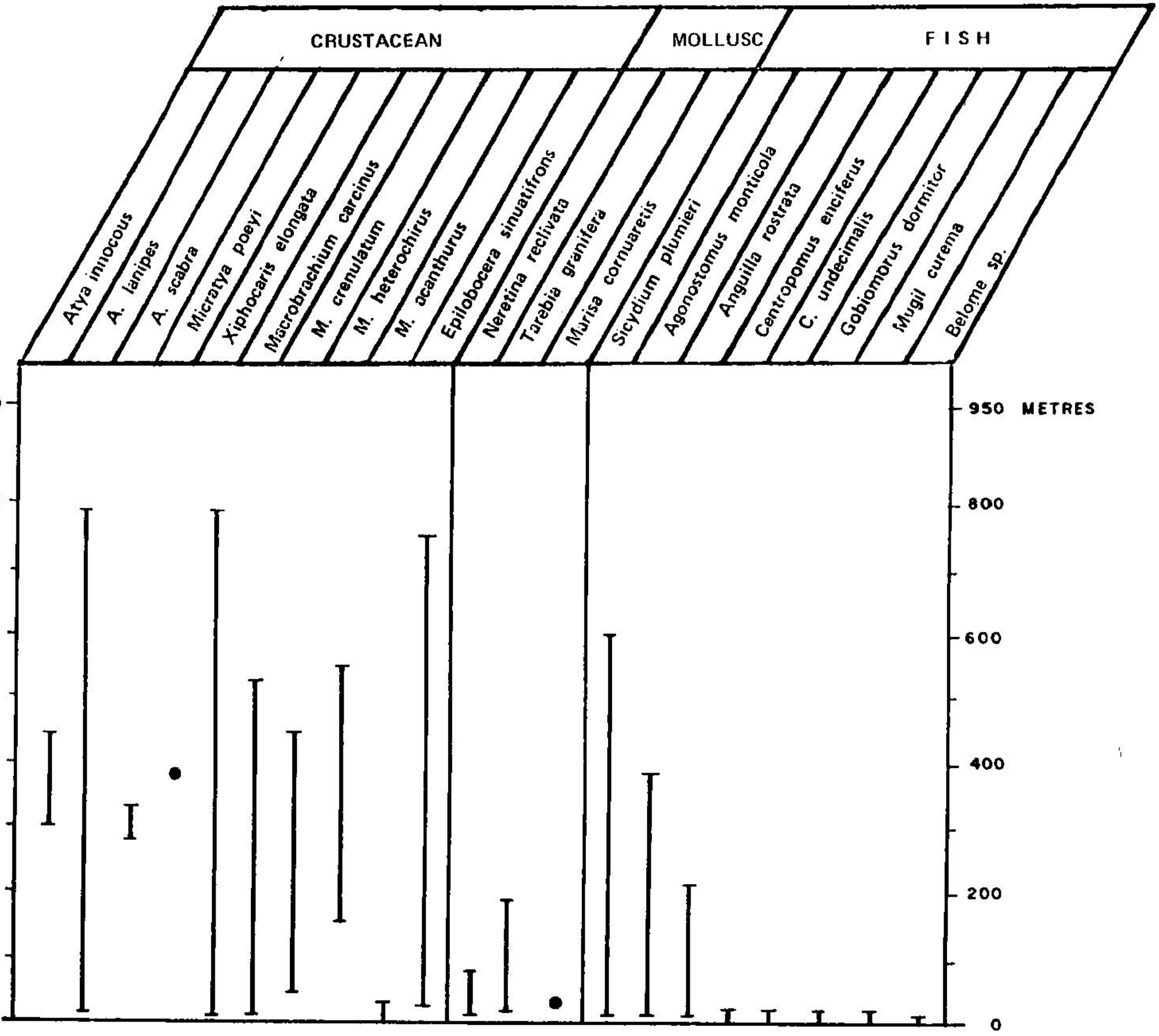
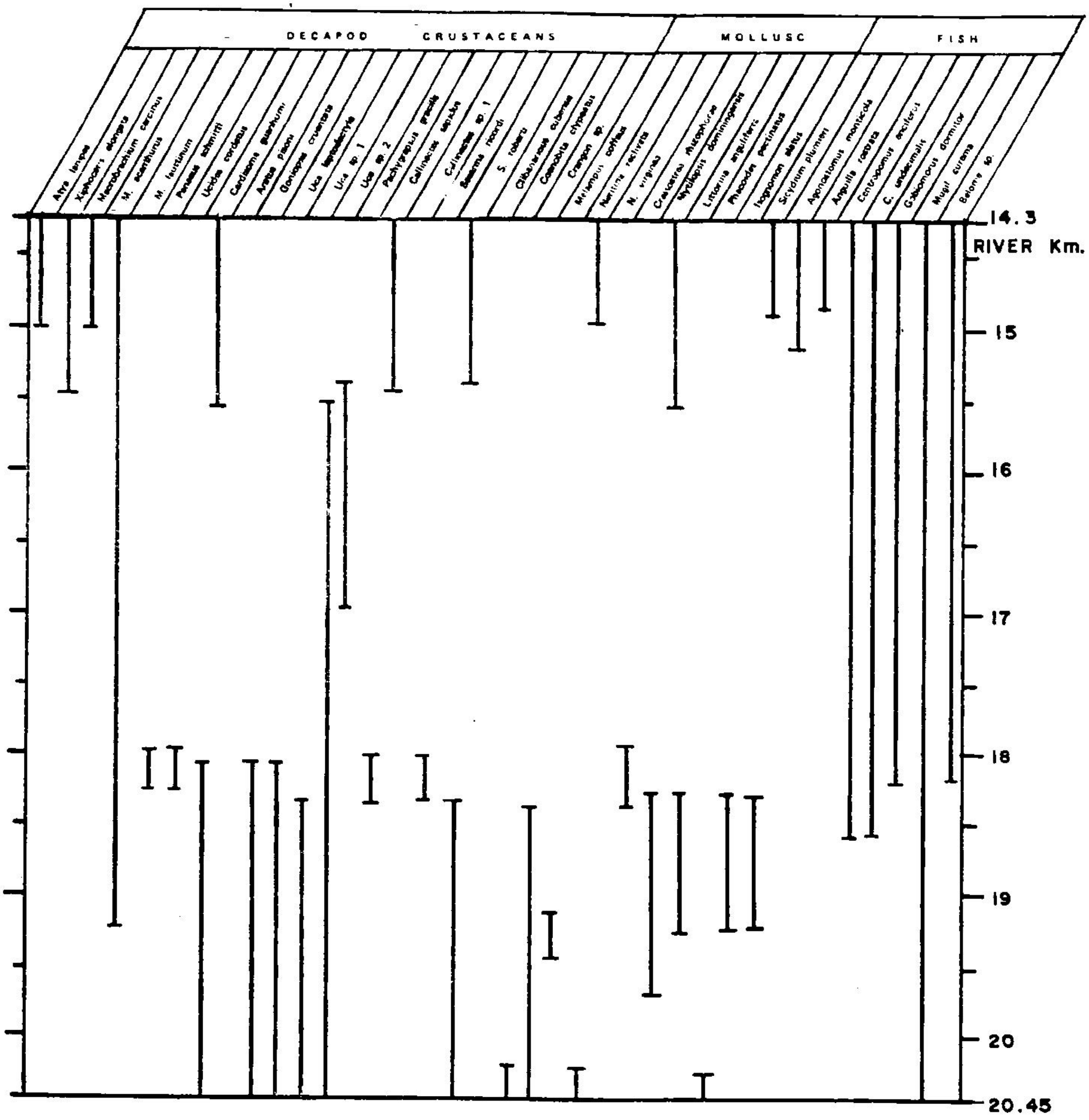


Fig. V-2

.Longitudinal zonation of macro-fauna along the length of the Rio Espiritu Santo estuary (14.3 river Km.- upper limit: 20.45 river Km.- mouth).



and 2 for Arachnida.

In the Rio Espiritu Santo main freshwater stream (Table V-
8 orders were observed, Q. Jiménez 6, Q. Sonadora 6, Q. Grande 4 and the estuary 8. In Q. Jiménez (Table V-8) and Q. Sonadora (Table V- the same number of orders and species was observed but it was noted that the following were not observed: Hydracarina^2, Hemiptera, Coleoptera, Amphipoda and Decapoda. In Quebrada Grande (Table V-7) in addition to these, there were also missing Diptera^2, Diptera^5, Ephemeroptera and Plecoptera. Not observed in the estuary were Diptera^5, Trichoptera, Hydracarina^2 and Plecoptera. However, the appearance of Hemiptera, Amphipoda was observed with a marked increase of decapod crustacean larvae in the estuary (Table V-10).

The average number of individuals observed in a 15-minute collection per sampling station was estuary 14, Q. Sonadora7, 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 3-month survey and were grouped into 11 species in 9 families as follows:

5.17(a)

Thar~~c~~yx 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 station. ~~Tharyx sp. and~~

Table V-6 Distribution of drifting invertebrate larvae in Quebrada Sonadora

Quebrada Sonadora STATION NUMBER	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE														
		DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
East Branch																
1	945	2	1	2	1	-	1	-	1	-	-	-	-	-	-	-
2	780	1	1	2	-	-	-	-	1	-	1	-	-	-	-	-
3	668	3	4	-	-	-	3	-	-	-	-	-	-	-	-	-
4	603	2	-	1	1	-	1	-	2	-	-	-	-	-	-	-
West Branch																
1	831	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	794	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-
3	677	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
4	523	1	-	2	-	3	5	-	1	-	5	-	-	-	-	-
5	462	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Main Stream																
6	440	1	-	-	-	3	-	-	-	-	2	-	-	-	-	-
7	380	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-
8	295	2	1	-	2	-	-	4	-	-	-	-	-	-	-	-
9	185	4	2	-	1	-	-	1	5	-	-	-	-	-	-	-

Table 7. Distribution of drifting invertebrate larvae in Quebrada Grande

STATION NUMBER Quebrada Grande	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE														
		DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
1	850	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
2	700	1	-	-	-	-	4	-	-	-	1	-	-	-	-	-
3	500	-	-	3	-	-	1	-	3	-	-	-	-	-	-	-
4	350	-	-	1	-	-	3	-	2	-	1	-	-	-	-	-
5	250	2	-	-	6	-	7	-	-	-	1	-	-	-	-	-
6	150	4	-	-	2	-	3	-	-	-	1	-	-	-	-	-
7	85	1	-	-	1	-	2	-	-	-	3	-	-	-	-	-
8	63	3	-	-	7	-	6	-	-	-	1	-	-	-	-	-
9	55	2	-	-	1	-	2	-	-	-	-	-	-	-	-	-
10	44	1	-	-	1	-	1	-	-	-	4	-	-	-	-	-
11	39	7	-	-	3	-	-	-	-	-	-	-	-	-	-	-
12	34.5	4	-	-	5	-	-	-	-	-	1	-	-	-	-	-
13	26	1	-	-	8	-	-	-	-	-	2	-	-	-	-	-

TAXON	#OF INDIVIDUALS	%OF TOTAL
Family Cirratulidae		
Tharyx sp.	377	68
Family Capitellidae		
Species 1	102	19
Family Pilargiidae		
Sigambra tentaculata (Treadwell, 1941)	43	8
Family Nereidae		
Stenoninereis martini	7	-
Family Paraonidae		
Aedicira belgica (Fauvel, 1936)	5	-
Family Capitellidae		
Species 2	5	-
Family Glyceridae		
Glycera tesselata (Grube 1863)	3	-
Family Capitellidae		
Species 3	1	-
Family Eunicidae		
Marphysa sp.	1	-
Family Phyllodocidae		
Species 1	1	-
Family Terebellidae		
Species 1	1	-
	546	

Table V-8. Distribution of drifting invertebrate larvae in Quebrada Jiménez

STATION NUMBER Quebrada Jiménez	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
West Branch West Fork																
1	0.20	1	-	-	-	-	-	-	1	-	2	-	-	-	-	-
2	1.00	2	1	-	-	-	2	-	1	-	-	-	-	-	-	-
3	1.40	2	-	1	-	-	2	-	-	-	2	-	-	-	-	-
4	1.60	1	-	2	2	-	-	1	1	-	3	-	-	-	-	-
East Fork																
1	0.20	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-
2	0.80	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-
3	1.10	-	-	-	-	-	-	3	-	-	3	-	-	-	-	-
4	1.60	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Main West Branch																
5	2.20	1	-	-	-	-	-	-	2	-	1	-	-	-	-	-
6	2.25	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
7	2.65	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-
8	2.72	1	-	-	-	-	-	-	2	-	1	-	-	-	-	-

Table V. 8.(Continued) - Distribution of drifting invertebrate larvae in Quebrada Jiménez

Quebrada Jiménez STATION NUMBER	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE														
		DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
East Branch West Fork																
1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.45	1	-	-	-	2	-	-	1	-	-	-	-	-	-	-
3	0.60	2	-	2	-	3	-	-	-	-	1	-	-	-	-	-
4	1.00	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
East Branch East Fork																
1	0	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-
2	0.10	-	-	-	-	3	3	-	-	-	2	-	-	-	-	-
3	0.60	3	-	-	-	-	-	-	-	-	5	-	-	-	-	-
4	0.90	5	-	-	-	2	-	-	-	-	-	3	-	-	-	-
Main East Branch																
5	1.40	-	-	6	-	-	12	-	-	-	-	-	-	-	-	-
6	1.95	-	-	-	-	3	3	-	1	-	-	-	-	-	-	-

Table V. 8. (Continued) - Distribution of drifting invertebrate larvae in Quebrada Jiménez

STATION NUMBER	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE														
Quebrada Jiménez		DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
Main Stream																
9	3.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	3.86	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-
11	3.90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	4.10	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
13	4.20	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
14	4.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	4.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	4.53	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
17	4.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	4.82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	5.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	7.58	1	-	-	1	-	1	-	1	-	-	-	-	-	-	-

Table V-9 Distribution of drifting invertebrate larvae in the Rio Espiritu Santo River

STATION NUMBER R E S River	ELEVATION (M)	DRIFTING INVERTEBRATE LARVAE DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
1	750	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	730	6	-	-	-	-	-	-	-	-	2	-	-	-	-	-
3	720	2	3	-	-	-	1	-	1	-	9	-	-	-	-	-
4	600	7	3	-	-	-	-	-	3	-	17	-	-	-	-	-
5	550	5	-	-	-	-	2	1	-	-	-	-	-	-	-	-
6	520	8	-	1	-	-	-	-	-	-	1	-	-	-	-	-
7	450	3	1	-	-	-	2	-	1	-	-	-	-	-	-	-
8	400	-	-	3	1	-	-	1	3	-	-	-	-	-	-	-
9	360	1	-	1	-	-	5	-	1	-	2	-	-	-	-	-
10	300	3	2	-	2	-	1	-	-	-	1	-	-	-	-	-
11	200	9	-	2	3	-	6	-	-	-	-	-	-	-	-	-
12	180	13	1	-	1	-	3	-	-	-	-	-	-	-	-	-
13	150	5	3	-	1	-	6	-	-	-	2	-	-	-	-	-
14	80	-	2	3	2	-	3	3	1	-	2	1	-	-	-	-
15	70	-	2	3	-	-	3	3	1	-	2	-	-	-	-	-
16	60	-	-	3	2	-	-	3	1	-	2	1	-	-	-	-
17	50	-	2	-	2	-	-	3	1	-	-	-	-	-	-	-
18	43	-	2	3	2	-	3	3	1	-	2	1	-	-	-	-
19	40.5	3	-	1	-	1	-	-	-	-	2	-	-	-	-	-
20	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	30.5	1	-	2	-	-	-	1	-	-	-	3	-	-	-	-
22	27	13	-	6	-	32	3	-	-	-	6	12	-	-	-	-
23	25	6	-	10	21	-	6	-	-	-	3	5	-	-	-	-
24	23	1	-	-	11	-	1	-	1	-	-	2	-	-	-	-
25	21	6	3	15	57	-	20	-	6	-	10	12	-	-	-	-
26	18	16	1	-	20	-	4	-	2	2	11	-	-	1	-	4
27	15	-	-	2	5	-	2	-	7	2	2	-	-	-	-	1

Table 7-10 Distribution of drifting invertebrate larvae in the Rio Espiritu Santo River estuary

		DRIFTING INVERTEBRATE LARVAE														
R E S Estuary STATION NUMBER	ELEVATION (M)	DIPTERA 1	DIPTERA 2	DIPTERA 3	DIPTERA 4	DIPTERA 5	TRICHOPTERA	EPHEMEROPTERA	HYDRACARINA 1	HYDRACARINA 2	ODONATA	PLECOPTERA	HEMIPTERA	COLEOPTERA	AMPHIPODA	DECAPODA
1	5.4	2	-	-	3	-	-	2	1	-	6	-	-	-	-	3
2	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3		2	-	7	8	-	-	-	-	-	-	-	-	2	-	-
4		-	-	6	1	-	-	-	-	-	-	-	-	-	2	9
5		1	-	1	-	-	-	-	-	-	-	-	-	-	-	9
6		-	2	-	1	-	-	-	1	-	-	-	-	-	-	3
7		3	2	1	1	-	-	-	-	-	-	-	-	-	-	7
8		-	2	1	5	-	-	-	-	-	-	-	1	-	-	82
9		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
11		-	-	1	-	-	-	-	2	-	-	-	-	-	-	7
12		-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
13		-	-	2	-	-	-	-	-	-	-	-	-	-	-	5
14	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4

Sigambra tentaculata were found from the sewage outfall 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 species had a pattern of delimited distribution by station~~. Tharyx sp. and Sigambra tentaculata were found from the sewage outfall (Station #7) to the Atlantic Ocean. Stenoninereis martini 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 V-11).

5.1.4 Mollusc

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

Class Gastropoda
  Subclass Streptoneura
    Order Prosobranchiata
      Family Neritidae
        Neritina reclivata
        Neritina virginea
      Family Littorinidae
        Littorina angulifera

Mollusc

Class - Gastropoda

Sub-class - Pulmonata

Order - Basommatophora

Sub-order - Actophila

Family - Ellobiidae

Melampus coffeus

Sub-class - Prosobranchiata

Order - Archaeogastropoda

Family - Neritidae

Neritina reclivata

Neritina virginea

Order - Neogastropoda

Family - Littorinidae

Littorina angulifera

Family - Thiaridae

Tarebia granifera

Family - Pilidae

Marisa cornuarietis

Class - Pelecypoda

Order - Filibranchia

Family - Ostreidae

Crassostrea rhizophorae

Family - Dreissenidae

Mytilopsis dominingensis

Family - Lucinidae

Phacoides pectinatus

11

MONTHLY AVERAGE PARTICLE SIZE ANALYSIS OF SUBSTRATE

(FEB. 1977 - JAN. 1978) EXPRESSED IN %

IN THE RIO ESPIRITU SANTO ESTUARY

STATION NO.	DEPTH (M)	GRAVEL	VERY COARSE SAND	COARSE SAND	MEDIUM SAND	FINE SAND	VERY FINE SAND	SILT	CLAY
1	1.6	30	35	10	5	8	6	3	3
2	1.7	20	28	20	11	12	5	2	2
3	2.2	15	15	10	30	15	12	1	2
4	1.8	25	25	5	10	5	20	4	6
5	3.2	15	12	10	15	13	15	9	11
6	4.2	25	10	5	5	35	10	5	5
7	2.7	10	5	10	10	30	20	5	10
8	6.3	2	3	5	5	20	20	7	38
9	4.2	5	2	1	2	30	40	5	15
10	3.3	10	15	6	18	6	30	4	11
11	1.7	10	5	3	15	22	15	8	22
12	4.7	3	15	7	15	15	20	5	20
13	4.8	2	2	5	25	35	11	3	17
14	3.7	1	5	4	12	20	18	5	35
15	1.6	1	3	5	6	15	20	10	40
16	4.1	3	3	7	5	7	15	15	45
17	4.6	2	6	10	12	8	12	10	40
18	1.7	2	4	6	10	30	30	9	9

62

Neritina reclivata was dominant in both freshwater and upper estuarine habitats. It was not found above an elevation of 85 M. and except for Q. Sonadora with an altitudinal range of 180 M - 945 M, it was found elsewhere. .. rather interesting observation on shell erosion has been noted for this species.

The scarcity of M. cornuaretis was quite marked and it was noted only in a shaded pool (station No. 17) in Q. Jimenez. T. granifera was found to be abundant in the freshwater habitat especially in shaded riffles.

A fascinating array of life is supported by the tangle of arching roots and branches of the red mangrove, Rhizophora mangle. Mollusc such as Neritina virginea, C. rhizophorae, and I. alatus were fairly abundant. M. coffeus and L. aguilifera were restricted to the mouth of the estuary.

5.1.5 Flora

In the freshwater habitats, the periphyton consisted mainly of mosses, ferns and Oscillatoria sp. Diatoms attached to mosses were composed of Navicula sp., Pinnularia sp., Nitzschia sp. and Fragilaria sp. Macrophytes were mainly composed of the water hyacinth Eichhornia crassipes and Elodea sp.

5.1.6 Fishes

Eight species of fishes were common in the Rio Espiritu Santo System:

Order Anguilliformes
 Family Anguillidae
  Anguilla rostrata

Order Beloniformes
 Family Belonidae
  Belome sp.

Order Mugiformes
 Family Mugilidae
  Agonostomus monticola
  Mugil curema

Order Perciformes
 Family Eleotridae
  Gobiomorus dormitor

Order Perciformes
 Family Gobiidae
  Sicydium plumieri

Order Perciformes
 Family Centropo~~n~~midae
  Centropomus enciferus
  Centropomus undecimalis

S. 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 *Belome* 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 whereas the others were restricted to the upper three quarters of the estuary (Table V-12).

Table V-13 Mollusc and fish of the Rio Espiritu Santo River estuary

STATION NUMBER R. E. S. ESTUARY	DISTANCE FROM ORIGIN (Km)	WIDTH (M)	DEPTH (M)	MOLLUSC								FISH							
				Melampus coffeus	Neritina reclivata	N. virginea	Crassostrea rhizophorae	Mytilopsis domininingensis	Littorina anguliferra	Phacoides pectinatus	Isognomon alatus	Sicydium plumieri	Agonostomus monticola	Anguilla rostrata	Centropomus anciferus	C. undecimalis	Gobiomorus dormitor	Mugil curema	Belome sp.
1	14.30	20	0.25		X			X				X	X				X	X	X
2	14.90	18	0.60		X			X				X	X	X	X	X	X	X	X
3	15.30	20	1.80					X					X		X	X	X	X	X
4	15.60	14	2.00					X							X	X		X	X
5	16.60	24	2.60												X	X		X	X
6	16.90	16	3.00												X	X		X	X
7	17.40	20	5.00												X	X		X	X
8	18.10	10	4.70			X									X	X	X	X	X
9	QJG	2	0.25			X	X	X		X	X				X	X	X		X
10	18.30	16	4.90					X							X	X		X	
11	18.60	19	6.00					X							X	X		X	
12	19.20	20	3.80				X	X		X	X							X	
13	19.80	24	4.30				X											X	
14	20.45	10	2.00	X					X									X	

QJG - Quebrada Juan González; X - present

5.1.7 Physicochemical data

In situ measurements of pH and temperature clearly indicated a general tendency to increase downstream, the exception being Q. Jimenez which showed a negligible decrease. The general picture for dissolved oxygen was one of gradual decrease downstream. Again, ~~Q. Jimenez which showed a negligible decrease. The general picture for dissolved oxygen was one of gradual decrease downstream~~. Again, Q. Jiménez displayed some variation, that is, there was a slight increase to 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 4.35 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 Q. Juan González, 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 extend-

The Quebrada Jiménez tributary was also surveyed with respect to Ca and Mg concentrations. The results are shown in Table V-21. With the exception of station No. 9 values of Ca and Mg concentration 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.

5.2.5 Estuary

Some 10 estuarine stations were surveyed to determine the NO_2^- + NO_3^- nitrogen and sulfate loads. The results for sampling period of low flow conditions are given in Table V-23.

These measurements tend to conform with 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).

Table . Summary of the Results (mg/l) 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	5.62± 0.06	0.30±0.00	1.04±0.01	2.08±0.04	15.75± 0.96
Grassland	8.18± 0.22	0.39±0.00	1.88±0.07	4.20±0.20	21.07± 1.36
Upper Estuary	88.14±23.03	3.29±0.84	2.34±0.23	14.86±3.33	34.27±97.83

CONCENTRATIONS OF CALCIUM AND MAGNESIUM
IN QUEBRADA SONADORA (mg/l)

Sta. No.	Ca	Mg
East Branch		
1	0.65	1.13
4	0.78	1.11
West Branch		
2	0.80	1.09
5	0.98	1.57
Main Stream		
6	1.04	1.61
8	1.06	1.54
9	0.74	1.13

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

5.4 1 Shell erosion in N. reclivata

Neritina 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 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 muco-scleroprotein secreted by the snail and contains a small amount of mucopolysaccharides (Wada, 1966). Digestion of the fresh shell with trypsin and papain or detergents did little to dissolve or lyse the conciolin layer, th~~r~~ough it was soluble in chlorine bleach. The layer at the shell apex tended to be dissolved away sooner than the rest of the shell. Prolonged rinsing of the apex amending shell revealed no further shell damage.

In general, smaller snails were undamaged or less damaged than larger, older snails and erosion of shells of younger snails was confined to the shell apex. A typical temporal sequence of the shell erosion is shown in

TABLE V-2

Chemistry of PES estuarine sediments

Stations with Sediment

		Concentration		
Element	BDL	10 ppm	10-100 ppm	100 ppm
Ag		1-9, 11, 16-18	10, 12-15	
B	4-9, 18	1-3, 11, 16. 17	10, 12-15	
Be	4-9	1-3, 11, 16-18	10, 12-15	
Bi	1-9	11	10, 12-18	
Cd	1-9, 11, 18	12-15	10	
Cr	11, 16-18		3, 4, 10-15	1, 2, 5-9
Ga	1, 2, 8, 9, 11, 15-18	3-7, 10, 12-14		
Ni	17, 18	1, 3, 5, 8, 9,	2, 4, 6, 7, 15, 16	10-14
P	1-9, 15-18	10-14		
Pb	17, 18	1-4, 15, 16	5-14	
Sr			1-9, 11	10, 12-18
Te	11, 18	1-9, 16, 17	10, 12-15	
Tl	1-5, 11, 14-18	6-10, 12, 13		
V	11, 18			1-9, 10, 12-17

TABLE V-2

Chemistry of PES marine sediments

Stations with Sediment

		Concentration		
lement	BDL	10 ppm	10-100 ppm	100 ppm
Ag		1-9, 11, 16-18	10, 12-15	
B	4-9, 18	1-3, 11, 16. 17	10, 12-15	
Be	4-9	1-3, 11, 16-18	10, 12-15	
Bi	1-9	11	10, 12-18	
Cd	1-9, 11, 18	12-15	10	
Cr	11, 16-18		3, 4, 10-15	1, 2, 5-9
Ga	1, 2, 8, 9, 11, 15-18	3-7, 10, 12-14		
Ni	17, 18	1, 3, 5, 8, 9,	2, 4, 6, 7, 15, 16	10-14
P	1-9, 15-18	10-14		
Pb	17, 18	1-4, 15, 16	5-14	
Sr			1-9, 11	10, 12-18
Te	11, 18	1-9, 16, 17	10, 12-15	
Tl	1-5, 11, 14-18	6-10, 12, 13		
V	11, 18			1-9, 10, 12-17

5.4 LABORATORY EXPERIMENTS

5.4 1 Shell erosion in *N. reclivata*

Neritina 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 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 muco-scleroprotein secreted by the snail and contains a small amount of mucopolysaccharides (Wada, 1966). Digestion of the fresh shell with trypsin and papain or detergents did little to dissolve or lyse the conciolin layer, th~~r~~ough it was soluble in chlorine bleach. The layer at the shell apex tended to be dissolved away sooner than the rest of the shell. Prolonged rinsing of the apex amending shell revealed no further shell damage.

In general, smaller snails were undamaged or less damaged than larger, older snails and erosion of shells of younger snails was confined to the shell apex. A typical temporal sequence of the shell erosion is shown in [illegible] .3. The specimens on the extreme left show no visible erosion. The pair of shells, second from the left show incipient apex erosion, more pronounced in the bottom specimen, the pair second from the right are typical of badly eroded shells showing exposed layers of calcite and aragonite with conchiolin layer 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 lacking 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.

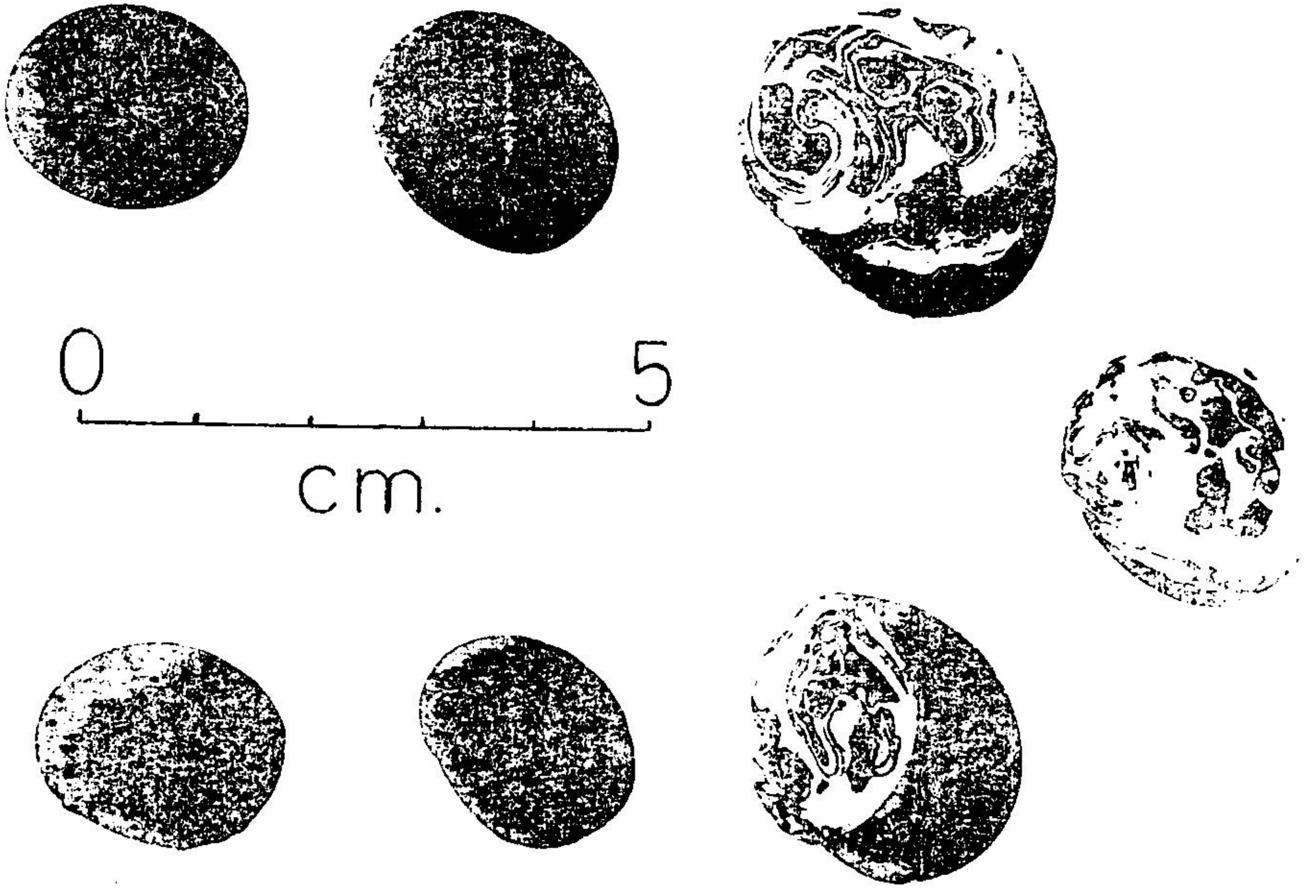


Fig. V-3. Photograph of typical temporal sequence of shell erosion in *Neritina reclivata*.

5.4.2 Bioassay on salinity tolerance of Freshwater Decapod Crustacean Larvae

M. acanthurus zoea 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. innocous* survived between 25% sea water and sea water during the experiment of 96 hours.

M. crenulatum 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 survival rate fluctuated between 10% sea water and sea water, with 50% to 60% sea water showing 100% survival.

X. elongata zoea did poorly in freshwater, 10% sea water and sea water, One hundred percent survival was observed between 50% and 80% sea water.

Table . Salinity tolerance bioassay of some decapod crustacean larvae.
F.W. = stream water. S.W. sea water.

	24 hours			48 hours			72 hours			96 hours		
				Atya lanipes (Zoea III, IV)								
% Sea Water	Rep.1	Rep.2	Rep.3	Rep.1	Rep.2	Rep.3	Rep.1	Rep.2	Rep.3	Rep.1	Rep.2	Rep.3
F.W.	4	0	1	2	0	0	2	0	0	2	0	0
10%	3	3	4	3	3	4	3	3	3	3	3	3
15%	3	3	4	2	2	2	2	2	1	2	2	1
25%	4	4	4	3	4	4	3	4	3	3	4	3
50%	4	4	4	4	4	4	4	3	4	4	3	4
60%	4	4	4	3	4	4	3	4	3	3	4	3
70%	4	4	4	4	4	4	4	4	3	4	4	3
80%	4	4	4	4	2	4	4	2	4	4	2	4
90%	4	4	4	4	4	4	4	4	4	4	4	4
S.W.	4	4	4	4	4	4	4	4	4	4	4	4
				Atya innocous (Zoea II)								
% Sea Water												
F.W.	4	3	4	3	3	3	3	3	3	3	3	3
10%	4	4	4	4	4	4	4	4	4	4	4	4
15%	4	4	4	4	4	4	4	4	4	4	4	0
25%	4	4	4	4	4	4	4	4	4	4	4	4
50%	4	4	4	4	4	4	4	4	4	4	4	4
60%	4	4	4	4	4	4	4	4	4	4	4	4
70%	4	4	4	4	4	4	4	4	4	4	4	4
80%	4	4	4	4	4	4	4	4	4	4	4	4
90%	4	4	4	4	4	4	4	4	4	4	4	4
S.W.	4	4	4	4	4	4	4	4	4	4	4	4
				Macrobrachium crenulatum (Zoea II)								
% Sea Water												
F.W.	3	3	4	0	0	0	0	0	0	0	0	0
10%	4	4	4	0	0	0	0	0	0	0	0	0
15%	4	3	4	2	1	2	2	0	2	2	0	2
25%	4	4	4	4	3	4	4	3	3	4	3	2
50%	4	4	4	4	3	4	4	3	4	4	3	4
60%	4	4	4	4	4	4	3	3	3	2	3	2
70%	4	4	4	4	4	4	2	3	3	1	1	1
80%	4	4	4	4	4	4	0	2	2	0	1	1
90%	4	4	4	4	3	2	3	2	1	0	1	1
S.W.	3	4	4	3	4	4	1	3	3	0	0	0
				Macrobrachium acanthurus (Zoea)								
% Sea Water												
F.W.	0	0	0	0	0	0	0	0	0	0	0	0
10%	4	3	4	3	2	4	3	2	4	3	2	4
15%	3	4	4	3	4	4	3	4	4	3	4	4
25%	4	3	4	4	3	4	4	3	4	4	3	4
50%	4	4	4	4	4	4	4	4	4	4	4	4
60%	4	4	4	4	4	4	4	4	4	4	4	4
70%	4	4	4	4	4	4	4	4	4	4	4	4
80%	4	4	3	4	4	3	4	4	3	4	4	3
90%	3	4	4	2	4	4	2	4	4	2	4	4
S.W.	4	4	4	4	4	4	4	4	4	4	4	4
				Macrobrachium heterochirus (Zoea)								
% Sea Water												
F.W.	4	4	4	3	1	4	0	0	0	0	0	0
10%	4	4	4	4	4	4	4	4	4	3	4	3
15%	4	4	4	4	4	4	4	4	4	3	2	3
25%	4	4	4	4	4	4	4	4	4	4	4	3
50%	4	4	4	4	4	4	4	4	4	4	4	4
60%	4	4	4	4	4	4	4	4	4	4	4	4
70%	4	4	4	4	4	4	4	4	4	3	4	4
80%	4	4	4	4	4	4	4	4	4	3	4	3
90%	4	4	4	4	4	4	4	4	4	2	1	2
S.W.	4	4	4	4	4	4	4	4	4	0	0	0
				Xiphocaris elongata (Zoea)								
% Sea Water												
F.W.	4	4	3	3	3	1	2	0	0	1	0	0
10%	3	4	1	2	2	0	1	0	0	0	0	0
15%	3	2	0	3	2	0	3	2	0	3	2	0
25%	4	4	3	4	4	3	3	3	2	3	3	2
50%	4	4	4	4	4	4	4	4	4	4	4	4
60%	4	4	4	4	4	4	4	4	4	4	4	4
70%	4	4	4	4	4	4	4	4	4	4	4	4
80%	4	4	4	4	4	4	4	4	4	4	4	4
90%	4	4	3	4	3	3	3	3	3	3	2	1
S.W.	1	0	0	0	0	0	0	0	0	0	0	0

Decapod Crustaceans

In this study Twenty seven species of decapod crustacean were identified in the Rio Espiritu Santo system ~~inclusive~~ ~~of~~ the estuary.

Gifford and Cole (1971), 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 riffles. ~~They~~ showed a preference for slow flowing streams. Chace and Hobbs (1969) claimed that the animal showed 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 fresh water regions. It seems to be at home in mountainous and cascading streams, upland pools and in waters of lowlands. In our study, contrary to Gifford and Cole (1971), the species was observed at Q. Sonadora, common in riffles and at an altitudinal range of 295-440 meters.

A. innocous exhibited the peculiar trait of facing the current and procuring food by the constant movement of the bristled first and second pereoipods 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.

end of March to the end of July.

The postulate of Chace and Hobbs (1969) that a marine phase is necessary for the family Atyidae . agrees with our results for A. innocous. The other species will be discussed later. The zoea 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 100% sea water, they were appreciable affected in freshwater.

A. lanipes was found in every stream where shrimp were 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 was noted between 5 and 780 M. Gifford and Cole (1971) expressed ~~the view~~ that A. lanipes is found in those waters where A. innocous cannot survive but this study shows that this is not the case since both species are to be found in common habitats. A. lanipes prefers to feed just below riffles entering pools whereas A. innocous 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. innocous. When not feeding, A. lanipes moves to a shaded area where the water current is quite slow. 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 zoea died in freshwater and did not thrive well in either 10% or 15% sea water.

A. scabra is found in the same habitat as A. innocous 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 usually located in crevices between rocks, while the latter were found only in rocky riffles. The method of feeding is most likely quite similar to that of A. innocous 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 presence in December, hence breeding occurs around this time.

Gifford and Cole (1971) reported that M. poeyi, the smallest of the decapod crustaceans was restricted to one stream (unfortunately, the authors did not identify the particular stream). Our study shows that this species was found only 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 in drainage ditches with strong currents among roots of aquatic plants. They also observed 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 pereoipods could well indicate filter feeding.

Chace and Hobbs (1969) ~~made mention of the fact~~ that ~~though the species~~, M. poeyi breeds throughout the year, most of the eggs are swept downstream and out to sea.

study indicates that the adults are usually found at a higher elevation than juveniles. Further, juveniles are always abundant in the upper estuary. The species is second in abundance to A. lanipes and consequently contribut~~ion~~es much to the biomass of the system. It was observed that [illegible] its ~~mode of feeding~~ ~~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% sea water 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 McIver, 1966). The mature males are equipped with massive claws which make them deadly predators. Their feeding pattern is to lie in wait for its victims. The observation of heavy populations in areas where garbage was dumped indicates that the animal, while omnivorous, is also a scavenger (Lewis, 1961).

Ovigerous females were noted between May and October with the highest fecundity in August (Lewis, Ward and McIver, 1966). Our study showed that they were common from the end of March to the end of July.

Dugan et. al. (1975) give 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 implants the sperm mass near the female genital pore. Within 24 hours, as the female deposits eggs into her brood chamber, they are fertilized by sperms. At 28°C, development of fertilized eggs take 16 to 20 days. M. carcinus carry 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 M. carcinus larvae 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 water where they remain during their larval development (usually 30-50 days). Larvae that remain in freshwater or 100% sea water do not survive (Lewis, 1961; Choudhury, 1970). First stage larvae do not feed and after passing through 8-10 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 has been observed, lives in brackish and freshwater at low altitudes (Choudhury, 1970). During the day, according to Chace and Hobbs (1969) the animals were found along the shore-line among aquatic plants and tended to be active at night moving debris accumulation to the surface. They relish animal and plant materials and are both omnivorous scavengers and cannibalistic (Ingle and Eldred, 1960). The cannibalistic tendency was observed during the laboratory culture of our study in that 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 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% 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) observed that optimum salinity for M. acanthurus larvae was 16‰ at 28°C. 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 whereas they moved throughout the water column as salinity increased. It appears that this behaviour 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.

M. crenulatum abounds in pools of feeder streams as 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 seach of food and a fragment of any meat stimulates them to action. Collection of ovigerous females were made in February, March, April, May, August and September (Chace and Hobbs, 1969) and 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 freshwater 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 feeding pattern was not observed but the presence of claws, though not as massive as *M. carcinus* and *M. crenulatum* would suggest that a similar type of feeding is implicated. Chace and Hobbs (1969) noted ovigerous females in February, March, July and Novembe and our study established that they were common from March to the end of July.

The bioassay experiments showed that the larvae of M. heterochirus did not thrive well in freshwater and died after 48 hours.

E. sinuatrifons, 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 the freshwater Rio Espiritu Santo System, more abundant in shaded pools and are common throughout the year at an altitudinal range of 18-750 meters.

The riverine Espiritu Santo estuary is flanked by Rhizophora mangle on its lower half and the decapod crustacean fauna, although not abundant, is typical of mangrove shores. Brachyuran crabs such as Ucides cordatus, Aratus pisonii, Goniopsis cruentata and Pachygrapsus gracilis were common in the mangrove swamps of R. mangle especially in the lower reaches of the estuary. U. cordatus was found in b~~o~~urrows between mangrove roots and similar observations were noted for Uca sp. 1. The distribution of both species was limited to areas periodically inundated by the tides. G. cruentata was always observed w~~o~~andering among mangrove roots of R.

mangle and *Laguncularia racemosa* and occasionally among the golden fern, *Acrostichum aureum*. *A. pisonii* was only observed crawling on mangrove roots and branches but never on the forest floor. *P. gracilis* inhabits submerged mangrove roots and on decaying tree stumps.

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 ~~G.~~ C. *clypeatus* ~~use~~ 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 borrows 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 areas. However, it was not so 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 ~~on~~ an estuarine species and was the most abundant shrimp. Very rare were *M. faustinum*, *Crangon* sp. and *Penaeus schmitti* which were limited to the mangrove areas.

[illegible]

The phenomenon of drifting invertebrates although of relatively recent interest constitutes an important phase of work today. Dendy (19[illegible]) discovered that invertebrate drift was a normal process even in the absence of strong currents. Muller (1954) 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 phenomenon, 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 dislodgement of individuals of the bottom organisms and exposure to the risk of being carried away into the drift is affected by behaviour, especially responses to light and water rates. He also stated that there is no evidence that drift is a form of migratory movement in response to population pressure.

The drifting pattern of the invertebrate as observed in the Rio Espiritu Santo system varies. In the main river's freshwater habitat it was observed that the movement of Diptera[1], Diptera[2], Odonata and Trichoptera were about the same. The other species were more or less irregular. In

Q. Jiménez and Q. Sonadora , the species observed were somewhat irregular in distribution. In Q. Grande, on the otherhand, all species except Diptera[2] and Hydracarina[1] showed an almost equitable distribution. In the estuarine habitat Decapod larvae exhibited a rather regular distribution (except for sampling station No. 35 where 82 were collected) as compared to the other species especially Amphipoda, Hemiptera, Coleoptera, Odonata and Ephemeropte

The average number of individuals per sampling station showed 22, 4, 9, 7 and 14 for Rio Espiritu Santo proper freshwater, Q. Jiménez, Q. Grande, Q. Sonadora and the estuary respectively. From this one can conclude that the Rio Espiritu Santo proper freshwater habitat is more productive with Q. Jiménez the least.

The large number of species (13) in the freshwater of Rio Espiritu Santo proper would seem to reflect less environmental interference than Q. Grande with fewer species (4) and consequently the probability of greater environmental stress.

6.3 Benthic Annelids

Sigambra tentaculata and *Tharyx* 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 gravid indicating that this is an established breeding population. *S. martini* is a Caribbean biological indicator of stressed situation (natural or man-induced) and the presence of *S. tentaculata* is also indicative of stressed conditions (Charlene Long, personal communication).

Mollusc

Neritina reclivata was abundant in both fresh and brackish waters while *M. cornuaretis* was observed to be the least dominant. The latter species and *Tarebia granifera* were restricted to fresh water. *M. cornuaretis*, an ampullarid snail, is a control agent for *Biomphalaria glabrata* the intermediate host of bilharzia. 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 in the bottom and sides of the streams and river. It is believed that this snail out competes *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 roots while the population of the latter species was quite small and occupied exposed mangrove roots. *M. domingensis* was found almost throughout the estuary, more abundant in the upper portion and frequent 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 mudflats whereas *N. reclivata* was quite abundant on rocks and bottom sediments in both freshwater and upper estuary.

The dominance of *N. reclivata* 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 environment, 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 limits of distribution.

It was observed that shell erosion was common to this species in fresh water while in estuarine conditions the phenomenon was quite rare and only in the form of a tiny hole in the apex. Ferguson (1959) has suggested that shell erosion might well be a condition which results from a craving for extra calcium.

The experiments undertaken with apex-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. reclivata.

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 umbo of the shell of the mollusk, Margaritifera margaritifera is often dissolved away and replaced by white nacre,

6.5 Fish

In the R.E.S. system, 8 species belonging to 6 orders. Three of these (S. plumieri, 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 of an altitudinal range of 5-600 M. while A. rostrata was found within the altitudinal range of 5-200 M.

Five species (Belome sp., M. curema, G. dormitor, C. enciferus and C. undecimalis) are exclusively estuarine and except for Belome 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 behaviour of fish population in the estuary. It is hoped that at the completion of this research many interesting and useful details will come to hand throwing more light on this subject.

6.7 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 extending up to 2 m.

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Except for the sewage outfall and tannin produced by mangrove, light penetration was usually high and in some cases extending up to 2 m.

readily forms soluble compounds when exposed to both air and water and many serious or fatal poisonings have resulted from accidental ingestion of thallium (Encyclopedia of the of the Chemical Elements, 1968). In the United States, thallium sulfate was recently banned from usage in rodenticides (Thomson, 1976). It would be interesting to know the status of thallium sulfate in Puerto Rico. / In the RES estuary, copper was found in concentration 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 mg/l (~~Wiber,~~ Raymont and Shields, 1964) and the shore crab Carcinus maenus at 1-2 mg/l (Wilber, 1969) ~~1969)~~. 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

6.8 Chemistry of Estuarine Sediments

Thallium (Tl) 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 salt are cumulative poison and are used as poison for rats, for 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 hazard in 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 their 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 element in the food web should be investigated. In fact, Encyclopedia Americana (1967) noted that all thallium compounds are very toxic and can produce loss of hair, gastrointestinal and nervous disturbance and ultimate death. Also, thallium luminium exceeding 1.5 mg/l constitute a hazard in the marine environment. Lowman *et. al.* (1971) noted that Al concentrated 15,000 times in benthic algae; 10,000 times in plankton; 9,000 times in the soft parts of molluscs: 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 EPA (1973) suggested that the concentration of this element exceeding 0.01 mg/l in the marine environment constitute 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 squilla)*, 20 mg/l in the form of Na_2CrO_4 for the shore crab *Carcinus maenus*. 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). EPA (1973) pointed out that concentration of chromium equal to or exceeding 0.1 mg/l would constitute 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 the food web of the RES estuary.

readily forms soluble compounds when exposed to both air and water and many serious or fatal poisonings have resulted from accidental ingestion of thallium (Encyclopedia of the of the Chemical Elements, 1968). In the United States, thallium sulfate was recently banned from usage in rodenticides (Thomson, 1976). It would be interesting to know the status of thallium sulfate in Puerto Rico. In the RES estuary, copper was found in concentration 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/1 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 mg/1 (~~Wiber,~~ Raymont and Shields 1964) and the shore crab Carcinus maenus at 1-3 mg/l (Wilber 1969) ~~1969)~~. 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 are more soluble and more toxic than pure vanadium and Arkhipova et. al. (1967) reported LD_{100} of 40 mg/kg. VCl_3 on rats in 3 days. The National Academy of Sciences (1967) reviewed the medical and biological effects of vanadium and noted the following:

Lethal Doses of Vanadium Compounds

Compound	Rabbit	Lethal Dose, mg/kg Guinea Pig	Rat	Mouse
Colloidal vanadium pentoxide	1-2	20-28		87.5-117.5
Ammonium metavanadate	1.5-2.0	1-2	20-30	25-30
Sodiun orthovanadate	2-3	1-2	50-60	50-100
Sodium pyrovanadate	3-4	1-2	40-50	50-100
Sodium tetravanadate	6-3	18-20	30-40	25-50
Sodium hexavanadate	30-40	40-50	40-50	100-150
Sodium vanadate		30-40	10-20	100-150
Vanadyl sulfate	18-20	35-45	158-190	125-150

Derived from Faulmer Hudson.

It is also stated that the sources of vanadium include welding of vanadium containing steels, coating of some welding rods. industrial processing of various vanadium compounds and nonmetallurgic use in ceramics, chemical and electronic industries. Vanadium in the atmosphere. may be caused by combustion of coal and processing of crude and heavy fuel oils.

A glance at the other elements observed in the sediments shows that some, for example, beryllium, alluminium, cadmium and chromium can bioaccumulate in the various trophic levels EPA (1973) suggested that concentrations of beryllium and al-

[illegible] exceeding [illegible] in the marine environment. Lowman et. al. (1971) noted that Al concentrated 15,000 times in benthic algae, 11,000 times in plankton; 9,000 times in the soft parts of molluscs: 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 EPA (1973) suggested that the concentration of this element exceeding 0.01 mg/l in the marine environment constitute 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 squilla)_, 20 mg/l in the form of Na_2CrO_4 for the shore crab _Carcinus_ _maenus_. 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). EPA (1973) pointed out that concentration of chromium equal to or exceeding 0.1 mg/l would constitute 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 the food web of the RES estuary.

(7) The behaviour of mineral transport in the Rio 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 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.

(8) 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, 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.

(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

Conclusions

(1) Of the 7 types of rock formations (Quartz diorite and diorite, Tabonuco formation, Hato Puerto Formation, Alluvium, Mafic dikes and sheets, Terrace deposits and Swamp deposits), 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.

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

(3) In the freshwater habitats, mosses, ferns, diatoms, *Elodea* sp. and *Oscillatoria* sp. were dominant, whereas waterhyacinth, diatoms and mangroves were dominant in the estuary.

(4) 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.

(5) The presence of two benthic polychaetes, namely, *Sigambra tentaculata* and *Stenoninereis martini* indicated stressed conditions in the estuary.

(6) The problem of shell erosion in *Neritina reclivata* was delved into through laboratory experiments. It was concluded that predation was responsible and only living snails were attached, indicating that the particular conchiolin resulting from mucoid secretion is specifically necessary for calcium uptake by other individuals of the same species.

(7) The behaviour of mineral transport in the Rio 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 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.

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(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; a 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.

8. An overview and suggestions for future investigation in the watershed.

(1) Potential Sources of Pollution

These include the following:

8 Poultry Farms-105,000 chickens.
4 Pig Farms -- 1,650 pigs
3 Dairy Farms -- 400 heads of cattle
1 Dog Kennel -- 30 dogs
3 Solid Waste Landfills
Runoffs from Urbanizations and Agricultural Lands.
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 votalization 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 three fold: (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 an energy resource (methane) than 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 one located at about the confluence of Quebrada Jiménez and the main stem of Rio Espiritu Santo poses a public health hazard and should be relocated. Wastes are usually left exposed and the site is a breeding ground for rodents and flies. Another possible hazard is the seepage of organic pollutants, bacteria, etc. into the river system.

(c) The Rio Grande Sewage Treatment Plant is inadequate to cope with the growing population of Rio Grande. During heavy rains, it was noted that the plant could not process the volume of waste. Consequently, improvement of this plant is necessary and a more long-term solution would be the installation of a tertiary treatment plant. This will not only reduce the phosphorus concentration but will also ensure the reduction of the water hyacinth.

(d) About 12 industrial plants are located in the watershed. Many of these assemble parts whereas two of them do complete processing, including the use of large amounts of chromic acid. The acid and other wastes are discharged into rivulets nearby and may be regarded as a potential source of pollution to the Rio Espiritu Santo system.

(e) The mangrove lining the east side of the estuary from the confluence of Quebrada Juan González to the Atlantic Ocean seems to be in danger. Coco Beach Land Development is doing constructions adjacent to these mangroves and gradual erosion or filling may eliminate them.

(f) There is some indication that the mouth of the estuary is gradually filling up. The source of siltation and sedimentation should be investigated and corrected.

(2) Bacterial flora of entire system

A year's investigation on the total coliform bacteria in the estuary showed a high concentration and in many cases 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.

(3) Hydrology of entire system

Hydrology constitutes a most vital area of water resources and management and its importance can hardly be over-emphasized.

(4) Food web of the entire system with particular reference to the estuary.

Generally estuaries may have either detritus or plankton as the base of the food web. In the RES estuary, it was noted that detritus from mangrove and other allochtonous sources was abundant and was probably the main base of the food web. But subsequent studies revealed that plankton, especially diatoms, shrimps' larvae and copepods, was quite abundant as well. The indication is that both detritus and plankton are important in the food web but the extent of importancy of the plankton throughout the year is still not known.

(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) chemical analyses of effluents at point sources, water at sampling stations, biota and suspended and bottom sediments.

(d) Laboratory bioassays and field biomonitoring.

(e) synergistic effects of pollutants and environmental factors.

(f) laboratory experiments on the fedback of some toxic elements found in bottom sediments to overlying water.

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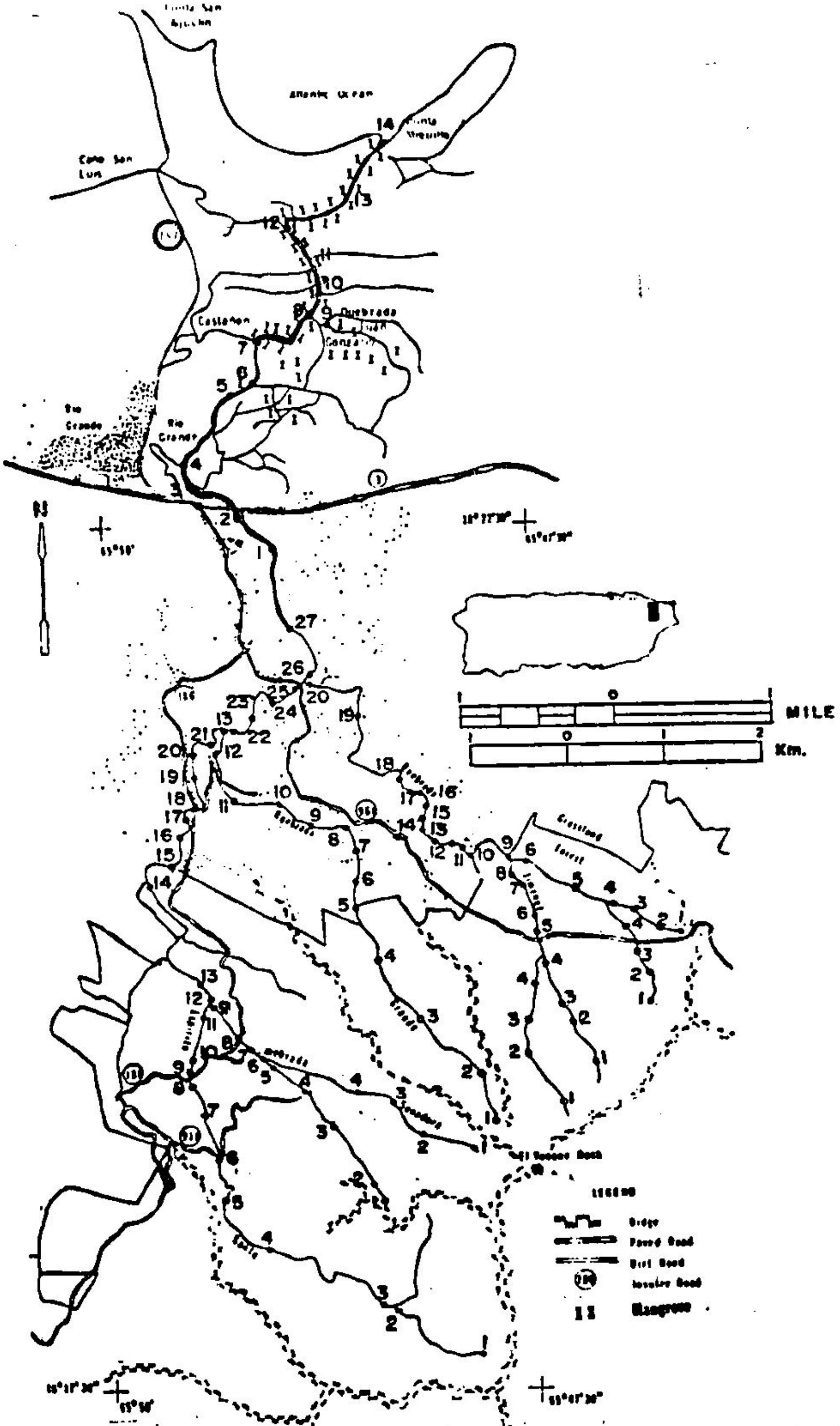

IV-1

Figure . Rio Espiritu Santo Drainage Basin showing sampling stations.

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