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A LIMNOLOGICAL SURVEY OF

?THE RIO ESPIRITU SANTO WATERSHED, PUERTO RICO

(1976-197)

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pret pe 4

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ACKNOWLEDGEMENTS

Objectives of the survey

Primary Objectives ~

Secondary objectives ~

Description and Geography of the Study area ~

Ecotypical Sectionsof the Watershed ~

Geography and Physiography

Geological History

Geological Background

Stratigraphy ~

River Bed Substrate Description ~

Substrate Characteristics of the Riverine

System

Rio Espiritu Santo River

Quebrada Jinénes

Quebrada Grande ~

Quebrada Sonadora -.

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suacer Chemistry

Field Mechods

pecaped Crustaceans ~:

vt

pifsiton and Drifting Invertebrate Larvae ~

Benthic Annelids and Bottom Sediments

Molluse

Fish

Algae and Macrophytes ~

Physicochemical Characteristics

Sampling Handling and Preservation

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identification Procedures ~

Decapod Crustaceans ~

Plankton and Drifting Invertebrate Larvae ~

Benthic Annelide

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Fish -

Algae and Macrophytes

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Benthic Annelids and Estuarine Sedisent Parricle.

Size Analysis Tt

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5.2 Phesicochenical Analyses

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nis moral support and encouragement.

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FIGURE

w-2

W-2

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IW -3.

v-3

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OF FIGURE:

Vertical profile of the Rio Espiritu

Santo and its tributaries -.

Rio Espiritu Santo River system ~

Ao epi, Sanco Deginase Basin

Hoes SUEELE Set pe Saas

Constant £1 | deen for shrimps .

culture ~~ ab

Photograph of typical temporal sequence ~

of shell erosion in Neritina reclivata ~ %

The altitudinal distribution of macro-fauna in the Rio

Espiritu Santo freshwater system 44

engitudinal zonation of sacro-fauna along the length of the

Rio Espirity Santo estuary «

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ABSTRACT

This study constitues the first complete limno- j

Logical survey o: din Puerto Rico and

conducted over

exanined the flora and fauna and thel® Giseributior

te atudied the geology and chemistry of water and

sediments and identifies the potential sources of pa-

lution and thelr effects on the environment. Included

also

re laboratory experiments which were conducted to

hed Light on some of the problems encountered during

the investigation, Finfilly, possible areas for future

studies are identified.

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Vertical profile of the Rio Espiritu -

Santo and its tributaries -

Rio Espiritu Santo River system

Rio Espiritu Santo Drainage Basin

showing sampling stati

Boe caprrihe Sato we haa

Constant flow a

culture -

Tan pling stahene:

for ?shrimps

Photograph of typical temporal sequence ~

of shell erosion in Neritina reclivata

the altitudinal distribution of macro-fauna in the Rio

Espirita Santo freshwater syster «

Longitudinal zonation of sacro-fauna along the length of the

Rio Espiritu Santo estuary « " * Sp

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ur 8

nr 8

nr 10

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LIST OF TABLES

size analysis. oe : . ae

Grande

Distribution

Singnez --.

Distribution of drifting

Espiritu Sante river

Distribution of drifting invertebrare

Zepizite Santo estuary, : ~<

Particle eize analysis of substrate ve

Santo estuary cesececeeeseresseesceers o>

Nolluse and fish of the Alo Espiritu Santo estuary é

Selected physical and chenical characteristics of Quebrada

Sonadora - pereeiesl : &

Selected physical and chanical characteritics of Quebrada

Grande

Selected prysical and chenical characteristics of Quebr

Sinénes, : :

Selected physical and chenical characteristics of Rio

Espirita Santo river «

Selected physical and chenical

Espiritu Santo estuary eave

Summary of results f2r coddum, potassium, calcium, magnesium

Shi chloride in the Ric Espiritu Santo freshwater according

fo vegetation types :

se

?76

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vou

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vo 3B

Cus

Vay

Concentrations of calcius and ma An guebeade Sonadora

Concentrations of caleiua and magn Quebrada Grande

Concentrations of caleium and nagnesiun in Quebrada Jiménez .

Concentrations of calcium and magnesium in the Ric Espiritu

Santo river

Concentrations of sulfate and nitri

Rio Espiritu Santo estuary -

Salinity tolerance bioassay of

Cheninleg as aa Lote sotianine

nitrate nitrogen in the

sone Gecapod crustacean larvae

Letmont

AGE

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nological Survey of the Ric

y santo River Drainage System

nereduct ion

Previous Limnological research in Puerto Rico

while sone 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, 1964) on fresh water algae; Gardner (1932) on Myxo-phyceae: Garcfa-Diaz (1938) on insects: Hagelstein (1939) ?on Diatonaceae; Osborn (1940) on bryozoans; Tressler (1942) on Ostracoda from bromeliads and Candelas (1956) on plankte other studies done recently include those of Candelas and candelas (1964) on physical and chemicai nature of eight

jakes; Hart (1964) and Jones (1964) on contributions to

the Limnology of Puerto Rico; Chase and Hobbs (1969) on

decapod crustacean

Erdman (1972) on fishes; Wolfe (1972)

and Wolfe and Rice (1972) on trace element studies in the

Aflasco River; Montgomery (1973) on trace metal chelators

of ane/auanasibe, Magee and cules Rivers: the eco-

(05). it ee

Bhajan (1995, Cecil Caml

NBGEST steveys of(Bhajan (2973) on

ie 60

az6n, Sranderi

and Salada streams; Bhajan (1973) on the Manat{ Rivers

Bhajan (1974) on Rio Seco; Bhajan (1977) on Los Frailes

creek; Bhajan (1973-1978) on several other s lier water

bodies in various terrestrial ecological impact statemen

sovin: (473, 1478) ,Tébon ef al (97870997) Bhajan etal (ir

en bilharzia im peterveine ane Ines ant

Quikenes Margot and Fuste (iq) on Tor baguere

Jake,

---Page Break---

Frovious Limnotogival Research on The Ric Esp

Santo River Drainace systen.

Maguire (1970) studied aquatic communities in bro-

meliads; Gifford and Cole (1971) and Vill

and

crustaceans , Cuevas and Clements (1975)

and Clene:

(1976) seca:

stream water chenistry, Accordingly, at the tine of preparing this manuscript, no complete limnological study of ar 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 alitte-tinitations,

can be considered a first ate

pt teunderteke a full

study of the Limnological aspects of a watershed.

Objectives of the Survey

Primary objectives

?The primary objectives of this study are to (a) de

ine the geology of the system (b) identify the most important and common species of flora and fauna (c) study the distribution of the species (4) 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 problens related to this

survey through laboratory exseriments and (£) suggest

future investigations.

---Page Break---

Secondary Object

?the overali,objectives of the Rio Espiritu Santo

overall objets

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 environ~

ment 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,other tropical areas,

---Page Break---

nertheast Puerto 5 the ®

tes in the El Ye

nountsin at an

elevation of 90M. It courses about 20.5 Km, and dis~

charges into the Atlantic Ocean. In the upper watershed

there are two main tributaries, nancly, Quebrada Grande

and Quebrada Sonadcra, Quebrade Jinénez unites with Rio

Espiritu Santo in the middle portion of the watershed and

Rio Grande, Castafion Creek, Quebrada Juan Gonzflez and

Cafe San Luis are the principal tributaries of

estuary

situated in the lower watershed. A profile of distance soa level of the main tributaries of the river is

n Figure andthe >

Tens ver: gra and drainage area of princips:

)

ceibutaries are cumsarized in tabte T-'.] cebracs Grande

hae a lencth of 6.47 kr. with an average gradient cf 13.6

and drains an area of about 1.9 Kn®, Tt joins

4/100 3

the Rio Espiritu Santo at 10.9 riv from its origin

ye mene - ° ~

Quebrada Sonadéra in length, an

a cf 1.5,

erage gradient of 21 H/t00 ¥ and drains an

am?,

joins the main river at 6.2 river Kn. at an

the ceologic formation consists

rite.

Quebrada Jiménez is 7.68 Km. long with an average gradient of 12.6 4/100 4 and has a drainage area

qe

ng the main river at 13.2 river im,

---Page Break---

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2 s0xTP OFseH S°LT eet we srt aoe sougute epexqond

wnpantty 92 Sor et set uwty apueap epezqand

earaorp zazend Sut 9 st ote oste ezopruos vpeaqend

voryeuxoy (wu) ?uy goa

Protos) uorIeAeTa ?Sa sorzeangr3,

eo opett Axenas9 01 ?w 05

OT ?$0°S ?ATO ?w oS 09 ~w ODOT

9-02 ts sptoz oaues naraydea

7 Tae FuaMT FID way C oT Tan -

sbeurera ?perp ?ay ysbuey

uyseg (s'a"u) oaues nqraTdsq ory 30 soTaeqze30NreUD oWOS

eraes,

---Page Break---

at an elevation cf 17.5 m. The geologic form

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 boths
Quebrada Grande and Quebrada Jiménez are located in the
forest and grasslands, respectively.

?The upper part of the main river traverses four
Gistinct types of forest: the ovarf or Mossy, Palm, Colo-
rado and Tabonuco. In its middle course it passes through

ane
grasslands and some cultivated areas the lower portion

includes some grassland, agricultural. - and mangrove
conmunities.
is about Ekim beng
The estuary tune om at
?

15.6 river Km. it receives the Rio Grande river which flc.

adjacent to the town of Rio Grande and is the recipient

of various types of the town's wastewater. At 17.4 river

Ka. the Castafion CrSekinités with the estuary and dischar

sewage effluent from Rio Grande. The confluences of both

Rio Grande and Castefion Creek are usually abundant with

water hyacinth:

Quebrada Juan Gonzélez 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 (Bubulews ibis ibis)

rookery.

: Caio San Luts Creek joins the estuary at

river Km. It flows through swamp lands and mangrove

---Page Break---

Fig. II-2 Ric Espiritu santo River system.

---Page Break---

_ Selorade forest type

. Ggepland; minor cultivs

comer, plant specter include

tue): common plant spec!

Cyathen arbores (helecho gigante, tree

hembra, trumpet tree), Peychotria berteriens (cachinbo comin

Pala forest type (above 450M):

omon plant species include Prestoca sontana (palma de Sierra, Sierra pain).

1s type (below 600M); comon plant species include Dacryodes

excelea (tabonsco), Piper adunoun (hiquitto), Cyathea arbores (helecho gtgante,

tree fern), Casearke srbores (rabo ratén}, 2. desandre (tosteds, tld honey

ree), C._sylvestris (cafeiilo), Citherex:tus fructicosum (pendula, pasture

C._sytvestris, Eracticosun

fiddlewood), Pelicoures riparte (1

abo, yellow palicoures), Ocotes Leusoxyle=

(tenret geo), Guaree guidonte (guaraguao, Anerican masiovood)

nao mvuntant(tittle and oosbury 1976) tn the shove four forest types ressent

as the upper watershed are Wicropholle chrysophylleides (caimititie) and Cyrstie

conto:

(palo colorado, svamp eyritie)

?The wiédie watershed locetes approvimatsly between 25 M and 200 1t above sea

evel consists off

?Traneiticnel motet forest»

Comon plent

ies include Nectandre patens (Ieurel geo colerads), Ocotes levcoxyion (Iaure? ge0), Guares guidonta (quarames), Caserta arbores (rebo

atén), g. decanden (tostedo), C. sylvestris (cefetiio) and Solame teruz

(perengena eimarrona, turkey berry).

on of typical crops such as breadfruit (pana), banare

nes?, plantain (platanc? and mance (nénso!

---Page Break---

mangrove forest alzost cover

Panta "ie

200M south of the

moet of ft wus destrayed ty Coco 5

Jn Development. About

the red

cgreve

sophora mangle flanks both banks to about 600

below the confluence of Castation Creek.

?The white mangrove, Leguucularie racenosa, vas observed around Caio San Luis

and was sore abundant on the enetern side of the estuary especially at the lower

reaches of the mangrove forest.

---Page Break---

Geeceny

raphy and Fiveios

?The Rio Espirit: fance Fiver re:

agehers 2as

of the island of Puerto Feo. The area 4s nominally tour:

ww

30" and 28°27" 25" north latitudes and StL" as west longitudes. In general, the river ries, is

but one of several rivers draining the Sterra de Iuguille mountains.

?The physiography of the region can be dese

2 in teins

techalous as follows. The highest sources of the systex begin in

ountain uplands witch dostoste success!

sy the St. John peneplain

math on alluvial,

giving vey to the Caguana peneplain, with a river

ain (iitenelt, 1958)

3.2 Geological History

Most of the rock formstions in the drainage

gytter dave from

whicr vegan in th

upper Cretaceous period, elthorg

late Upper Cretaceous period, lasting th

lene (roughly between 50 and 70 million yeers

amed up the Sierra de Lugsitio, expestas mich

ich nas been observed (Witcheli, 195+" yeyerho:

which has been observed (Wiicheld, 2550" veverhos!

east-west folding also has exposed different formpttons, the principal

le

roid activity having occurred in the post is si2dte Oligocene (about 25 to 45 mitiicn years age) ?Fersazno, 1960).

?The completion of this activity virtually coneluées sourcatn

les to which reference can

formation and left the recognizable zor

be nade in today?s context

---Page Break---

. towever, and pyroclast

leo the app

fa heap of volcanic erie? (Zeinroth, 1969).

yoteants ignecus activity apparentiy took plece during the

tires orogeny (60-75 willion years ago). The intrusive rocks

associated ith this episode are largely grancdiorite, quarte~

oe.

aiorite and minor quantities of quartz phephyry and gabtro.

fe are elso sxtrasive forsations (voleante) in the Sierra,

Ge Wugalite cut by muneroce vertical dikes most of vaich are dist

aintese porphyry. Andasite, the extrusive equivalent of éierite,

ehowe etrecttteation bee

wee of ejection in a sulmartne enviroae:

pyroclarts cbus formed are the tuffs whlch abound in sections of the © asm).

som. The

?re nay be sassive, stratifled and may grade into Linesto

or shales, Unconeclidates tuff ts termed "voleante ask?, and vier

= to slizhe setencrohten during the orogeny, glassy ashes ag voleante sandstone or siltstone.

andeciiz rock omations tend to weather deeply, particulerly tn the

areas of the St. John ané Caguana peneplais

se rocks in ceneral, produces soils Mh in clay,

lew in eand with prominent formation of iron

---Page Break---

tomes

Altrough there are not near

pe rocks

cra de luguillo, thors forzed or deposited éuriar the

plasatocene era certainly quelify as fnportant since they are well

represented in river and stream substzsta.

?meee rocks are derived

from alluvial deposits, svanp and marsh (largely organic muck)

deposits, blanket deposits, beach sands and indurated dunes. In

general, the parent meterials of the deposits include quartz,

calcite, veleante treceia and plutonic debris, and are, by and large,

unconsoligates. Ratios of quart to other constituents are general indications of the Litholoay of the watershed from vhich the

deposit is formed, since tr

sport only occurs via wind and water

flow.

ost metamorphic rocks are associeted vith the orogeny and

dered prominent features of the El Yunque Quadrangle

ae Luguilte). Rather, true metamorphosis {s more

prominent in the eouth-west part of the

and, with a zone from

conerie to Humecao of denonstrated netanorphic mineral assemblase

(3iiaebrana, 1960).

3.3 Stratigrarty

3.3.1 River Bed Substrate Description

Mapping of exposed geological formetions in the Rfo Espiritu

drainage area hae been carried out by the U.S. Geological

survey (FSGS0 end Briggs, 1972\ Seiders, 1971). There are 7

principal units identified as both typical of strata in the watersh

---Page Break---

se An th

ado Fepirita

Mep ETT - 1,-ead The appropriate sub

= Geological Survey documents are: Hato Puc:

y Terrace deposit (¢t), Alluviun (Ga), Mafie étkes

1nd sheets (Tint), Guarcz Dicrite end Diorite (Tea), Tebosuco

Forsation (Ft) ané Svamp deposit (Qs).

?The Hato Puerco Formation describes a very thick sequence of dominantly massive tufts and voloante breceia (Meyerhoff and Smith,

ea

1921). Brecota refers to sharp, angled stone fragments cen together with sand or clay. The Foruation {s exposed throughout the £2 Yunque quadrangle and consists of thick bedded voleante sandstone and brecsia of andesitic to basaltic composition.

Suto:

inate rock types include thick bedded voleante and calcareous mudstone and thers features are Indicative of the submarine

environsent in wht

wn this Formation was very Likely formed (Setders,

ag).

?The Tabonuce Formation is the name applied to conspicuously

exposed dark gray, medium bedded mudetone (principally) and lese-

well-exposed voleanie sandstone. The formation is partially

conforsably overlain by the Hato Puerco Formation. The formation

ke ont

fy competes of méstone, and voleante sandstone which ts

probably andesitic. The voleantc sandstone grades into fine and

then (rai

) Ante coerse voleante breceia.

"

Ne dikes and sheets

?fer to the very dark tron-ané-

wagnesium rich plutonic formaticrs vnich cut the andesitie or

yolcante extrisive formations. They are composed of diabase and

---Page Break---

porphyry stocks

?the plutonic {geneous acti:

Mlorite and quer

of the Sierra tugutlio ant nd Caguana peneplains.

cvanp deposits are sedimentary

The Terrace, Aliuviun af

features nore 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 hes ocurred

both to the tufts end voleanie sandstone of the Hato Puerco Formator

land the Tabonuco Formation respectively. The deposits are rich in

sit and some of the mast fertile agricultural lend in Puerto Rico

OM, aertved from the same weathering and transport which gave rise

to the deposits.

?the Riverine Systen

43.3.2 Substrate Characteristics

the drainage teein is conventently sub-divided into & seperate)

2 Blo Eepiritu Santo River |

Grainase systems. These are the

es: Quevreda Sonadora Seoek, Quebrada

and ite 3 sain tri :

Grande, mock and Quebrada Stnénes,feoom The geological aubetrate |

utary vith the Rio

confluence of each &

characteristic of #1

Espiritu Santo River is shown tn Table IL-l The size of drainace

of the Rfo Fepiritu Santo River is

area of each trfvutary and th

sie.

included in the

?The U. 8. Geological Survey has performed substrate analysis of

the principle rock formation in the Rio Espiritu Santo River drainage

basin. The Tables IIT-| and ITT- >. sumarizes USGS cata (Seiders 1971)

on Chenical analysis of Quarts diorite and voleanic vent breccia of the

Puerco Formation, Both fomstions are proninent tn the #

comtvantle and the congrieuouely well veors

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TABLE IIT = 1

CHEMICAL A

LYSIS OF EL YUNQUE QUADRANGLE FORMATIONS

Hato Puerco Formation

Major Quartz Fragent Fragment,

: Oxides __dorite GrayeGreen Oxidized

si0, 67.1% 49.2% 47.9%

A105 15.8 17.2% 17.0%

Fe,04 2,2 4S 8.0

Feo 2a 5.4 3.8

?MgO 1.7 75 6.7

cao 5.1 8.4 Ba

Na,0 3.3 2.8 3.3

K,0 0.92 0.12 0,31

TiO), 0.25 0.78 0.75

P05 0.07 0.09 0.09

wn 0.12 0.10 0.17

co, £0.05 <0.05 £0.05

ou

?tione of the samples contained ebave 3% water.

otha

---Page Break---

TABLE

CHEMICAL TRACE ANALYSIS OF EL ¥'

UE QUADRANGLE FORMATIONS

Hato Puerco Formation

Minor Quartz Fragment Fragment

Elements diorire Gray-Green 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 - - -

we - - -

Ni - 0.003 0.003

Pb 0.0007 - 0.002

se 0.001 0.003 0.003

sn - - 0.002

Sr 0.03 0.05 0.05

v 0.007 0.015 0,02

Y 0.0015, 0.002 0.002

ve 0.00015, 0.0002 0,0002

ze 0.007 0.005 0,005

---Page Break---

?The following elesents.vere ?Looked for, but not found",

?Ag, As, Au, B, BL, C4, Ce, Ge, HE, Hg, In, Ia, Li, Pt, Re, Sb, Ta, Te,

%, 72,

I) W, Zn, and Eu.

2.1 Rlo Espiritu Santo Aiver

Geological formation and substrate information for the drainaze?

z-3

area of the Rfo Espiritu Santo Aver are qpmmurizes in Table Sf

oe crea posed ©

Of the actual area creined, more than 89 is,Hate? Puerco Formation,

nore than Of 1s formation of Quartz diorite and diorite, with

?he actus

ort quarts dlorite a

. where the

pottes ts prinetpally compose? of Svaxp deposits and Alluvium

(TetieW-). Between these points eubetraces compoced of eas!

of

?the other possible geological strata are Zosnd.

---Page Break---

a, Hato Puerco Formation

6.28 wa! 0.88 Terrace deposits

0.2 kat 3.01 datuvian

0.36 Ks 8 Matte atkes and sheets

1.80 me? 8.7 Quarts dlorite & atorite

Location

Origin - 1.20 Ka. tea

1.20 Kn ke

"30 Ke = 6) Rp

6.90 a = 7.40 Ge

7280 He = ap

7:80 Km = ae

8.30 ke = 9.40 Tint

gilio Xe = 9.90 mp

3.90 Ke 10. ae

10.85 Ke -10. ip

10.95 Ke <2 Qe

12:35 fm -12 ep

12.15 Km -12 ae

12.35 tm -12. Tent,

12.55 mm -13. Qe

ABS ke -23180 Tit,

3380 fe -14165 Qe

bes Hm -15165 &

35.65 fm ?18.05 . Qa

3805 xm ?20.45 as

?Tq - Quartz diorite and diorite: xt - Tabomice Formation: Kp - Hate

Puerco Formation: Qa - Alluviuz: Timi - afte dikes and sheets, Qt-

Terrace deposits: Qe - Svaxp deposits,

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Reletively mali cones of Terrace deposite (2.36), Alluviun (

Marte atkes

steer then 1)

comprise the renaining strata drained by the Quebrada Sinénes tritutery.

Riverine substrat

1s begin in the Hato Puerco at the origin (Teble

G). Terrace and Alluviun deposits are interspersed with Hato Puerco

altihdes of

formation at relatively high altitudes. Dikes are found at She 70

to 55% at doa at 295 and at 28m with sections of Hato Puerco, Terra:

acd Alluviua interspersed

---Page Break---

Terrace deporite

0.090 B® Altaviun

0.200 rs 2.58 Maric dikes ané sheets

0.005 tn? 0.13 ?Tatonuco formation

Table IIT. Geologic formation of Jiménez streambed

TTT

Location (2) Geologie Formation

Origin - 2.60 Ke. 880 - 195 mp

280k - 2.92 Km. 195 - 175 a

2.92fm - 3.10 Ha. 175 ~ 160 1p

3.20 ~ 3.58 Km, 160 - 125 a

358k - 3.98 ian. 225 - 200 a

3.98 - 4.28 Ka. 100 = 95 ep

4 .28km - 4.49 Ka. 95 - 83 ca

Aybonm - 4.76 He. 83-70

4,76 = 4.92 He. TO. 55

Ugem - 5.13 i, 55 = 50 mp

5.23 - 5.33 Km, 50 - 49.5 Tint,

5.32Rm - 6.43 Hm, 4g.5 = 30 Xap

6.43hm - 6.63 Ke, 20- aL a

6.63% = 6.71 te. a- ws sep

6.7m = 6.96 He. 19.5.- 19.0 Ga

5.9682 = 7.02 Fa 19.0 - 18.5 ?Theat

7.0LKm - 7.53 Ka. 38.5 - 18.0 a

7.53Km - 7.68 Xe. 18.0 - 37.5 Det,

sp ferrace deposits: a - Alluvius

20 Puerco Formation: @t -

SSin Aven and sheets

---Page Break---

cebrade rand

Jeolosical for

and substrate information for the werersh

aren drained ty

juetraia irande Swaok are given in Table T

ector drained, nearly 884 is composed of Hato Puerco early % consists of Terrace and ALiuvium deposits

vith amino!

sectors of Matic éikes and sheets (

391) and Tebomuce

formation (02%).

Riverine substrates begin on the Hato Puerco formation at the origin and then alternate between Terrace and Alluviun deposits dom to 50 metere elevation where the Hato Puerco is re-exposed. After a short drop oF about 10 meters in Alluviua, an exposed Maric dike Le found at about Lo neters elevation, Thereafter substrate between cectione of the exposed Hato Puerco forsation

re &

acd Alluvis depostte. this cata $e sumarized in Table ITY,

---Page Break---

Geoloste Formation

er.87 Hato Puerso Fornacion

ute Terrace deposits

ue alluvium,

2.5 Magic dikes and sheets

0.02 ?Tabonuco Formation

repte TITS. Geologie formation of Grande strean-bed.

a

Location Elevation (z) Geologic Formation

origin - 3.60 f= 850-90

3.60 tm 90-70 ae

3.95 Ym 70-68 ee

was Se 66-62 ae

4.0 Km = 4.60 Hs 62-50 ee

4.60 Hm - 4.80 He 50-48 Kap

4.80 we = 5.2 Kn 48-40 a

5.22 Km = 5. tn 0-38 Tmt

5. Ka = 5.59 Ra 38-37 Rp

5.59 Km = 5.69 Ke 37-35 ee

5.89 Xm - 6.09 tie ip

6.09 Km - 6.29 Ke 2.5-3 ae

6.29 Hie - 6.29 Hn 3-30 kp

6.39 Ke = 6.47 a 30-26 ce

Kup - Hato Puerco Forsation: Qt - Te

Tint ~ Gikee and sheets.

ce deposits Ga - Alluvium

---Page Break---

¢ trivstary of the Blo Espt:

sal dratas

aren Le

jo Quebrada Sonsdorey

Geolorical Somation and substrate infomation for ined by Guebraca Sonadora Sspdam are shown

Orly 2 formations are exposed in the drainage

sector of the Quet:

=

a Soradora Sta, Thay are Hato Pures

fomation comprising 90f of exposed formations and Tatomiso formation

comprising the renatnder.

The riverine substrate begis® fn the Tabonuco formation at

the origin and the Hato Puerco exposition occurs at sbout 930 m.

A sumary of altitudes and Aistances at which the change occurs

1

ie given in Table IITA.

Table IIE-7. Geologie Fornetion of Quebrada Sonadora Dratnage Area

Aves ? ?eoleste Formation

2.35 we? 0 Eato Puereo Formation

0.35 fae 10 ?Tabonsco Formation

vnation of Sonadore Stresa-bed.

Location Geologie Formation

origin - 9.2 i. ?Tadormce Formation

0.2 Ye = 2.8 Ke Hato Puerco Forration

---Page Break---

Methodology

Sampling Station

teria

?The Rio Espiritu Santo River system wa traversed

on foot from its origin including the three main high

gtadient tributaries to the head of the estuary, A boat

Was used for the estuary survey. =

wu Cent,

A total of 101 sampling stations ?as exanised? thise were comprised of shaded and unshaded pools and rifties, weak and fast curront areas, confluent sites, areas near or at suspected contaminated spots such as poultry and dair: farms, sanitary landfill and domestic wastes, within each of the four types of forest recognized as Duarf or Mossy, Palm, Colorado an@ Tabonuco; grassland, agricultural land and snangreve areas.

The stations were distributed in five areas as follows: Quebrada Sonadora 13, Quebrada Grande 13, que~ brada Jiménez 34, freshwater of Rio Espiritu Santo proper 27 and the estuary 14. The upper limit of the estuary is located above Highway No. 3 at sampling station No, J.

Field Methods

Decaped Crustaceans

---Page Break---

22.

?The following methods were used

Yocks and stones were disturbed in riffle areas and the

animals collected in a net helé across the stream.

b) conical wire mesh traps with baits such ae raw meat,

cod fish and coconut were used for luring crustaceans

in pools.

) dip nets

?) visual observation

?) diving

£) 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 ar:

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

organisms.

Plankton and Drifting Invertebrate Larvae

a) A plankton net of bolting silk No. 25 was used for

both freshwater and estuarine collections.

b) in freshwater, the plankton net was lowered just

below riffles for a period of 15 minutes and surfac

and subsurface hauls were implemented in pools.

os for

©) in the estuary, surface and subsurface %:

15 minutes at each station.

---Page Break---

Sonthic ¢rve/its an¢ bottom sediments in the estuary

a) Ponar crab dedge which encloses an area of 0.05

nm? wa used.

b) One of the Triplicate samples was preserved for encm

ucrone and benthic organtase costed using # 2x

tora wottanse

4) detailed observations on Neritina reclivata were

stricted to sampling stations No, 15 threagh 2/

of the Rio Espiritu Santo proper, since this

part of the river has large populations of the

snail, many with extensive shell damage.

4.2.8 Alone eel facies

a) Rock and soil substrates were examined

b) attached algse were scraped off and preserved

for identification.

---Page Break---

4.2.5 Pash

a) Visual observation

b) communication with local fishermen

¢) throw nets

4.2.7 Physicochemical neasurement

Fresh water:

a) In situ measurenents for dissolved oxygen and temperature were determined with a YSI Dis~ solved Oxygen Meter, Model SIA equipped with a YSI Oxygen temperature probe.

b) pH was measured with an Orion Specific Ton Meter Model 404 having pl 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 pli, conduct- ivity, 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.

---Page Break---

43

4.3.2

4.3.12

4.3.2.2

gamble handling anc 2:

All organisns

10% formaldehyde or 70% alconc! exc;

????

<T57 individuels of Neritin

2 reclivate which were

taken to the leboratory for experiments and observations

?on shell erosion.

Laboratory Methods

Identification procedures

Decapod Crustaceans

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

b) Confirmation of some species by Dr. Vélez of

the Biology Department, University of Puerto

Rico andothers by the Smithsonian Institute,

Washington, D.C.

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) sand,

Jacques (1947) were used to ide

sity invertebrate

larvae.

---Page Break---

Benthic @rre4n's

2 a) Tdentified by Miss Charlene D. Long of Arlington,

massachusettsant 7. CUetsten Eracus

ef whe g/aivers ity ef Fe rede. Sweted

IE ae a v

Fev phe ten 7

{ Oi ,Contitmed by De. H.C. Dutnie, BruAsy difotnens,

Mimverate og? cen renee, Con Fiand .

\O aeaa8 Fish x2 x Lr revtog,? Ge | Ola nnetn |

\ a) Confirmed by keys of Erdman (1972).

XN 4.3.2.4 Molluses

tnd Tutor

a) Identification keys of Warmke, (1961) and Emerson

and Jacobson (1976)

4.3.3 Estuarine bottom sediment analysis

The method used by C unnins (1962) and accepted

by EPA (1973) was used to determine particle size. The

bottom sediments of the estuary were sifted through U.S.

sieve nunbers 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 sanaf Tae

2 Bhe silt and clay, which

passed through sieve number 230 new calculated from the

original anount of sediment by ? Sing aut eclfagng .

atafentively

For chemical analysis, sediment samples from 16 stations

(Fig. 1V-2) were sieved to renove 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.

3

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of ye00"0 ?G2t"0-S290"0

oct 6400" ?<2"0-Gat'o

09, 600°0 S*0-Se"0 Pires any poH

Se 16'0 Teo pues 2nav09

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(ust ?6°L) 2TE*0 9-8 rere,

(we 6°61) $29°0 2-90

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Saonbe supa TenpyaTpaT i seg arqioa

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a To SHSTEATEBS 7a HT TEI Uy vas aes yaTEg JO oa

SSTAL ?sn up ?xoaddy -1ua 50 sito,

?quouaansgen 30

spouyem pun 9236 uso

*(2u60)_s9uM wors woHVa PUR (295T)

seyshraue ezjs-210F31?4 20y spomaM puw ?soTaoloyND ?MoLouTutoy poasaimur) Al oTAwS

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An atomic absorption spectrophorometer; Model 303

was used to obtain Ce and Me concentrations whereas the

standard cadmium reduction method with éiazo color

development (APHA "Standard Methods for Analysis of

Water and Wastewater, 1976) was used to derive the NO),

NO, nitrogen concentrations. Sulfate was analyzed using

turbidity measurements of barium precipitated standards in the presence of glycerol (Hach Chemical Co. Ame:

50010).

10.,

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Fresh shelis from wi

he Yiving anima

been removed were digested with Worthington «:

enzymes at pH 8 in the presence of calcium icn and

stabilization conditions deseribed by Sipos and Merkel

(1970). The digestion was carried out overnight (24

hours) at 25°C. Fresh snail shells processed as des-

eribed above were also digested with Signa Scientific

Co. papain enzyme in the presence of cysteine and EDTA

according to procedures outlined by de Jersey (1970).

The @igestion was carried out overnight (24 hours) at

10°C. Presh 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 sone 6 weeks with visual ins-

pection of the shells nade every two weeks. The rinsing

was carried out in a Series ef constant r/ow a, sania

WA afiliel enter from a meando

stream +> Ey binte,

System

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Fico Nuclear Center bet hag te be

gue mainly to the dif.

of funge! and tempera

e. At the

El Verde Field Station, a series of constant flow aquaria system was set up. PVC tubes were used to transparent water froma 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-3).

In order to maintain a constant level, a siphon consisting of a sieve and attached to a level controlled bottle was used to allow the outflow of excess water through a drain hose.

Inside the aquaria were-placed-sand; pebbles ?and

azgez stones to ainulate stream conditions. shrimps

were collected from the freth water streams and brovsht

to the laboratory. They were then {denti#ied, sevaraved

nto various aquaris, and fad with deteieue, brine sheiaps

and bits of meat and coconut. Temperature was about 19°C

to 20°C.

Bioassay experiments on salinity tolerance were

conducted when z00a oF larvae were available. fhen

gravid or berried fonales were observed, they were renoved

from the aguaris and transferred to wide-nouth gallon glass

jars, Aeration vas provided by means of a manifold system

consisting of two piston air pumps which sent air through

BY

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ecting tuse to 2 Pasteur =

the necessary aeration.

Dilution of filtered sea and stream wet

to achieve

salinity concentrations of 108, 15%, 25%, 508, 608, 708,

80% and 908 seawater including 100% sea water and stream

water was prepared. Four zoea or larva of the sane

species were then placed in 50 ml. beakers in triplicates

at the various salinity concentrations, No food was sup-

plied during the experiment which lasted 96 hours. Observ-

ations on survival and molting were made every 12 hours and

the results recorded.

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CyvADV USHi0 OL ONIGVS) adid DSVIS

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5.12

Results

The results consist of some selected physico-

chemical characteristics including water chemistry

fauna comprising of decapod crustaceans, plankton and

drifting iv

tebrate larvae, benthic organisms and

bottom sediments, mollusc, and fish, and flora consisting

?of pefiphyton and acres d, Has.

In addition, laboratory experiments on

shell erosion in Neritina reclivata have been examined.

Field Work

Decapod Crustaceans

Twenty seven species of decapod crustaceans were

observed in the Rio Espiritu Santo system and are listed

as follows:

order Decapoda

Suborder NATANTIA

Section Penaeidea

Family Penaeidae

Subfamily Penaeinae

Penaeus schmittd

section Caridea

crangon sp.

Section Caridea

Family Atyideae

*atya innocous

?heya Lani}

shiva Seabee

atya poeyi

TEproesriS stongata

---Page Break---

séction Caride;

Family Palaenonidae

subfamily Palaemoninae

sMacrobra acanthurus

*Vacrobrachium carcinus

sHigcrobracniun Crenulatun

Macrobracniun Faustinum

*Hagrobrachiun hecerochirus

suborder REPTANTIA

Section Anomura

Family Paguridae

Clibanarius cubensis

Section Anomura

Family Coenobitidae

Goenobita clypeatus

Section Brachyura

Family Portunidae

subfamily Portuninae

Callinectes sapidus

Gallinectes sp.

Section Brachyura

Family Pseudothelphusidae

Subfamily Epilobocerinae

*Epilobocera sinuatifrons

Section Brachyura

Family Grapsidae

Subfamily Grapsinae

Goniopsis cruentate

Pachygrapsus gracilis

section Brachyura

Family Grepsidese

subfamily Sesarminae

Aratus pisonii

Sesarma ricordi

Sesarma roberti

yo

---Page Break---

Section Brachyura

Family Gecarcinidae

Cardisoma guanhuni

Section Brachyura

Family Ocypodidae

Subfanily Ocypodifiae

Uca leptodactyla

Uea Sp. 1

Tea sp. 2

Ucides cordatus

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 7om. were collected in March.

Of the 10 species of freshwater decapod crustaceans, 9 were observed in Q. Sonadora with M. acanthurus missing.

7 le v=) Crable v-3),

1m Quebrada Grande, 20 well as in Quebrada aiénees @

species were observed:

crenulatum was least abundant and

not observed were Atya innocous, A. scabra, Micratya poeyi,

Macrobrachiun heterochirus and M. acanthurus. In the Rio

Ca

Espiritu Santo freshwater mainstream, # species were

observed with M. crenulatun the least abundant and A. in-

4h

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21.2

one

the estuary

the afcromenticned

reshwater crustaceans were

restricted to the upper limite of the estuary, Atya lanipes

which was found to be dominant in all freshwater habitats

was scarce. Similarly, Kishocaris elongata and M, carcinus

were not as abundant as in freshwater, However, M.

acanthurus increased in population size and was distributed

almost throughout the length of the estuary. The most abundant estuarine species observed was Uca sp. 1 as

compared to M. faustinum which was quite scarcey@ L7° +

?The altitudinal distribution of decapod crustaceans

ing quite conspicuous 4iy~.J.3), A, lanipes and 2, elongate

exhibited the widest altitudinal range (5-780H) followed

by E, sinuatifrons (18-750H) and #, carcinus (5-5234).

A. innocous was restricted between 295 and 440 M., Me

gcrenulatum 39-440M., , heterochirus 150-550M. and M.

acanthurus 0-30M.

The longitudinal zonation along the estuary fig 3)

was also quite pronounced. §, acanthuri

and vea sp. 1

showed the widestaistribution, whereas M. faustinum, P.

Schnitti, C. cubensis, and Crangon sp, exhibited limited

zonation patterns.

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

aeacRida. Five species were noted within the Order Diptera

w

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ante Eyer ee Upper inte: 20.05 sive

fanaa

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ity Sante

hwater strean(Tahle 1

@ orders were observed, O. Jiménez 6, 0. Sonagora 6, 0.

Ciable u-8) (Cable o-<

Grande 4 and the estuary ?. In Q. Jiménez.and 0. Sonadoza,

the same number of orders and species was observed but it

was noted that the following were not observed: ydracarina*

i.

Henptera, Coleoptera, Amphipoda and Decapoda. In Quebrada

Walle 7)

Grande,in addition to these, there were also missing

Diptera?, piptera®, Ephemeroptera and Plecoptera. Not

observed in the estuary were Diptera?, Trichoptera, Hyéra~

carina ame écee-Feres yowever, the ance of Hemip-

4 EES 1 the appeai f Hemip

tera, Anphipoda\; marked increase of decapod crustacean

in the estuary(Table U-1e),

?The average number of individuals observed in a 15-

dary

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 2-month survey and were grouped into 11 species

in 9 families as follows:

eS

?Tharefx sp. was the dominant species and made up

68%. Capitellidae sp. 1 and Sigambra tentaculata constitute

198 and @& respectively. The remaining eight species each

represented less than 14 of the total. The two major as

well as two of the less common species had a pattern of

delimited distribution by gation. Therys-ep?and

s!

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Fanily cérratulicae

Tharyx sp.

Fanily capitellidae

species 1

Fanily Pilargiiéae

Siganbra tontaculata

(readwell, 1941)

Fonily Neroidae

Stenoninerets martini,

Redicira belgica

(Fauvel, 1936)

Fanily Copitedlidae

species 2

Family Glycerigae

Family Capiteliiaae

species 3

Fanily funicidae

Maxs

P-

Family Phyllodecidae

species 1

Fanily Terebellidae

species 2

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102

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546

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\g invertebrate larvae in Quebrada Jiménez

Table. 8. (continued) ~ Distribution of drifting

INVERTEBRATE LARVAE

DRIFTING

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DRIFTING INVERTEBRATE LARVAE

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oun

the sewace

gigambra pentaculate were

cons?

ute 19$-and 6 reepectively. The yemainine eignt

Sbecies each represented less than 1¢ of the torsi- The

tuo. pajor ac eit ae-tro Of THE Tess apecies Hac a rateess

Tharyx sp. and

sigembra tentaculata vere found from the sewage outéal?

(station #7) to the Atlantic Ocean, Stenoninerese martint

and Capitelligse species were found from the outfall south

to the head of the estuary.

?the particle size analysis of estuarine substrate

shothat very coarse sand and gravel decreaselin quantity

trom the head to the mouth, whereas very fine sand, silt

and clay tenho increase (Tablet).

5.1.4 Mollusc

?men species of mollusc were observed in the Rio

Espiritu santo system:

---Page Break---

Class = Gastropoda

Sub-class - Pulmonata

order ~ Basomnatophora

Sub-order - Actophila

Fanily - Ellobiidae

Melampus coffeus

Sub-clase ~ Prosobranchiata

Order - Archaeogastropoda

Family ~ Nericidae

Neritina virgines

order - Neogastropods

Fanily - Littorinidae

Léetorina angulifera

Family - Thiaridae

Terebia granifera

Fanily - Pilidae

Maris cornuarietis

Class - Pelecypoda

order - Filibranchia

Fanily - Ostreidae

Crassostrea rhizophorae

Family ~ Dreissenidae

Mytilopeis doniningensis

Fanily ~ Lucinidse

acoides pectinatus ? f1

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uvussans 40 SISKTN 3ZIS SIOTRAVE SOWING ATHLNON

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5

ramen inte

21.5

-1.6

and upper estuarine habitats. It was ai

dora with an

elevation cf 85M. and except fer Q. Son

altitudinal range of 180M = 945 M, it was £

14 elsewhere.

on on shell erosion has been noted for this

epecies.

The scarcity of M. cornuaretis wes quite marked and

it was noted only in shaded pool (station No. 17) in

Q. Jimenez. 1. granifera was found to be abundant in

the freshwater habitat especially in shaded rifles,

A fascinating array of Life is supported by the

tangle of arching roots and branches of the red mangrove ,

Rhizophora mangle. Mollusc such as Neritina vireinea,

¢. rhizophorae, and 1. alatus were fairly abundant. ¥.

coffeus and L. aguilifera were restricted to the mouth of

the estuary.

, the. periphyton consisted

ilerrria ies a

mainly of mosses, ferns.awé . ?Diatofs attached

to mosses were composed of Navicula sp,, Pinnularia sp.,

Eight species of fishes were common in the Rio

Bopiritu Santo System:

Order Anguitiiformes

Fomily Anguillidae

Anguilla rostrata

---Page Break---

order Bele:

comes

Pas

y Belonidae

Belome sp.

order Mugitornes

Family Mucilidae

Agonostomus monticola

Hagil crema

order Perciformes

Family Electridae

Gobionorus ¢ormitor

Order Perciformes

Family Gobiidae

Sicydiun plunieri

order Perciformes

Family Centropoftidae

Centropomus enciferus

Gentropomus undecimalis

§. glumiers, A. monticola and A. rostrate are fresh water species although they wer: also observed at the upper Limits of the estuary. §. plunferi was found to be the nost 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 renaining 5 species are strictly estuarine. However, their presence except for Selome sp. was also observed just above the upper limits of the estuary (station No. 27). M. curema was noted as the dominant

species and wae distributed throughout the length of the

estuary whereas the others were restricted to the upper three

o

quarters of the estuaryy Table 7-1

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quosoad = x fzoryzuop wear epeadend ~ 9f0

Aaengo zoapy owes mITITdsa OFA at|y JO YSFT Due OMNTION Ey FoTTEL

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ys

In situ measurements of pH and te

indicated @ general tendency tc increase downstream, the exception being Q. Jimenez which showed a negligible decrease

?The general picture for diss

decrease downstream! Again, -Qv-dimenez which showed @

was one of gradual

negiigitte-decreave: | The?genezal picture-fordinsoived

onygerwee-one-of gradual decrease-domnstreim. Again,

0. dingner @isplayed sone variation, that is, there was

a slight increase to sanpling station tio. 8, followed

by a tendency to decrease beyond this point, In the

estuary, two average low readings of dissolved oxygen

were recorded, At station No, 7 an average of 4.25 mg/l.

at the surface and 3.0 mg/1 at the bottom were noted and

nost Likely attributable to the sevage discharge from the ton of Rio Grande. At station No. 9 in Q. Juan Gonssilez,

the low @issoived 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

correspond4#o the depth of the sampling stations. In the

estuary visibility vas high in most cases, at tines extend

ing to the bottom up to about 2.5 neters. Occasionally, due

to heavy rains, water transparency was rather low extend

ce

---Page Break---

respect to Ca and Me concen:r:

in Table V-2!

Wich the exception of station No. 9 values

Ca and Mg concentration are lou indicating thet this tributary contributes little to che metal ion burden at the confluence with the Rio Espiritu Santo River

Quebrada Grande and Quebrada Sonadora were also analyzed with respect to calcium an magnesium concentra tions at the sampling stations for this survey, Results are shown in Tables V-20 and V-i9 respectively. The lowest netal ion burden contributed by any of the tributaries comes from Quebrada Sonadora, This is consistent with observations of Cuevas and Clenents (1975) that land use patterns in-fluence stream burdens, since Quebrada Sonadora courses through undeveloped forest.

Estuary

Some 10 estuarine stations were surveyed to determine the NO} + NO} nitrogen and sulfate loads. The results

for sampling period of low flow conditions are given in

Table V-23. ck

These measurenents tend to confors,a marine type

chemical environment at the bottom of the estuary such

a5 that associated with a variable tidal wedge of high

salinity (salt wedge),

---Page Break---

vabie + Summary of the Results (mg/2)

sium, Caicium, Magnesium, and Chloride in Stream Water Ac-

cording to Vegetation Types.

for Sodium, Votas-

(Cuevas & Clements, 1975).

Vegetation

?Type Sodium Potassium Calcium Magnesium Chloride

Forest 5.624 0.06 0,3040.00 1.0480.01 2.0840.04 15.754 0.96

Grassland 8,184 0.22 0,3940.00 1,8840.07 4,200.20 21.074 1.36

Upper

Estuary ?8,14423,03 3,2940.84 2.3440.23 14.8643,33 34.27497,83

we

---Page Break---

CONCENTRATIONS OF CALCIUM AND MAGNESIUN

IN QUEBRADA SONADORA (mg/1)

sta. No. ca Me

East Branch

1 0.65 2.33

? 0.78 aaa

West Branch

2 0.80 1.08

5 0.98 3.87

Main Stream

6 1.08 a.62

8 1.06 1.54

9 0.74 2.13

---Page Break---

5.3

Chemistry of estuarine sediments

Semi-quantitative analysis showed that the following

elenents were found to be above 100 ppm concentrations in all

sediments examined: Al, Ca, Cu, Fe, Mg, tm, K, Na, and Ti

whereas concentration levels below detectable limits w noted for Sb, As, Ba, Ce, Cs, Co, Ge, HE, Mo, W, U, 2n 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),

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FF

5.4

LABECATRRY Ere cImeTS

shell erosion in 8. reciivate

Nerstina ceclivata was dominant in both freshwater and upper estuarine habitats. Polynosphisn of variations in color pattern were evident anong all of the populations of N. rectivata presunably oving to variations i+ deposition of calcium carbonate in the form of calcite and aragonite infiuenced by specific properties of the conchiolin overlayer (Watabe and Wilbur, 1960). The conchtolin over~ layer appears to be formed during the denaturation of a nuco-scleroprotein secreted by the snail and contains a snot] amount of mucopolysaccharides (Kade, 1966), Digestion of the fresh shell with trypsin ond papain or detergents aid Little to dissolve of lyse the conciolin layer, though 4 was solubie in chlorine bleach. The layer at the shell apex tended to be dissolved avay sooner than the rest of the shell. Prolonged cinsing of the apex anending shell revealed no further shell danage.

tn general, smaller snails were undanaged or less damages than larger, older snaiis and erosion of shells of younger snails was confined to the shell apex. A typical

temporal sequence of the shell erosion is shown in

---Page Break---

TontersFaron

denent 30 ee, 16-200 oe

ae 3-9,22, 26-26 20,1235

B 45,38 2-3,22,26.27 3e,22-35

be OD 2-3,23, 26-28 36,3225

BOLD a 20,22-18,

ca -1-9,22,28 12-25 20

cr 12,1618 3, 4,20-25 2,259

ca 4,28,9,22,25-38 ?3+7,30,22-24

mi 37,28 23,589, 2,4,6,7,25)16 ro-28

° 1-9,25-38 20-24

n 37,38 1-4,35,36 5-24

sr 2-92 20,22-28

1,38 1-9,36,27 10,22-25

mL 25,22,24-28 6-20, 22,33

v 23,28 19,20, 12-27

---Page Break---

satin

2 425,28

Be LP

Bw 1g

ca -1-9,2,28

ce 12,26-38 3,4, 20-25 1,2,5-9

ca -42)8)9,22)25-28 3-7, 20,22-14

mi 37,38 1,3,5:89, 2,4,6,7,2506 20-28

P 1-9,25-28 yo.

17,38 2-4, 15,36 51h

Ven 30,32-28

te 1238 1-9,26,37 20, 22-35

n 2-5,22,28-28 6-20, 22,13

v 33,26 1-9,20,22.27

---Page Break---

5.41 Shell erosion in X. reelivata

fas 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 i+ deposition

of calcium carbonate in the form of calcite and aragonite

influenced by specitie properties of the conchiolin

overlayer (fatabe and Wilbur, 1960), The conchtolin over

layer appears to be formed during the denaturation of a

uco-seleroprotein secreted by the snail and contains @ anal

arount of mucopolysaccharides (Kaga, 196), Digestion of

the fresh shell with trypsin and papain of detergents éid

Lastle to dissoive oF lyse the conciolin layer, ehyoush

4 was soluble in chlorine bleach. The layer at the shell

apex tended to be dissolved avay sooner than the rest of the shell, Prolonged rinsing of the apex anending shel

revealed no further shell dana

In general, smaller snails were undamaged or less damaged than larger, older snails and erosion of shelis of younger snails was confined to the shell apex. A typical

temporal sequence of the shell erosion is shown in

---Page Break---

The specimens en the

ne visinle erosicn. The pair of shelis, stcond from the

left show in

apex ero:

n, more pronounced in the

bottom spe: ical

jen, the pais second from the right are

of badly eroded shells showing exposed layers of calcite

and aragonite with conchiolin lay

x interspersed. The

whitish sections shown in the photographs occasionally

have a blue or bluish green hue. The shell on the extreme

Tight shows how severe shell erosion can develop, virt~

vally Wie entire surface of the shell lacking the fresh

shiny coniolin layer, Direct observation of predation

in progress was not unccnmon with as many as 4 snails stacked

one upon the other in 3 instances of some 59 observations.

---Page Break---

Photograph a

---Page Break---

bioassay on sal

Crustacean Larvae

M. acanthurue goea did not survive at all in freshwater whereas those of A. lanipes seemed to have done very

poorly under

ilar conditions

All zoea of A

innocous survived between 2)

and sea water during the experiment of 96 hours.

|. erenulatum zoea survived for the first 24 hours in

freshwater and 10% sea water. They also survived between

25% and 70% sea water but did best at 50% sea water.

M. heterochirus zoea died after 48 hours in freshwater,

but 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

fundred percent survival was observed between

50% and 80% sea water.

7

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Oc cr [Ee

Hitacara Saat (ont)

sm tence (200822)

e nmessssres fl comsassane

Bi pitanaeess oumssaunan onnsansaue Wessessses ?naneasena

eg

: erenaees maszzznaas cannaazane sennaaaate sonanasacs

Eeeeermeent Pommnepaed oimenned Lovaeeerets oomnnseee:

a

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| Decapod Crustaceans

ih ends ghiidy Prenty seven species of decapod crustacean

were identified in the Rio Espiritu Santo system inclusive:

ef the estuary.

Gigford and Cole (1972), failing te find any A. innocous in the Sonadora ané Rio Espiritu Santo concludes that this was a result of steep turbulent waterfalls, sone of notice able height, and svitt ritties, Bbsy showed a preference for slow flowing streams, Chace and Hobbs (1969) elainthat the animal shovel very Little restriction in terns of its | ecological and geographic distribution being found in the mouth of the Layou River (Dominica) 100 feet from the Carib bean Sea and in other fresh water regions. It seems to be at hone in mountain?? and cascading streams, upland pools and in waters of lowlands. In our study, contrary to Gifforé and Cole (1973), the species was observed at Q. Sonadora, common in cifeles and at an altitudinal range of 295-440 neters.

A. innocous exhibitMche peculiar trait of facing the

current and procurly food by the constant movenent of the bristled first and second pereoipods of the chelae to and

from the cirrent arid mouth, In constant flow aquaria, they

are usually found where the water is in constant movonent.

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.

---Page Break---

end of March to the end of July.

postulate of Chace and Hobbs (1969) that a marine phase

?or the family Atyidae agrees with our

results innocous. The other species will be discussed later. ?The zoee of A. innocous exposed to salinity concentrations

from freshwater to sea water showed that while the larvae seemed

to thrive exceeding?

well from 10b to 2008 sea water, they were
appreciable affected in freshwater,
A. lanipes vas found in every stream where shrinp were

present (Gifford and Cole, 1971) and is considered to be
the most widely distributed of the decapod crustaceans
tnroughout Puerto Rico (Chace and Hobbs, 1969), Results of
this study clearly indicate that it ie the dominant spectes
wohch apounds in all the freshwater Rio Espiritu Santo systen
but is quite scarce in the upper estuarine waters, Ite alti-
vadinal dietethation yap opted betwnen 5 and 780M, citfora
and cole (1971) that A. lanipes is found in
those waters where A. innocous cannot survive but this study
shows that this is nots since both species afeyfound in

conaon habitats. A. lanipes prefers to feed just below rif-

fies entering pools whereas A.

innocous is usually found at

the edge of riffles entering pools. A. lanipes feedson detri-
tus 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-low. Gifford and Cole
(2971) indicated that it is probably the most important species
for the recycling of detritus and nutrient input into the
streans.

A marine phase is postulated (see above) and our salinity tol-
erance bioassay analysis accords with this view. Most of the zoca

Gied in freshwater and did not thrive well in either 10% or 15%
sea water. ye

---Page Break---

A. seabra 18 rouna 4n tu

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 obser However, sub=

sequent examinations of fast flowing feeder brooks of Quebra~

da Sonadora confirmed the reports of Gifford and Cole (1871),

?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 riffies, the |

method of feeding is most likely quite similar to that of Ay |

innocous because of the presence of bristles on the chelae,

Chace and Hobbs (1969) found gravid fenales of A, scabra

at the end of January and Gifford and Cole (1971) reportea

their presence in Decenber, hence breeding occurs around this time. !

Gifford and Cole (1971) reported that M, poeyi, the smal~

lest of the decapod crustaceans was restricted to one streang

our study shows that this species was found, in Q. Sonadora

at an elevation of 380 meters in a shaded pool with weak

currents. Chace and Hobbs (1969) noted at least to quite

aifferent habitats; rivers and cascading brooks and in drain~ |

age ditches with strong currents among roots of aguatic

plants. they alsoff?"? that by using pronox the animal i

showed greater sensitivity to this poison than other crustas

coans. Gifford and Cole (1971) inferred that the presence of

tufted pereoipods could well indicate filter feeding.

Chace and Hobbs (1969) made-menticn of the-feet that theugh

the-spectss, HN, poeyi breeds throughout the year, most of the

eggs are swept downstream and out to sea,

vemgs wyrmrg ee me Poprpes pox pear exyere ong ?Gaemeny

---Page Break---

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

ee

abundance to Ay lanipes and comqely 2. contributfen

much to the biomass of the system, It was observed that Hees t

ite-mede-ut 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 aguatic plants (Lewis, Ward, and Metver, 1966), The mature males are equipped with massive claws which make them deadly predators, Their feeding pat~ tern is to lie in wait for its victims, The observation of heavy populations in areas where garbage was dumped indice ates that the animal, while omnivorous, is also a scavenger (Lewis, 1961),

ovigerous ferales were noted between May and October with

the highest fect

ity in August (Lewis, Ward and McIver, 1966).
our study showed that they were common from the end of March

to the end of July

&

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bugan et,

(1875! give an e

lent review of the

lige cycle of Macrobrach.

Mating follows the female's

prenating 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 felmle deposits eggs into her brood chamber, they are fertilized by sperms, At 28°C, development of fertilized eggs take 16 to 20 days. M, garcinus carry 120,000 to 140,000 eggs while M. acanthurus may have 8,000 to 18,000 eggs, Stage I larvae of M, carcinus (vewis and Ward, 1965) and M, acanthurus (Choudhury, 1970) are 1.44 mm ané 2.25 - 2.35 mm in length respectively, Stage

arene

IM. careinug.are fre swimming while those of M. acanthurus

usually cling to vegetation and becone planktonic at Stage H1, 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 1008 sea water do not survive (Lewis, 1961; Choudhury, 1970), First stage larvae do not feed and after passing through #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

---Page Break---

both omnivorous scavengers and cannibalistic

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 meta~

morphosis at salinity concentrations of 35% and 23,5s¢respect-

ively whereas no larvae reared at 12% reached metamorphosis.

Choudhury's work (1970) showed that larvae

ared in salinity

concentrations higher or lower than 60% sea water failed to ne-

tanorphose, Choudhury (1971) showed that larvae reared at 338

salinity perished within 11 days and that the maximum survival

and development took place at salinitics between 15t and 208 at

a temperature range of 23-27°C, Dugan et. al, (1975) observed

Hughes and Richard (1973) observed that M. acenthurus larvae

remained at the bottom of an experimental canal with running

waters during a decrease in salinity whereas they moved through-

|

|

this behaviour prevents the larvae §:

moving to the sea

and

intains 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 heyad dspute-

---Page Break---

H. cronulatum abounds in

weil as in shallow rocky areas of larger stveas

it is

also common in drainage ditches (Chace and Hobbs, 1969),

?This study showed that they were also present throughout the

reshwater system especially in pools at an elevation of

30-440 meters, Like other members of this genus, the

larger individuals are usually found concealed ben

h 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 fenaies

were made in February, March, April, May, August and Septenber

(Chace and Hobbs, 1969) and they were conmon 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 extrenes of fresh- |

water or sea water. Twenty five to seventy percent sea water was

best suited,

According to Chace and Hobbs (1969) both young and adult

M. heterochirus were found to be restricted in riffle areas

and low cascades, Our study indicates the importance of rif-

fles where they were found to be common at an altitudinal range

of 150-500 meters,

the presence of claws, though not as massive as M, carcin,

and M, crenulatun would suggest that a similar type of feed-

Tie toting ratern wasnt oars tot |

sng 42 tepiicated, Chace and Hotbe (1969) noted ovigerous |

---Page Break---

females an Fe

study established tha

they were

the bioassay experiments showed that the 13;

us did not thrive well in freshweter snd died

E, sinuatrigons 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 strean banks, However, the young are restricted to an aquatic habitat, ?They feed on any kind of decaying material and ate thus considered sanitary engineers of the forest (Gifford and Cole, 1971). Very little is known of their life cycle.

our work shows that £, sinuatifrons are found throughout

reaches of the estuary. U,

4

cordatus was found in bérrows

between mangrove roots and similar observations were noted

for Yea sp, 1. The distribution of both species was limited

to areas periodically inundated by the tides, G, cruentata

a

was always observed wondering among mangrove roots of Ry

---Page Break---

and Laguncularta racemosa ané occasional:

the golden tern, Acrost: aureur,

observed crawling on mangrove roots ané branches but never on the forest floor. P, gracilis inhabits submerged mangrove roots and @n decaying tree stumps,

Other species of brachyuran crabs such as Uca Jeptodactyla, Sesarma ricordi, Callinectes bocourti (referred to as sp. 1 in the tables) and the two species of ancmuran crabs, Cli~ banarius cubensis and Coenobita clypeatus were also observed in the lower reaches of the estuary. U. leptodadhia ane s. ricoréi inhabit sandy shores, However, the latter species ana §! ciypeatus 326 often found arong grasses and in areas

where beach debris accumulates. Aquatic crabs such as ¢.

cubensis and C, bocourti were observed in the mangrove forest,

but the latter species was also present in grassland ari located in the upper half of the estuary,

Other brachyuran crabs such as Cardisoma guanhum Sesarna

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 bi

observed behind mangrove forests and the adults may establish

populations in cane fields or grasslands quite a distance from

the river or sea shore, $, 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

---Page Break---

also collected in the mangrove

ag. However, it was not

s0 common as C. bocourti wh:

ch also shares both mancrove

and grassland habitats.

he caridean shfimps Atya lanives, Xiphocaris elongate

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

ee aw

close to the river mouth. Zt is typically gm estuarine

species and was the most abundant shrimp. Very rare were

uM. faustinus, Crangon sp. and Penaeus schmitti which were

Limited to the mangrove areas.

---Page Break---

covered that davertetrate Gri wus a normal process even i of strong currents. Muller (1951) accounted for the drift on the tacis of

competition for food and space and further cay it as an agent in population @ispersel. Waters (1965) spoke of "behavioural drift? to indicate a aif- ference between constant and catastrophic types. He also seened to sgree

with earlier studies in respect of the coutrol and regulation of popul-

ation densities. Elliott (1967) advanced another reason for the drifting phenonenes namely, thet organisas lost footing or vere dislodged in the competitive struggle for food and space. Hynes (1972) citing (Muller, 1954 and Waters, 1961) ut forvard the view that drifting resulted through po- polation explosion in areas and that the process replaced lost specimens further downstrean, hile others in the drift provide food or are simply dost, 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 e very interesting work in Ghane, Hynes (1975) showed that arifting fauna is normally the result of mechanical éislodgenent of indt-

viduals of the bobtos organims end exposure to the risk of being carried

away into the drift 1s affected by behaviour, especially responses to light

sted that there 4s no evidence that drift so

te drifting pattern of the invertebrate as observed in the Rio

Reptrith Santo cysten varies. In the ain river's freshwater habitat it was

observed that the movasent of Diptera?, Diptera?, Odonste and Trichoptera

were about the sane. The other species were more or less irreguler, Tn

---Page Break---

iner ané G. Sonadore , the specter ob:

a

syation. Tn @. Grande, on the otherhand, all specter except =

and Hydracarina? shoved an almost equitable distribution, In the ine

habites Decapod larvae exhibited a rather regular ai

ybution (except for

sampling station No. 35 where 2 vere collected) as compared to the other

species expecially Amphipoda, Heniptera, Cvleoptera, Lfonatu and E pte mere te

?The average number of individuals per sampling station showed 22, ?

4, 9; 7 and 14 for Rio Espiritu Santo proper freshwater, Q. Jiménez, Q.

crane, Q. Sonadora ant the extutry respectively, Frm this one ean contide net tne tio Eeprita Santo proper freshuater habitat Se more protuctive with

nines the test. .

the lange mater of speichl2 tne treminter of Ho

eptrita Santo proper would seen to reflect less environmental interference

?than @, Grande with fever speci

s?fne consequently the probability

of greater enviromental stress.

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6.3

Benthic Annelids

Siganbre tentaculata and Thazvx 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. martin were all collected at the

headwaters of the estuary in February, 1977. Three of the

specimens contained large eggs and another appe:

indicating thatthis is an established breeding population.

martini is a Caribbean biological indicator of stressed

fan

situation (natural or man-induced), the presence of S.

kentaculata is also indicative of stressed conditions (Charlene

Long, personal coumunication).

---Page Break---

while Y. comuaretis was observed to be the least dominant. The latter species

and Tarebia granifers vere restricted to fresh water. %. commuaretis, an ampullarié

snail, is # control agent for Bionphalaria glabrata the intermediate host of

pitharsia. Its presence in a large pool (Station No. 17) im Q. Jinéner at an

altitude of 70 meters needs investigating. I. granifera, a chiarid snail is

?also used as biological control for 3. glabrata. It sometines forms heavy

mats in the botton and sides of the streams and river. Tr is believed that this

snail out competes 8. glabrata for space and food and also e

s its egg masses.

1M, coffeus and L. angulifera vere restricted to the mouth of the

j the former species was quite abundant and commonly observed on mud flats

and mangrove roots while the population of the latter species vas quite small and occupied exposed mingrove roots. ¥. douingensis vas found almost throughout the estuary, nore abundant in the upper portion and frequent river rocks. Tt some- tines shares ies mangrove root habitat with C. rhizophorae in the lover reaches of the estuary. The cuite scarce edible clans, P. pectinatus and I, alatus oc cupicd muéflate in the nidéie and lover reaches of the estuary. A dense popul-

ation of N. virginea vas established at station No. 8 anong sangrove roots and

ere

mudflats whereas N- 2 vas quite abundant on rocks and bottom sediments in both freshvater and upper estuary.

?The dominance of N

xeclivata can be explained by its wide range of

colerance from fresh to brackish waters. In freshwater it thrives on rocks

where periphyton is usvally abundant; in brackish environsent, it ie comonly

found in the mud between mangrove roots end occasionally attached to mangrove

roots. ?There scens to be a correlation between size and spatial distribution.

saatier snaile are found in brackish vaters and the lover parts of the Rio Es

piritu Santo whereas larger sizes are observed at their upper Limite of distribution

---Page Break---

It wus euservue that shell eresion was co in fresh water on te this specks

while in estuarine conditions the phenonenon as quite rare and only in the fore

of a tiny hole in the apex. Ferguson (1959) has suggested that shell erosion

caleiu.

night well be a condition which results from » craving for ext

?The experinents undertaken with spex-eroded shells are additional

indications chat predation is responsible for che erosion. That this predation

is intraspecific could be inferred fros several other observations

First, at least two other Neritina species exhibit shell erosion.

N, punctulats undergoes this response to calcium deficiency (Aguayo, 1976)

and N. virginea observed in the Rio Espiritu Santo estuary . The only other

virginea.

potential competitors such as Tarebia granifera or Biomphalaris glabrata were never observed attached to the external shell of a living specinen of N, recliva Secondly, only shells of living snails were observed to be attacked, indicating that the particular conch{olin 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 pat~ terns conventionally observed.

Finally, under the dissecting microscope, apex erosion features appeared as snall caves, occasionally with shiny green diamond-shaped crystals inside. On the whole, hovever, they most resenbled holes created by continued

dissolution of the celcitic or aragonitic layers below the outer conchiolin shield.

This may be a dissolution phenosenon dependent on metabolic ensyses for caleiue ccvbonate secreted by the individuals of the epecies.

Hynes (1972) alse noted that oven in soft waters where there is very Little ealeium the unbo of the shell of the mollusk, Margaritifera

margeritifera is often dissolved away and replaced by white nacre,

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ish

In the R.E.S. systen, 8 species belonging to 6 orders. Three of these (S. plusieri, A.monticola and 4. rostrata) axe known to be native to freshwater habitats though they have been observed in the region of the upper limits of the estuary. §. plumieri showed a preference of an altitudinal range of 5-600 M. while A. rostrata was found within the altitudinal range of 5-200 4

Five species (Beloue sp., M. curema, G. dormicor, 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 ork 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 re-~ search many interesting and useful details will come to

hand throwing more light on this subject.

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Physicochemical characteris!

Data of pi and tenperature showed a tendency 0 increase downstream in the freshwater system. General- ly, 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 « well established cattle egret rookery. In Quebrada Juan Gonzélez 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 ts 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 a.

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ingestion of thallium (Encyclopedia of the

of the Chemical Elements, 1968). In the United States,

thallium sulfate was recen: icides

y banned from usage in roden

(Phousen, 1976). ?

~~» It would be interesting to know

che status of challium sulfare én Puerto Rico./In the RES estuary, copper was found in concentration of over 100 ppm in the sedinents for all 18 stations. EPA (1973) suggested that concentrations of copper equal to or exceeding 0.05 og/1 constitute a hazard in the marine environment. ?The paper farther aeates thar che polychuere Hevea vizeus fu affyered teeta Beat nt

by copper at songgntrgtions of approninesely 0.1 ng, (ey

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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 Hurmer-stone, 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

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?Thallium (Ti) concentrations showed that 11 stations were

below detectabie 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 cum-
ulative poison and are used as poison for rats, for dyes,
pigments in fireworks, optical glass and as depilatory

Adverse effects of thallium nttrate within 3 days were report-
ed for rainbow trout (§. gairdneri) at levels of 10-15 mg/1;
for Daphnia sp. at levels of 2.4 mg/t-and Gammarus sp. at
levels of 4 mg/l. It was also suggested that concentration

of thallium equal to or exceeding 0.1 mg/1 constitutes a hazard in marine environment. In fact, the Aray Corps of Engineers Regulations on wastewater collection and treatment policy specifically mentioned that the constituent thallium consti: tutefa 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

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marine en!

concentrated 15.000 times in he:

ae; 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 e1 (4971) reported a concentration factor

of 1,000 for cadmium in fish muscle and EPA (1973) sug-

gested that the concentration of chis elenent exceeding

0.01 mg/1 in the marine environment constitute a hazard.

cadmium also acts synergistically in the presence of 1 mg/l

or more of copper and zine (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 poly-

chaete Nereis virens, 5 mg/l for small prams (Leander

souilla), 20 mg/l in the form of

2'Cx0, for the shore
crab Carcinus naenus, 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) festet out that, concentrarion of chrontum equal to

or exceeding 0.1 mg/l, constitute a hazard to the marine environment.

Most of the cited elements discussed above indicate

bicaceumslated 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

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?Yeopper is also concentrated by marine organisms with® 77)

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oo Of 40 me?ke. VEL,

on rats in 3 days demy of Sciences (2967)

reviewed the medical and biological effects of vanadium and

noted the followin

Lethal Doses of Vanadium Compounds

Lethal bose, ap lke

Cospound Rabbit Guinea Pig? Rat Mouse

Colloidal vanadium pentoxide 1-2 20-28

Ammonius metavenadste 1.5-2.0 12 20-30 25-30

Sedivn orthovanadate 23 2 50-60

Sodiun pyrovanadate 4 2 4-50

Sodiun cetravanadate 3 18-20 30-40

Sodium hexavanadate 30-40 40-50 40-50 00-150

Sodium venadste 30-40 10-20 190-250

Yanady!_sulface 18-20 35045 156-190 125-150

Derived from Faulner Hudson

Tt is also stated that the sources of vanadium include

welding of vanadium containing ste?

, coating of some welding

rods. industrial processing of various vanadium compounds and es 3, Chemical and eiectroats Industrses, Vanadien tn

nonmetallurgic use in{the atnospher=. may be caused by COMBUSYion

of coal and processing of crude and heavy fuel-oil

A glance at the other elements observed in the sediments

shows that some, for exarple, beryllium, aluminium, cadmium

and chromium can bioaccumulate in the various trophic levels

EPA (1973) suggested that concentrations of beryllium and al-

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concentrateé 15.01

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Eppirite Santo River drainage

on the basis of its seochenis

which precipitation varies froz 500 em to 150 om per year

Jong 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 & net export of nutrients because of plant mobilization followed by vegetable material decay and mineralization. Some of the chemical paraneters associated with biological product~ ivity 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 streans.

(8) Semi-quantitative analysis of estuarine bottom sediments showed that Al, Ca, Cu, Fe, Mg, Ma, K, Na and TH were found to be above 100ppm concentration, whereas concentration levels below detectable limits were noted for Sb, As, Ba, Ce, Ce, Co, Ge, HF, Mo, W, U, 2n 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

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7 types of rock fo

tions (Quartz diorice

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 Elows.

(2) Fauna and flora showed a marked altitudinal distrib-ution in the freshwater system and a pronounced longi-tudinal 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 zartini 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.

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Espirity 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 om per year

qlong 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 product~ ivity in streams have been measured previously ané 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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further down; @ distance being dependent on the inten+

sity 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 investi;

Seersnegs nS Stasesttons_for_ future invessisation inthe

(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 Agricultur:

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 dr:

tie reduction of pol-

lution in the environment (2) the creation of a stabilized

residue (sludge) that retains the fertilizing value of the

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original material and (3) the producti

resource (methane) than can be stored and used

segently

Some of the oxidation ponds which receive the waste from pige need inprovenents, such as volume compatible to number of pigs. Again, the bioconversion of pig waste to methane ané fertilizer would significantly reduce potential public health hazards,

(b) Of the three solid waste landfill, 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.

(4) About 12 industriel plants are located in the water-shed. Many of these assenble parts whereas two of them do complete processing,including the use of large anounts 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.

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le, The mangro

Lining the ea:

side of the estu

from the confluence of Quebrada Juan Gonzdlez 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 eliminace then

(£) 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 florafentire 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 fecel coliforns.

(3) Hydrology of entire system

Hydrology constitut

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

cuary, it

was noted that detritus from mangrove and other allochtonous sources was abundant and w:

probably the main

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pase of the food web. Bi

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

wed but the extent of importancy of the plankton through-

out 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 includ

(a) identifying potential point and non-point sources of pollution.

(b) establishing sampling stations

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

(8) Laboratory bioassays and field biomonitoring.

(e) synergistic effects of pollutants and environmental factors.

(?) laboratory experiments on the fedback of some toxic elements found in bottom sediments to over-

Lying water.

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