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EFFECTS OF FRESHWATER RUNOFF ON NEARSHORE TROPICAL MARINE FISHERIES

by

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Agreement No. 14-34-001-1150
Project No. A-017-VI

Technical Report No. 16
September 1983

The work upon which this report is based was supported in part by funds provided by The United States Department of the Interior as authorized under the Water Research and Development act of 1978.

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ABSTRACT

The island of St. John is a small tropical island 19 square miles extent and with a population of about 3,000 persons. About two-thirds (2/3) of the island is National Park, now designated as a Biosphere Reserve. At one time 95% of the island was cleared and planted in sugar cane, indigo, hemp, and bayberry. Most of the island is now in secondary to tertiary successional tropical forests.

The two watersheds and bays studies were Lesser Lameshur and Greater Lameshur Bay, both undeveloped areas. The geomorphic profiles for both watersheds are similar; a small flat alluvial plain with fossil beach berms and mangroves at the shore.

Easterly winds dominate this area, and the resultant swells enter the bay at a broad angle. During heavy weather they may be refracted enough to break on the cobble beach.

The marine fisheries of the V.I. exist in a low nutrient ambient area nearly devoid of the seasonal cues, which in temperate fisheries key the reproductive efforts of the fish so that their larvae appear at the time optimum for their survival and growth. In the V.I. appearance of nutrients and the timing of reproduction appear related; but instead of being keyed by seasonal changes, they may be related to the rain and freshwater input, to day length, tides,

to the occurance, survival, and maintenance of the young of various fishery species.

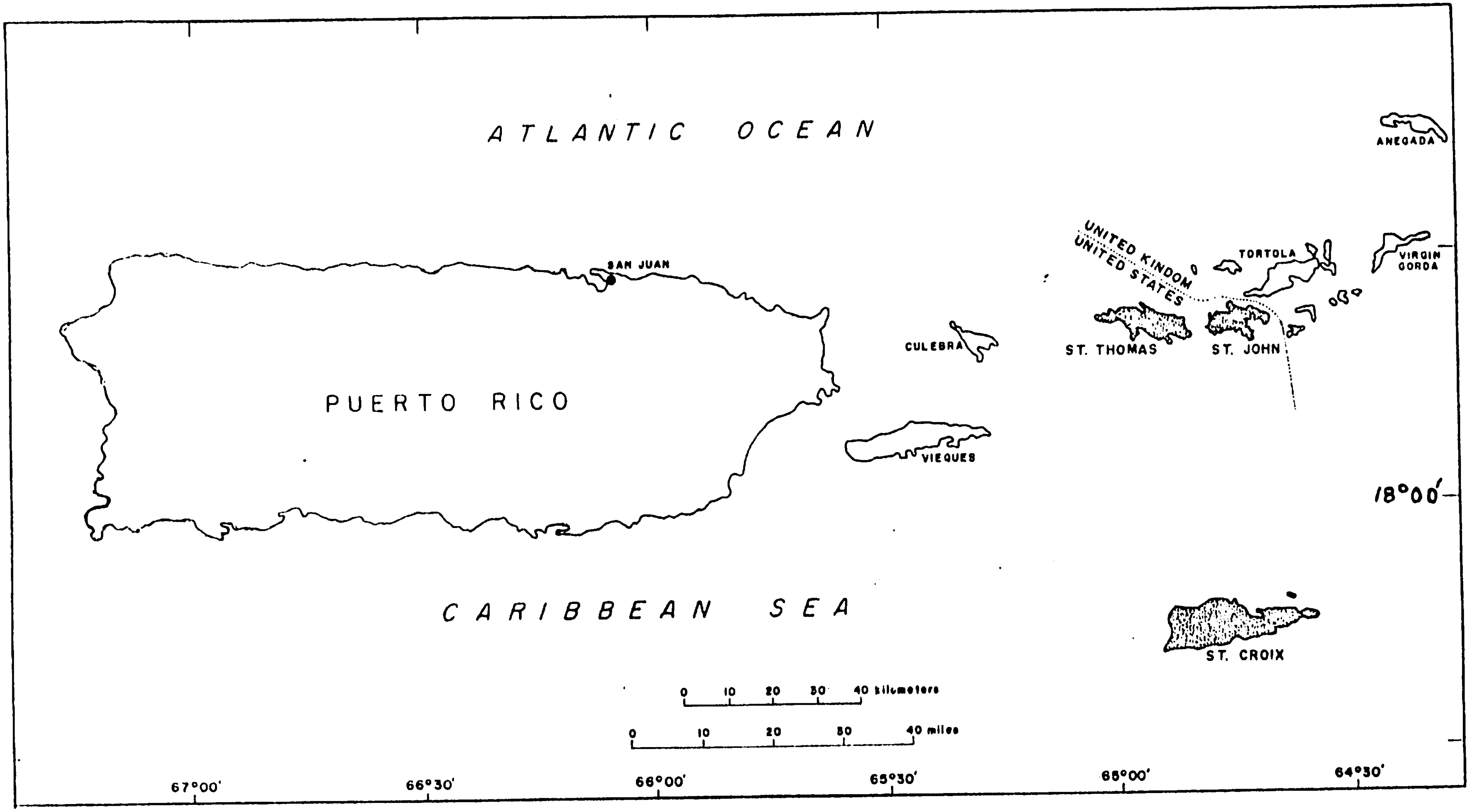

Figure 1.--Geographic setting of the Virgin Islands of the United States.

INTRODUCTION

Rainfall in the Caribbean is highly variable, both in time and location, but differences are not so pronounced specially that comparisons between two watersheds on the same island can not be made. Rainfall for the sampling year, May 1982 through June 1983, was below normal in total accumulation at both study sites. References to rainfall on St. John indicate that this is not unexpected. Bowden (1969) in particular says that the Lameshur watershed when "... Compared to three eastern stations of St. John ...... has a higher rainfall and a greater reliability." Most of the rainfall accumulation on St. John and the other islands tend to be in short showers of less than 1 inch. Evapotransportation is practically always higher than rainfall in this region (Sediment Reduction Plan), and the effects of the light rains are lost to the island almost immediately. Rainfalls of greater than an inch are needed to recharge the aquifer. If the rain comes after a dry period, however, the effects may still be lost due to runoff. The water will start to soak into the surface soil somewhat, but the dampening of the clayey Cramer-Isaac soils will make them less permable (Soil Survey, 1970), and most of the water from such a downpour situation will run off. The question of the effect of this runoff on local fisheries is examined in this study.

The surface soils or the watersheds for both bays are composed primarily of Cramer gravely clay loam with slopes of

12 to 60 percent. The U.S. Department of Agriculture Soil Survey (1970) characterized drainage as good, runoff as medium to rapid, and permability as moderate. The Cramer series soils here are generally shallow (25 - 50 cm) over partly weathered basic volcanic rock. The southern slope is cobbly alluvial land, and stony with resultant rapid permeability and low water holding capacity.

Drainage area for the watershed is 536 acres (2.17 km^2) (Sediment Reduction Program, 1979). A natural berm which rises between the flats and a cobble beach generally serves to retain the runoff. There is one permanently inhabited dwelling in the watershed, the N.P.S. ranger residence (Figure 2). A septic field is used for waste disposal. There are also two pit/chemical toilets for use of park visitors. A beach occupies the Northern shore of the bay. In Lesser Lameshur the Juacas sand beach to the east is seperated from the cobble beach by a rock outcropping which extends into the bay about 30 meters, with several rocks emergent. The outfall occurs on the western end of the cobble beach. Use of the beach by visitors is not high, as access must be over the single dirt road or by foot.

The bay bottom in Greater Lameshur near the cobble beach is rocky with scattered corals. The slope is gradual and 20 to 30 meters offshore in a depth of 2 meters the bottom change to sand. Maximum depth near the mouth of the bay is 15 meters. Most of the central part of both bays is covered with a grass bed composed mainly of Thalassia. The remainder of the eastern and western shore are steeper and rocky with good coral and gorgonian development.

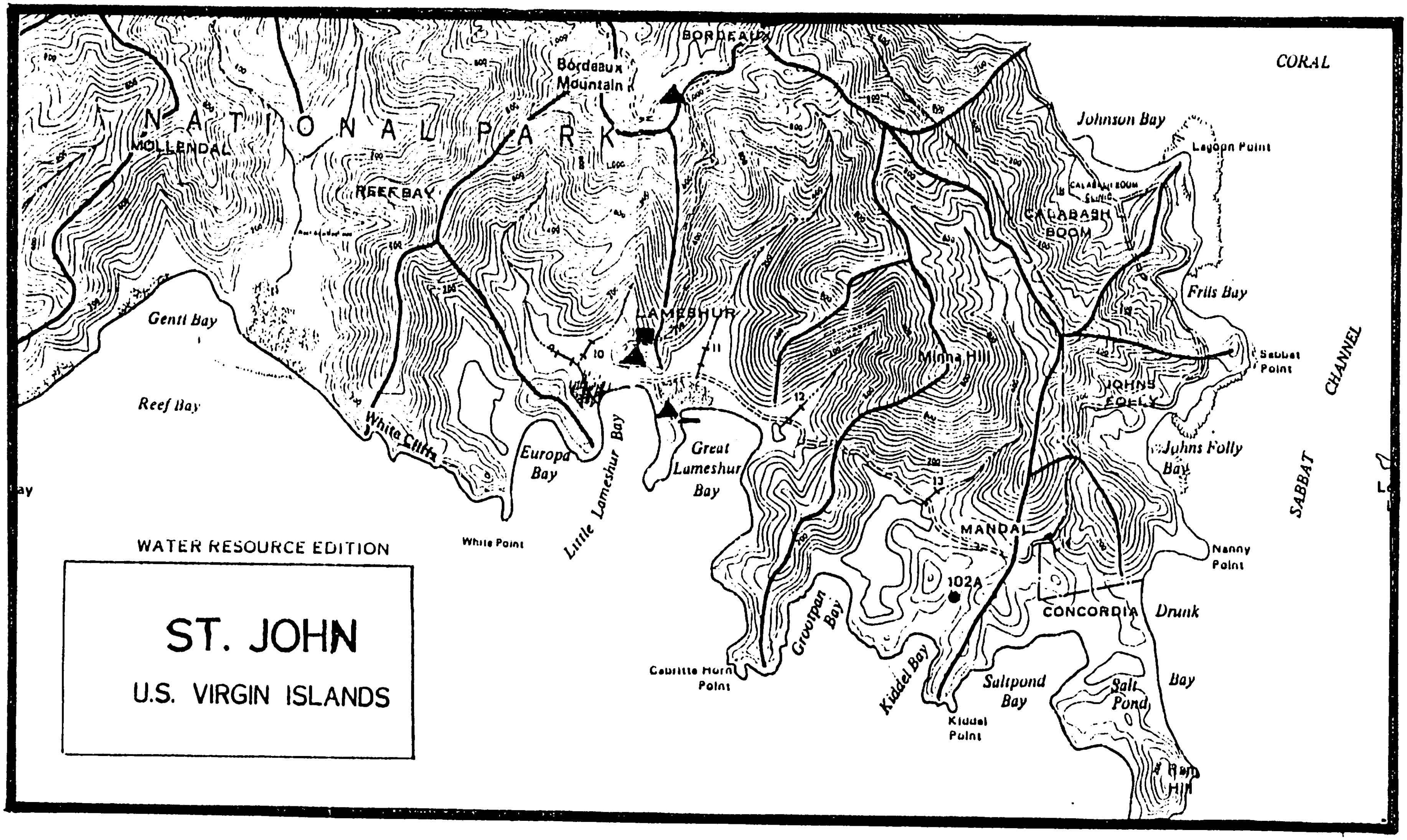

Figure 2: Location of the Lameshur Bays and significant Geographic Features

METHODS

There is an existing rainguage and data system. A weather station and tide guage was established at the shore lab at Greater Lameshur Bay. In periods of high flow, if the beach berm is broached, a fluorescent dye is to be introduced and the dilution factor computed from samples of bay water to estimate the true inflow. A record of nutrients was kept for 3 years, and oxygen and gross phytoplankton (cells per milliliter) were recorded in this study.

Reproductive condition was determined on adults of the common fishery species by dissection and measurement of the gonads as well as microscopic sections of the gonadal tissue. These measurements were correlated with rainfall and with the appearance of both larval fish and phytoplankton in the bay. The fish were taken by trap, net, and hand.

Zooplankton and phytoplankton were estimated by taking three standard tows with plankton nets weekly as well as by grab samples within the turtle grass and coral communities.

Ichthyoplankton was analyses from 20 samples taken in Greater Lameshur Bay, Lesser Lameshur Bay, and off Yawzi Point (Figure 3). Table 6 summarizes sample dates for location, type of sample, time of day sampled and volume filtered. The net used in sampling was a o.5 m ring net with a three point bridle and 153u mesh. Volume filtered was measured using a General Oceanics flowmeter in the mouth of the net.

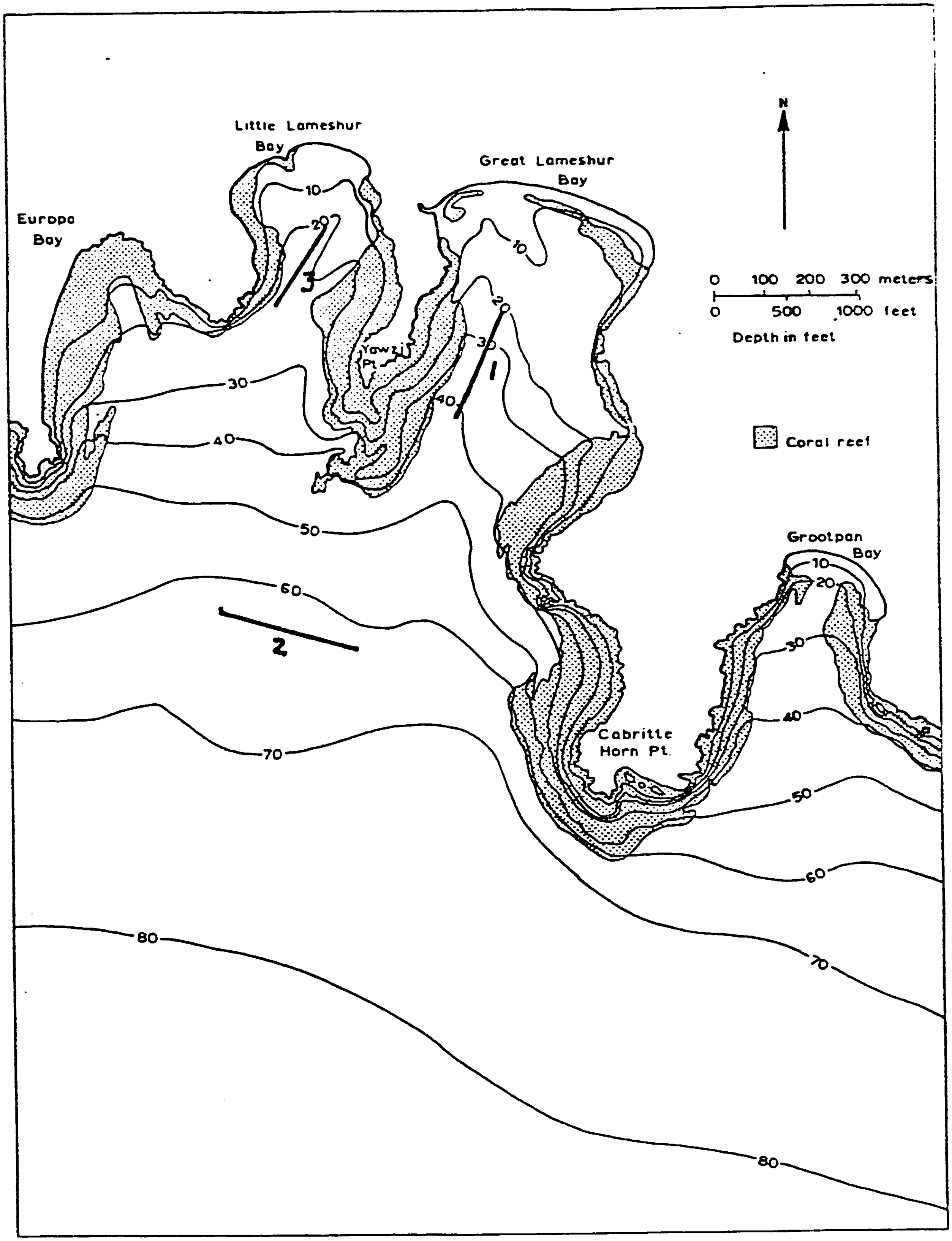

Figure 3: Bathyometry Ichthoplankton and Sample Stations

Horizontal tows were made at about 2m depth. Oblique tows were made using 2 meter stages at 6, 4, 2 m and just below the surface except for Little Lameshur which was too shallow. In Little Lameshur the stages were 4 and 2m and surface. The net was towed at each stage for 2 minutes. Times for horizontal tows varied and are reflected by the volume filtered.

Analysis and correlation of the data was done to show the relationship between runoff time and volumes with the gonadal condition of adults and with the appearance of food and larval forms in the bay.

Reporting was on a semi-annual basis and the reports have been designed to serve as a reference and guide for planners, developers, and local resource managers as well as providing data to the national OWRT offices.

RESULTS

Data resulting from the study are summarized in Tables 1-7. The daily, monthly and yearly rainfall are shown in Table 1 for Lesser and Greater Lameshur respectively.

The rainfall patterns in the southeast quarter of the island are very consistant over years of time (Purcell and Canoy, 1983) and generally are found to have a mean of 43.98 inches (111.7 cm). Rainfall was highest at both stations in April, May and October, and lowest in February, March and June.

	1982						1983					
DAY	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	.06	0	.08	0	2.06	0	0	0	0	0	0	.06
2	0	.48	0	.16	0	.04	0	.06	0	0.11	0.04	.02
3	.06	.69	.48	.01	.16	.06	.08	.03	0	5.46	0	0
4	0	.34	.09	.21	.12	.14	0	0	0	.73	0	0
5	.35	0	0	.10	.05	.03	0	0	.20	.17	0	0
6	0	0	0	.91	.02	.15	0	.03	.01	.10	0	0
7	.03	.49	0	.36	0	.97	0	0	0	.02	0.02	0
8	.10	.08	0	.53	0	0	.20	.29	0	.07	0	0
9	0	.22	.07	0	0	0	0	.15	0	.47	0	.14
10	.56	.11	.01	0	.02	0	.02	.18	0	0	0	.09
11	0	0	.01	0	0	0	0	.12	0	0	0	.30
12	0	0	.57	0	0	.03	0	.04	0	.02	0	.10
13	.31	.04	.17	0	0	.05	.01	.03	.03	.01	0	.15
14	0	.28	.10	0	0	.41	0	.06	0	.04	2.60	0
15	.32	.16	.06	.73	.15	.06	.02	.03	0	0	0.08	0
16	0	0	0	.01	.12	.03	.14	0	0	0	0.01	0
17	0	0	.05	.27	0	.11	0	.16	0	.06	0	.12
18	.72	0	.02	0	.01	0	0	.06	0	0	0.32	0
19	0	.02	.32	0	.06	.07	0	.06	0	0	0	0
20	.05	0	.02	1.80	.14	.05	0	0	0	0	0.05	.15
21	0	0	.04	.52	.47	.08	0	.22	0	0	0.03	.05
22	0	.04	.07	.69	.03	0	.01	0	.10	.02	0	0
23	0	0	0	.21	.01	.04	0	0	0	.03	0	0
24	.17	0	.07	.16	.12	.20	0	0	0	.08	.06	0
25	0	.06	0	.24	0	.30	.06	0	0	.07	0	0
26	.33	0	.26	.03	.01	0	0	0	0	.48	0.29	.02
27	0	0	0	0	.10	0	0	0	0	0	0.12	.03
28	0	.05	1.58	0	0	.15	2.02	0	.01	.07	0.56	.04
29	0	.08	0	.02	0	0	.11		0	.01	0.77	0
30	0	.03	0	.23	.15	0	.10		0	.14	0	0
31	0			.63		0	.50		0		0	
TOTAL	3.06	3.17	14.07	7.82	3.75	2.97	3.27	1.52	0.35	8.45	4.93	1.56
RAIN-DAYS	12	16	23	20	18	19	12	15	4	20	12	13

Total Year 59.56 inches

Table 1: Daily rainfall recorded in Lameshur Bay watersheds

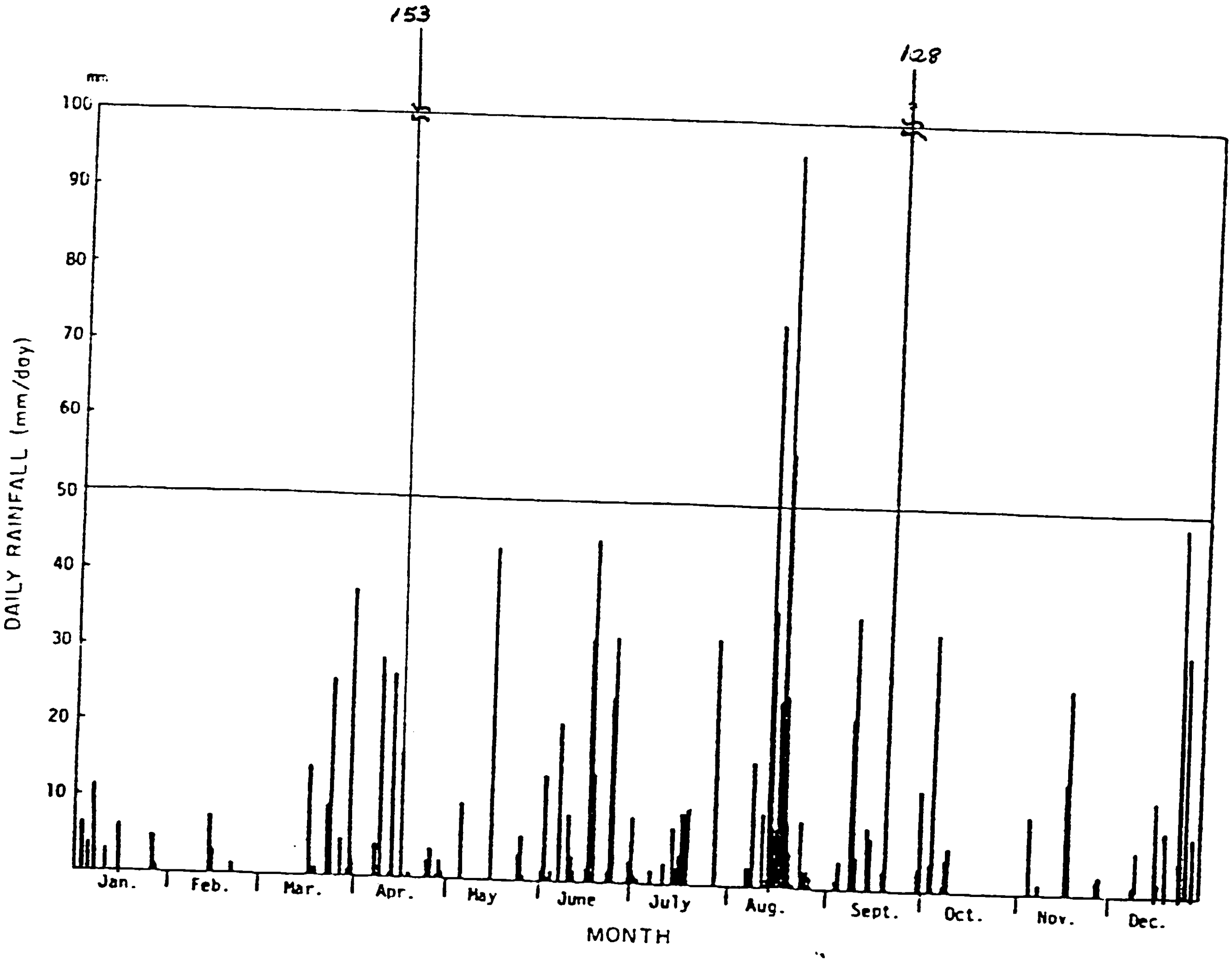

Figure 4 Rainfall data used in the estimation

Temperature of the surface water in degree centigrade at the bay sites (0.5 m water depth) is presented in Table 2 and the salinity given in part per thousand (ppt) is shown in Table 3. The temperatures in Lameshur Bays ranged from 30.8°C in October inshore to 26.2°C at Little Lameshur and 26.4°C at Greater Lameshure in February. Salinities for the two bays ranged from 34.0 ppt (October; GLB Station 1) to 36.2 ppt (December; GLB Station 2) and 34.0 to 38 ppt (February; LLB Station 1). The stations at the mouth of the bays tended to be cooler and more saline. Preliminary percolation studies show hyposaline, cooler, water to be percolating through the sand bottom at several sites during the months of November - February.

Phytoplankton blooms were found to follow rains by four to six days. The duration of the blooms was from six to 20 days depending on the volume of runoff and circulation of a given bay. The average density of cells during these blooms was about 30,000 per liter, but highs of over a million per liter were recorded at times. During normal periods dinoflagellates about equaled all other species with diatoms a close second. During blooms dinoflagellates increased by 100X, diatoms by about 10X and all other by 2-3X.

Zooplankton populations increased in one to three weeks after phytoplankton bloomed. No direct correlation could be found as to either the timing or the magnitude of the increase.

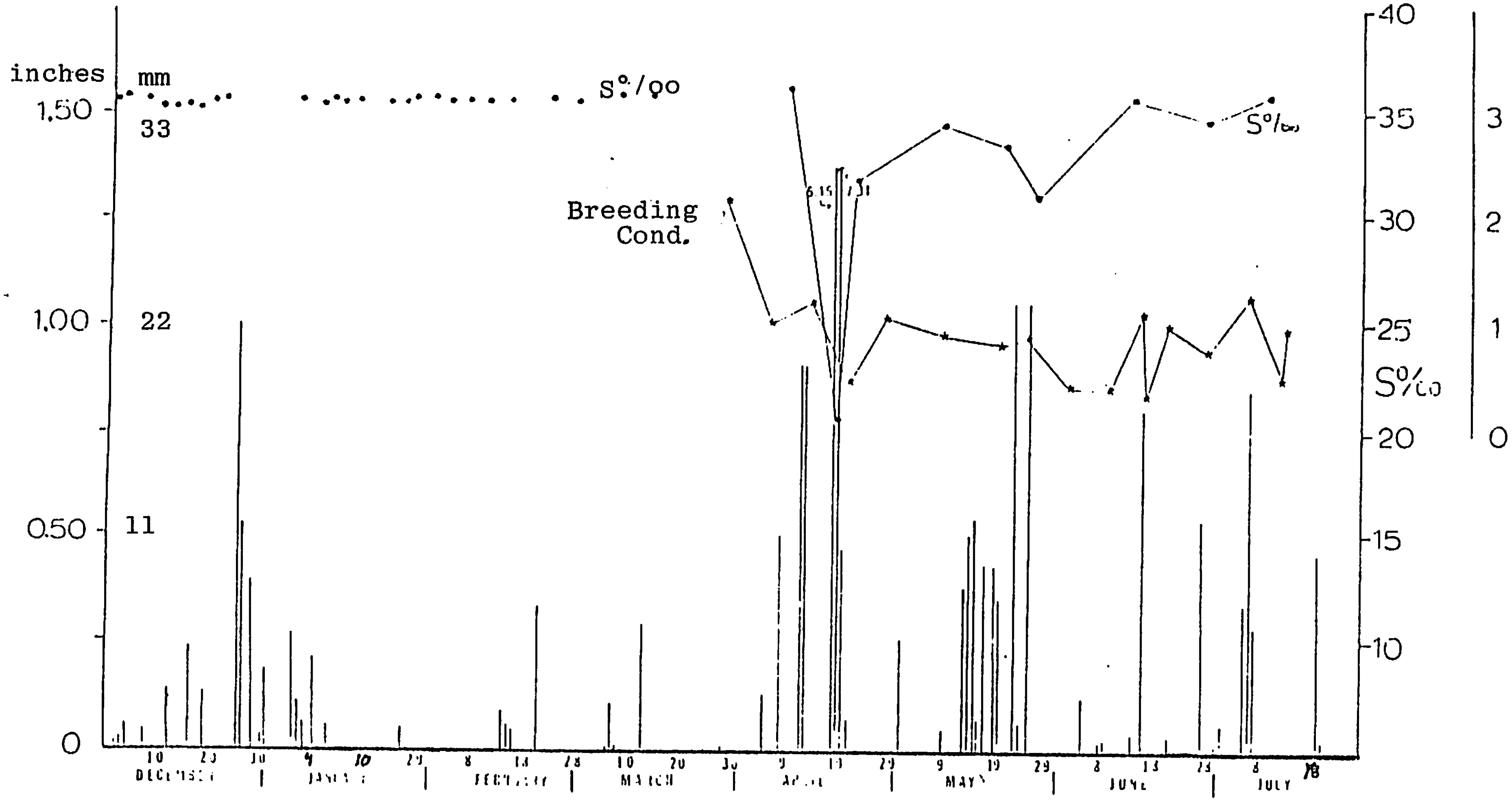

Figure 5 Rainfall, Salinity, and Average Level of Breeding Condition for Fish from the Lameshur Bays

		Greater		Lesser	
1982	10 May	30.0	29.8	29.2	28.0
	18 May	28.0	28.5	28.4	27.9
	31 May	28.5	28.2	28.5	28.0
	28 June	30.1	29.5	29.1	29.0
	31 July	30.0	29.5	29.1	29.0
	25 August	30.2	29.8	29.2	29.5
	7 Sept.	30.0	29.5	29.5	29.5
	30 Sept.	30.5	29.8	29.5	29.8
	10 Oct.	30.5	30.2	30.0	29.5
	18 Oct.	30.8	30.1	29.9	29.5
	28 Oct.	30.0	29.9	29.9	29.5
	8 Dec.	27.4	27.5	27.0	27.0
1983	20 Jan.	27.9	27.5	27.0	27.0
	20 Feb.	26.5	26.4	26.2	26.2
	18 March	27.9	27.8	27.5	27.0
	10 April	27.5	26.5	-	-

Table 2 : Surface Temperatures in Greater and Lesser Lameshur Bays

		Greater		Lesser	
1982	10 May	36.0	36.0	36.0	37.0
	18 May	35.0	36.0	36.0	36.5
	31 May	35.0	35.5	35.5	36.0
	28 June	35.0	35.5	36.0	36.5
	31 July	35.5	35.0	35.0	36.0
	25 August	35.0	35.5	35.0	35.0
	7 Sept.	35.0	35.0	34.5	-
	30 Sept.	34.0	35.0	35.0	35.0
	10 Oct.	34.5	34.5	34.0	35.5
	18 Oct.	34.0	34.5	34.0	34.0
	28 Oct.	34.5	35.5	34.5	35.0
	8 Dec.	35.9	36.2	34.5	35.5
1983	20 Jan.	34.5	35.5	36.0	35.5
	20 Feb.	36.0	36.0	38.0	37.0
	18 March	36.0	35.0	35.0	35.0
	10 April	34.5	35.0	-	-

Table 3 Surface Salinities in Greater and Lesser Lameshur Bays

They may be partly dependent on the specific populations present and the composition and volume of the runoff. During the zooplankton blooms the numbers rose from 10-15 thousand per cubic meter to as high as 600 thousand per m^3.

	DATE	Lesser STA. 1	 STA. 2	Greater STA 1	 STA. 2
1982	10 May	11,608	94	41	61
	18 May	8,457	92	400	68
	31 May	1,092	514	632	210
	28 June	458	79	206	59
	31 July	105	278	144	53
	25 Aug.	187	117	117	83
	7 Sept.	169	75	102	123
	30 Sept.	243	129	154	58
	10 Oct.	201	258	60	34
	18 Oct.	209	60	18	17
	28 Oct.	238	108	219	65
	8 Dec.	250	203	118	161
1983	20 Jan.	172	176	179	287
	20 Feb.	66	46	128	60
	18 Mar.	85	70	47	48
	10 Apr.	27	50	-	-

Table4 :

Total numbers of Phytoplankton from stations in Greater and Lesser Lameshur Bays (organisms per Liter).

		Lesser		Greater	
	DATE	TOW 1	TOW 2	TOW 1	TOW 2
1982	10 May	35	8111	13576	14508
	18 May	122	14875	11863	5677
	31 May	131	13870	9720	8437
	28 June	67	36411	23605	34948
	31 July	503	17768	36155	18242
	25 Aug.	385	166199	14868	6005
	7 Sept.	659	210575	115615	80822
	30 Sept.	5187	198449	636529	323626
	10 Oct.	1171	71593	145572	33617
	18 Oct.	1192	102184	304875	67493
	28 Oct.	73959	91968	44200	66498
	8 Dec.	140348	43177	125351	35495
1983	20 Jan.	46585	21283	35043	15208
	20 Feb.	78868	189499	66124	33163
	18 Mar.	2186	2232	9262	11753
	10 April	110926	139246	-	-

Table 5 : Zooplankton numbers in organisms per Liter

Table 6 <u>Sample parameters Ichythyoplanton tows</u>

Great Lameshur Bay

Date	12 Jan	14 Jan	26 Jan	26 Jan	23 Feb	23 Feb
Type of tow	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Oblique
Time of day	Night	Day	0513-0523	Night	1112-1114	1805
Volume	1202	563	322	515	56	140

Date	26 Feb	21 Apr	20 May	24 July
Type of tow	Oblique	Oblique	Oblique	Oblique
Time of day	1126	1945	0917	0717
Volume (m^3)	264	491	377*	375*

Little Lameshur Bay

Date	24 Feb	27 Feb	22 Apr	13 July	24 July
Type of tow	Oblique	Oblique	Oblique	Oblique	Oblique
Time of day	0615	1305	0651	0710	0649
Volume (m^3)	252	214	510	399	344

Yawzi Point

Date	18 Feb	26 Feb	20 May	24 May	24 July
Type of tow	Horizontal	Oblique	Oblique	Oblique	Oblique
Time of day	0710	1140	0815	0638	0619
Volume	179	248	406	278*	280

*) Flowmeter readings suspect, volumes estimated based on 3 most recent samples from same area.

Table 7 Egg and larval density by station and date.

Date	Egg Density	Larval Density
A. Great Lameshur Bay		
12 Jan	644	390
14 Jan	14,150	94
26 Jan	1,038	247
23 Feb	1,718	740
26 Feb	48	147
21 April	54	82
20 May	29	35
24 July	81	75
B. Little Lameshur Bay		
24 Feb	701	29
27 Feb	10	179
22 April	20	22
13 July	24	246
24 July	10	145
C. Yawzi Point		
18 Feb	6	42
26 Feb	1,946	8
20 May	95	292
24 May	864	585
24 July	513	1,056

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Table 8 presents egg densities for these samples reported as numbers of eggs per 1000 m^3. The eggs are reported as morphological types, except where identification is absolutely certain. However, it should be noted that types A,B and AB almost certainly are anchovy eggs while types F,I,V, and X are almost certainly herring eggs. In order to confirm these relationships, eggs with advanced embryos must be located so that they can be compared with described larvae. Types A,B and M are the most frequently encountered types occuring in three to five of the seven samples.

Table 9 gives similar information for the larvae. Type designations were made using the Gaelic alphabet to avoid confusion between egg type designations and larvae type designations. The following observations should be noted: BA early yolk-sac larvae correspond very well with late embryos of type Z eggs and probably represent a percoid species. BF larvae correspond with type X embryos. Carangidae 1 is probably a scad larva, but the specimen condition was too poor to confirm this. Gobiidae 2 seems to be a Coryphopterus species

The greatest biomass of adult fish in Lameshur Bay is composed of anchovies and dwarf herrings, however their eggs do not always make up the majority of the ichtyoplankton (see Table 8). Table 7 shows that, when they are abundant, they are extremely abundant, reaching densities over 12,000/1000 m^3.

Table 8 Egg abundance by sampling station. Abundances reported as number per 1000 m^3.

A. Great Lameshur Bay

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 Jul
A	20		78	143		6		
B	495	9309	19	21				
C			7					
D			96	257	23			
E		16	17	43				
F			9			6		
G			19		11			
H			3					
I			3					
J			6				21	
K		2	3					
L			43	1193				13
M		36	81	18	4	2		
N		50	22					
O			6			2		
P			6					
S	37							
T		4						
U		9						
V	2	3561						
W		1112						66
Y		2	4					
Z	2	23						
AA		2						
AB		11						
AD	1							
AE	1							
AF	1							
AG	37						5	
AH	8							
AI	5							
AJ	8		520					
AK	12							
AL	8							
AM	1							
AO								

Table 8.. Continued

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 Jul
AS						14		
AT						8		
AV						6		
AW						6		
AX			4			2		
AY			2					3
BA							3	
BI			12					
BJ			14					
BK			2					
BL			24					
BN			36					
Clupeidae 1	1							
Clupeidae 2	2							
Synodontidae 1	1	2		7		2		
Synodontidae 3			2					
Synodontidae 4		11						
Scarus Sp.	2							

B. Little Lameshur Bay

Type	24 Feb	27 Feb	22 Apr	13 Jul	24 Jul
A	75				
D		5			
J		5	6		
L	186		8	5	
M	107				
P			4		
V					3
Z	8				
AG			2		
AK	4				
AN	8				
AO	4				
AP	4				
AQ	67				
AR	4				
AS	111				

Table 8 Continued

B. Little Lameshur Bay

Type	24 Feb	27 Feb	22 Apr	13 Jul	24 Jul
AT	52				
AU	4			2	4
AZ				5	
BA				10	
BB				2	
BE					3
Synodontidae 1	67		2		

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
A		28	10		
B	6	121			4
C		56			
D					7
E				15	4
G				14	
I				7	
J			12	86	
L			47		
M		1653			
P			5		7
Q		4			
R		56			
S		8			
U			2		
AL				25	
AQ					11
AV					4
BA				54	
BB					4
BC					4
BD					7
BE			2		104
BF					11
BG					126

Table 8 Continued

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
BH			4	58	212
BL				29	
BN				90	
BP			2		
BQ			2	22	
BR			2	14	
BS				68	
BT				18	
BU				79	
BV				245	
Clupeidae 2			2		
Synodontidae 1					4
Synodontidae 2				22	4
Synodontidae 5			5	14	
Scarus sp.		20			
Soleidae 1				4	

Another point which this limited amount of data indicates is that there are large differences in ichthyoplankton communities among the locations and between sampling dates.

Attached as appendices are keys to the eggs and yolksac larvae. These should provide information concerning criteria for identification of the types.

Table 8 summarizes the distribution and abundance of fish eggs among these samples. The egg types appearing most frequently were types A,B, L, and synodontidae 1, all of which were found on 7 of the 14 sampling dates. Type M was found on 6 of the dates while types D,E,J and P were found on 5 of the dates. The biggest densities of individual egg types were 9309/1000m^3 for type B on 14 January, 3561/1000m^3 for type V on 14 January, 1653/1000m^3 for type M on 26 February, 1193/1000m^3 for type L on 23 February and 112/1000m^3 and 1112/1000m^3 on 14 January.

A key to the egg types is being developed. The following eggs have been tentatively placed in families: A,B,AB and AG in Engraulidae; F,L,V and BO in Clupeidae; Z in Callionymidae; K in Bothidae; and BT in Carangidae. Other egg types have been placed in family groupings as indicated by names (e.g. Synodontidae 1, Scarus sp.), and the placement is considered to be more sure than those listed above.

Table 9 summarizes the distribution and abundance of fish larvae among samples. The larval types which occured most frequently were Gobiidae 7 which occured on 10 of the 14 sampling dates, Syngnathinae which appeared on the 9 of the dates and

Clupeidae which appeared on 7 of the dates. The highest densities of individual larval types were 818/1000m^3 for Clupeidae, 339/1000m^3 for gobiidae 19, and 278/1000m^3 for Engraulidae 3.

Keys to the identification of larval types may be found in Appendicies A and B. The clupeid larvae which are all reported as one type may represent two or more species, but more than 90% of them match descriptions given by Powles (1977) for Jenkinsia lamprotaenia. Unfortunately most of the other clupeids are not adequately described to rule out confusion.

Microdesmidae I is probably genus Cerdale, but it is not certain as there are no good descriptions for this group of larvae. Diodontidae I matches Leis' (1978) description of Diodon antennatus which would be entirely possible, however none of the other western Atlantic diodontids are described so that there are no data concerning variance within the family. Monacanthidae 1 is either in genus Stephanolepis or Monacanthus, but this distinction awaits further analysis.

The scorpaenids represent an interesting taxonomic problem. The pectoral fins are much smaller in proportion to body size than is seen in most other scorpaenids (e.g. Miller, Watson and Leis, 1979; Moser, Ahlstrom and Sandknop, 1977; Taning, 1961) except some northern Atlantic Sebastes (Russel 1976). The urostyle is also much larger and more pronounced than seen in

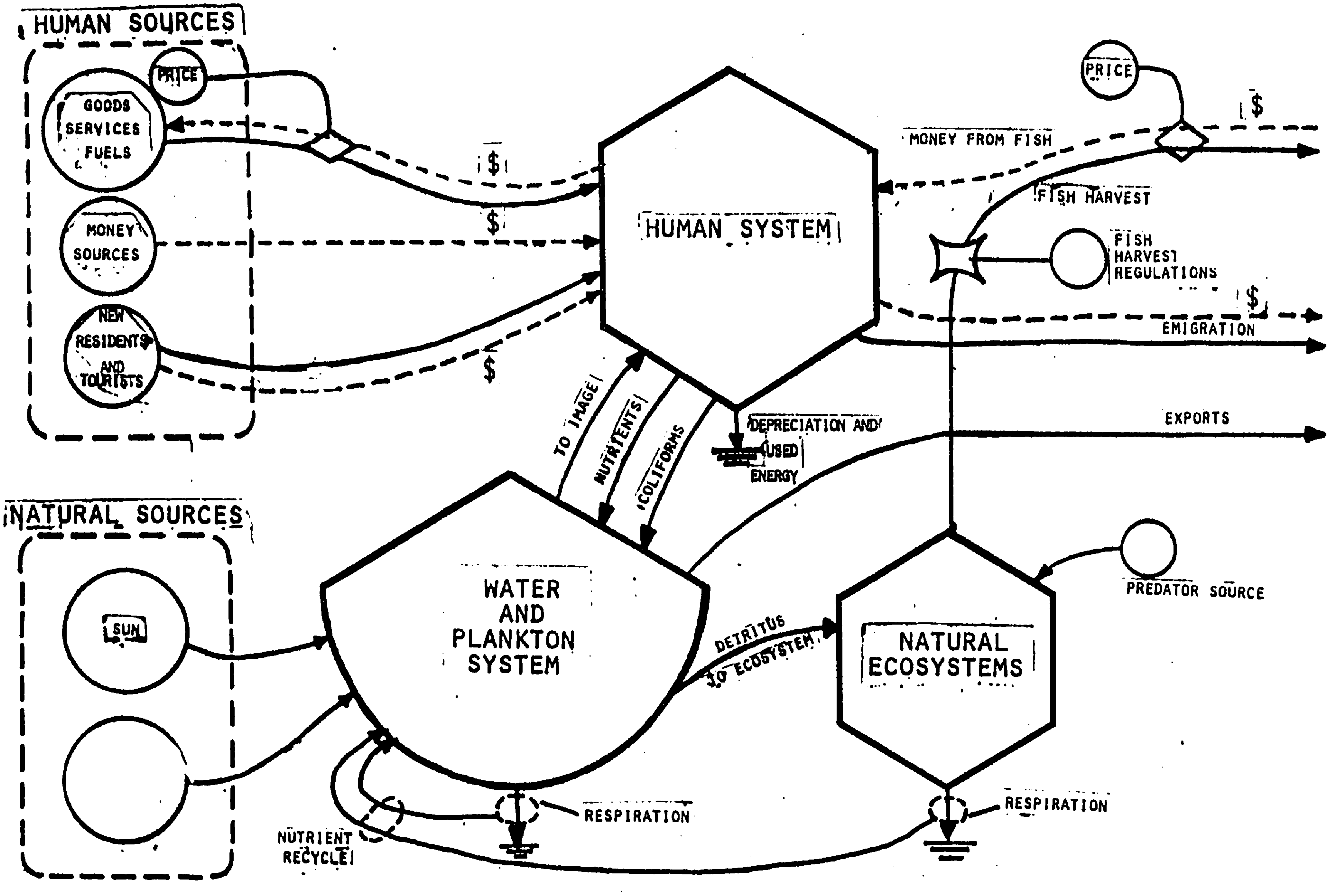

Figure 6A: General Model of Systems

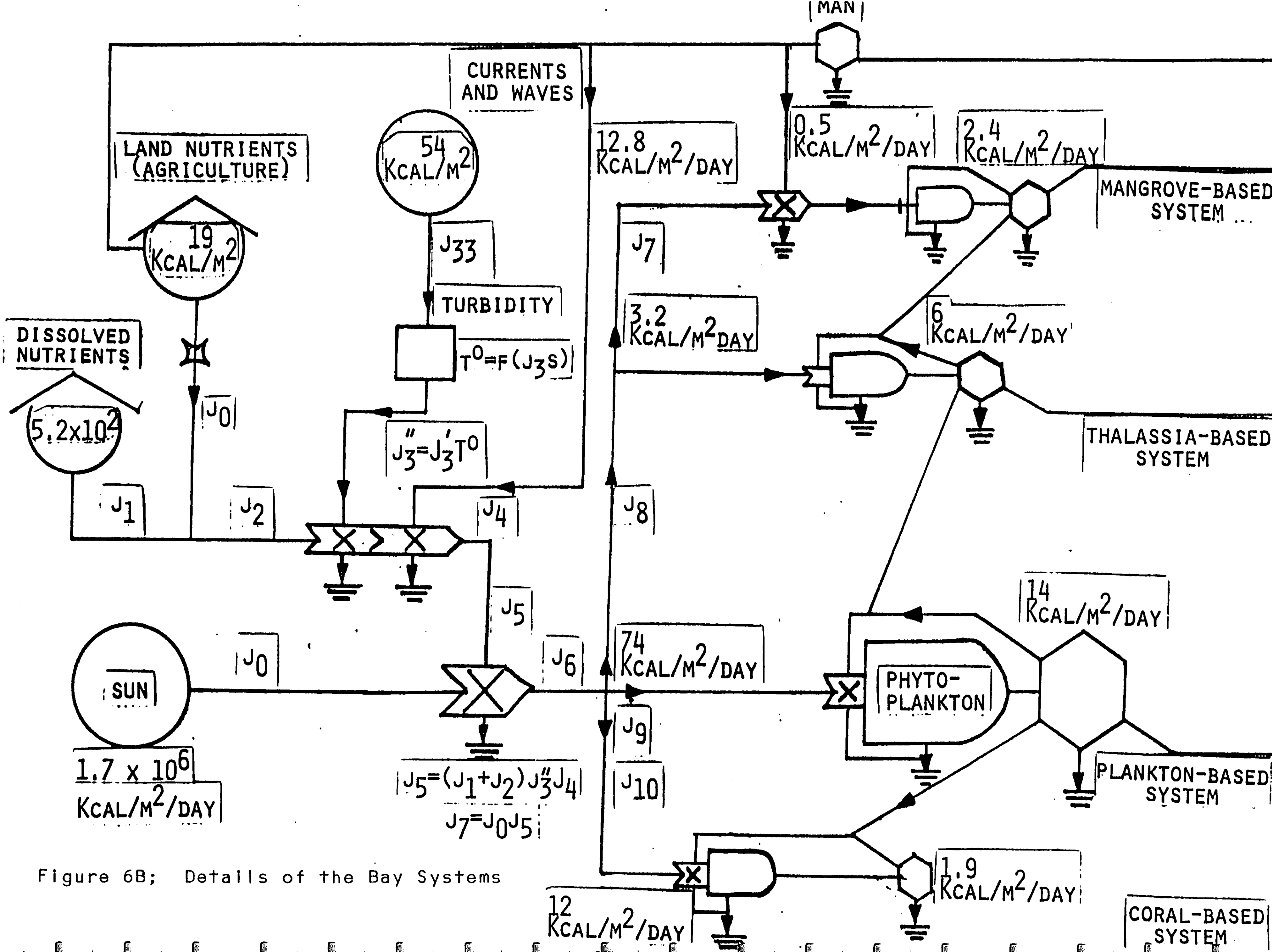

Figure 6B; Details of the Bay Systems

Table 9 Larval abundance by sampling station. Abundances reported as number per 1000 m^3.

A. Great Lameshur Bay

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 Jul
A			6					
β			6					
c			12					
δ			3					
e			6					
f			3					
ʒ			22					
h	31			17				
ı	1							
l				34				
m				7				
n					34			
o					4			
p					8			
r	2				8		3	
ρ	1				15			
τ					4			
u					4			
AA					4			
Aβ					8			
AC					11			
Ae					8			
Af			2		4			
Ah					4			
Aı			2		4		3	
Al			6					
Ar		2						
Aρ		2						
Aτ		4						
Au		2						
βf		2						
βh	3							
βm		6					3	
βp								
βp	2							
βτ	2							

Table 9 Continued

A. Great Lameshur Bay

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 Jul
βu	3							
cα	2							
cβ	2							
cc	3							
cδ	2							
ce	1							
cf	1							
c5	1							
ch	2							
c1	1							
c2	2							
cm	1							
cr						2		
cτ						4		
cu						2		
δα						2		
δβ						2		
δc						4		
δδ						2		
δe								3
δ5				17				3
δh								3
δ1								3
δ2								3
δm								3
er							3	
eτ							3	
eu							3	
fβ							3	
fc			4					
fδ			4					
fe			6					
ff			4					
f5			4					
fh			2					
fm			17					

Table 9 Continued

A. Great Lameshur Bay

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 Jul
Fn			17					
FO			17					
FP			17					
Clupeidae 1		9				2	6	
Anchoviella perfasciata 1			3					
Engraulidae 3	278					10		48
Engraulidae 4			4			8		
Petrotyx sanguineus	1							
Hippocampus sp.			22					
Syngnathinae			14	71	8	2	5	3
Scorpaenidae 1			3					
Scorpaenidae 2				36				
Scorpaenidae 3						4		
Triglidae		2						
Serraninae 1								3
Carangidae 1								3
Labridae 1		2						
Clinidae 1	1							
Clinidae 2	1							
Blenniidae 1	7							
Blenniidae 2						2		
Gobiidae 1	1		39	71		28		
Gobiidae 2				7				
Gobiidae 7	36	11		36	11	2	3	
Gobiidae 8	1							
Gobiidae 12						2		
Gobiidae 16				17				
Gobiidae 18				71				
Gobiidae 19				339				
Gobionellus sp.						2		
Gempylidae 1		2						
Scombridae 1					4			
Cubiceps sp.		2						
Callionymidae 1		48	2					

Table 9 Continued

A. Great Lameshur Bay

Type	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 Apr	20 May	24 July
Bothidae 1					4			
Sphoeroides sp.				17		2		

B. Little Lameshur Bay

Type	24 Feb	27 Feb	22 Apr	13 Jul	24 Jul
O		14			
r		9			
u		5			
βl	4	37			
βm		14		5	
βo		5			
βp		5			
βr		5			
cn	8				
co	4				
cp			6		
δs					3
δh				43	
δe					9
δo				2	
δr				2	
eβ					6
ep					3
er					3
Clupeidae 1		9		138	87
Engraulidae 4				2	
Syngnathinae		5			12
Scorpaenidae 2			2		
Scorpaenidae 4				2	
Scorpaenidae 6					13
Labridae 2			4		
Gobiidae 4		5			
Gobiidae 5	4	19			
Gobiidae 6		14			
Gobiidae 7		19		50	9
Gobiidae 8		14			
Gobiidae 9	9				

Table 9 Continued

B. Little Lameshur Bay

Type	24 Feb	27 Feb	22 Apr	13 Jul	24 Jul
Gobiidae 10			6		
Gobiidae 11			2		
Gobiidae 14				2	
Elacatinus sp.				2	

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
c				4	
ʒ	6			4	4
h				4	
p				4	
r					
τ	6				
Ae					4
Af					7
A1				4	
Al	6				
Am	6				
An	6				
Ao	6				
A.p	6				
Bh			2		
Bl			2	4	14
βm			5	11	7
βr			7		
δh				43	
δp				4	
δr					43
δr					7
δτ					7
δu					11
eA				4	7
eB					7
ec					4
ee			2	7	4
ef					4
eʒ				7	7

Table 9 Continued

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
eh				4	7
eı					4
el					4
em					4
en					4
eo					4
ꝼꝺ				4	
ꝼꝼ				4	
ꝼn			2		
ꝼp			2		
ꝼꞃ			5		
ꝼꞅ			5		
ꝼꞇ			7		
ꝼu			2		
ᵹa			2		
ᵹb			25		
ᵹc			22		
ᵹꝺ			2		
ᵹe			5		
ᵹꝼ			2		
ᵹᵹ			10		
ᵹh			25	4	
ᵹı			5		
ᵹl			5	14	
ᵹm			5	7	
ᵹn			5		
ᵹo			2		
ᵹp			2		
ᵹꞃ			2	4	
ᵹꞅ				2	
ᵹꞇ				5	
ᵹu				5	
ha				2	
hc				4	
he				4	
hꝼ				7	
hᵹ				32	

Table 9 Continued

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
hh				4	
h1				4	
hl				11	
hm				7	
hn				7	
ho				4	
hp				18	
hr				4	
hr				4	
ht				4	
hu				4	
1A				4	
1B				4	
1C				7	
1D				4	
1F				4	
15				4	
1h				4	
1l				7	
Clupeidae 1			15	79	818
Engraulidae 5			44		
Serrivomeridae 1			2		
Synodontidae 1				4	4
Synodontidae 2				4	4
Syngnathinae				11	11
Scorpaenidae 4				4	
Scorpaenidae 5					4
Serraninae 1					7
Serraninae 2			2		
Serraninae 3				22	
Labridae 2			2	18	
Clinidae 2					4
Blenniidae 3					4
Gobiidae 3		8			
Gobiidae 6			5		
Gobiidae 7				58	7

Table 9 Continued

C. Yawzi Point

Type	18 Feb	26 Feb	20 May	24 May	24 Jul
Gobiidae 8			10		
Gobiidae 9			2		
Gobiidae 11				2	
Gobiidae 16			2	7	11
Gobiidae 17			27	7	18
Gobiidae 19				11	
Gobiidae 20			17		
Gobiidae 21			2		
Gobiidae 22				20	
Gobiidae 23				4	
Gobiidae 24				4	
Microdesmidae 1				4	
Syacium papillosum			2		
Monacanthidae 1				7	
Ostraciontidae 1				4	
Sphoeroides 1			2		
Diodontidae 1				4	

literature description, however the presence of a pit in the parietal region and the development of head spines typical of scorpaenids confirms the identifications. Scorpaenidae 3 flexion larvae have pigment present in the pectoral axil which may prefigure the dense axillary pigment of several species in the genus <u>Scorpaena</u> but most obvious is <u>Scorpaena plumieri</u>.

The serrivomerid eel leptocephalus taken at Yawzi Point was a bit of a surprise, as the family Serrivomridae is typical of open ocean, and adults normally live at fairly great depth. Very few leptocephali of these eels have been recorded from the western Atlantic; and, after futher examinations, this speciment will be archived in either the U.S. National Museum or the Los Angeles County Natural History Museum.

Similarity index values were calculated for both egg types and larval types between stations for the whole set of samples for 24 July when all 3 stations are represented and between dates for Great Lameshur Bay. The index is that of Sørensen (1948) which is S = 2 x no. species in common ÷ (no. species at station_1 + no. species at station_2). These values are presented in Table 10. It becomes obvious from these index values that there is a high degree of variability and in all probability only a minor portion of the total number of species available have been sampled.

Despite the fact that 10 samples from Great Lameshur Bay and only 5 samples from Yawzi were processed, Yawzi Point had nearly the same total number of types of eggs and more species of larvae represented. Yawzi Point and Little Lameshur Bay have the same number of samples processed, yet Yawzi Point has nearly twice as many egg types represented and more than three times as many types of larvae.

Table 7 shows total egg and larval densities for each sampling date by stations. It would appear from these data that during January and February the major spawning and nursery area was Great Lameshur Bay, while in May and July Yawzi Point served as the major spawning and nursery area. This may indicate either a movement offshore by spawning fish later in the year or, as seems more likely, a shift in species spawning. This pattern of utilization needs futher investigation as it has implications for environmental impact elsewhere in the Caribbean.

Table 10 Sørenson similarity index value between stations and between dates for larvae and eggs. The parenthetical value is the largest value possible with the particular distribution of species numbers.

A. Egg types	Great Lameshur	Little Lameshur
Little Lameshur	.364 (.597)	
Yawzi Point	.484 (.863)	.375 (.719)

B. Larval types	Great Lameshur	Little Lameshur
Little Lameshur	.208 (.500)	
Yawzi Point	.246 (.947)	.218 (.462)

C. Great Lameshur by dates: Egg types

	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 April	20 May
14 Jan	.235 (.882)						
26 Jan	.133 (.844)	.293 (.732)					
23 Feb	.222 (.592)	.348 (.696)	.353 (.470)				
26 Feb	0 (.286)	.111 (.333)	.207 (.207)	.364 (.545)			
21 April	.138 (.690)	.160 (.800)	.278 (.556)	.333 (.889)	.154 (.462)		
20 May	.095 (.286)	0 (.333)	.069 (.207)	0 (.545)	0 (1.000)	0 (.462)	
24 July	0 (.286)	0 (.333)	.138 (.207)	.182 (.545)	0 (1.000)	0 (.462)	0 (1.000)

Table 10 (continued)

D. Great Lameshur by dates: Larval types

	12 Jan	14 Jan	26 Jan	23 Feb	26 Feb	21 April	20 May
14 Jan	.049 (.643)						
26 Jan	.077 (.982)	.054 (.650)					
23 Feb	.089 (.634)	.067 (1.000)	.098 .650)				
26 Feb	.170 (.783)	.188 (.839)	.046 (.800)	.056 (.839)			
21 April	.174 (.783)	.129 (.839)	.143 (.800)	.228 (.839)	.108 (1.000)		
20 May	.158 (.526)	.174 (.870)	.118 (.540)	.148 (.870)	.276 (.714)	.214 (.714)	
24 July	.053 (.526)	0 (.870)	.059 (.540)	.074 (.870)	.069 (.714)	.143 (.714	.100 (1.000

CONCLUSIONS AND RECOMMENDATIONS

1. The volume and concentration of freshwater and nutrients input to the nearshore waters depends on the development history of the watershed and its geomorphology.
2. Most fish species breed indiscriminately with respect to location or environmental cues such as freshwater, tide presence of food, etc.
3. The survival and growth of the larval fish depends, among other things, on there being food of appropriate size and type readily available from the time they hatch.
4. Therefore the survival of the young fish, but <u>not</u> reproductive attempts, depends on # 1 above. This provides a secondary level link of runoff quantity and quality.
5. It is possible to produce an ecosystem model to describe this system which with refinement could be used as a tool in planning and management.
6. It is recommended that V.I. Planners pay close attention to any development which will alter runoff characteristics.
7. It is also recommended that a long term (at least 2 years) study be initiated to determine critical parameters and to develop fully an ecosystem model for planning.

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Appendix A

A Key to Fish Eggs of Lameshur Bay

Dr. F.D. Martin

Key to the Fish Eggs of Lameshur Bay

1A Spherical or subspherical 2

1B Ellipsoidal, spindle-shaped or irregularly shaped 29

2A When viewed with transmitted light yolk cloudy,translucent, granular or opaque 3

2B When viewed with transmitted light yolk colorless, transparent 19

3A Oil droplet(s) (or yolk inclusions resembling oil droplets) 4

3B No oil droplets. 16

4A Oil droplet (or yolk inclusion) single 5

4B 1 to many oil droplets 13

5A No visible perivitelline space 6

5B Perivitelline space present 8

6A Diameter greater than 0.7 mm 7

6B Diameter about 0.6 mm, yolk granular or cellular. . .Type B (probably Engraulidae)

7A Diameter about 0.8 mm, yolk granular. . . . . .Type A (probably Engraulidae)

7B Diameter 1.2-1.5 mm . . . . .Type C

8A Perivitelline space very narrow, less than 5% of diameter . 9

8B Perivitelline space about 10% or more of diameter 12

9A More than 1.0 mm diameter 10

9B 1.0 mm or less diameter 11

10A Diameter 1.2-1.5 mm .Type G

10B Diameter 1.7-1.9 mm .Type Q

11A Diameter 0.8-0.9 mm .Type D

11B Diameter 0.5-0.6 mm .Type E

12A Embryo elongate slender; diameter about 1.2 mm. . . .Type F (probably Clupeidae)

12B Embryo robust, broad finfold; diameter about 1.2 mm .Type K (probably Bothidae)

13A Oil droplets 10 or less 14

13B Many oil droplets; no visible perivitelline space; diameter about 0.6 mm . . . . .Type S

14A Diameter less than 2.0 mm 15

14B Diameter about 2.2 mm; broad perivitelline space; yolk granular in appearance . . . . .Type H

15A Diameter 0.8-1.0 mm; perivitelline space 10% or less; 2-10 oil droplets . . . . .Type J

15B Diameter 1.0-1.2 mm; perivitelline space 10% or more; 1-4 oil droplets. . . . . .Type R

16A Perivitelline space visible 17

16B No perivitelline space visible 18

17A Diameter about 1.8 mm; embryo slender . . . . .Type I (probably Clupeidae or an anguilliform)

17B Diameter 0.5-0.7 mm; yolk granular in appearance. . .Type O

18A Diameter 0.6-0.8 mm .Type P

18B Diameter 1.0-1.1 mm . . . . .Type Y

19A One oil droplet 20

19B No oil droplet or several minute ones or one or two plus

several minute ones 25

20A Perivitelline space visible 21

20B No visible perivitteline space; 0.8 mm diameter . . .Type N

21A Perivitelline space 5-10% diameter 22

21B Pervitelline space 5% or less of diameter; 0.8 mm

diameter . . . . .Type L

22A Diameter less than 1.0 mm 23

22B Diameter 1.0 mm or greater 24

23A Diameter 0.8-0.9 mm . . . . .Type M

23B Diameter 0.5-0.7 mm . . . . .Type W

24A Diameter 1.3-1.4 mm; chorion surface with a fine granular

appearance, prismatic in transmitted light. . . . . .Type T

24B Diameter 1.0-1.2 mm; chorion smooth, transparent. . .Type U

25A Diameter less than 1.0 mm 26

25B Diameter about 1.3 mm; surface of chorion with a fine

pattern of hexagonal figures . . . . .Synodontidae

26A Chorion smooth and transparent 27

26B Chorion made up of many small flat plates; prismatic in

transmitted light; diameter 0.6-0.8 mm . . . . . . .Type AA

27A Fine reticulation of granular lines on surface of yolk . . 28

27B No such reticulation; diameter 0.6-0.8 mm . . . . . .Type Z

28A No oil droplets or 5-10 very minute ones; 0.5-0.7 mm diameter . . . . Type V
(may be Clupeidae, Jenkinsia sp.)

28B 1-2 very small oil droplets plus 5-10 extremely minute ones; 0.5-0.7 mm diameter. . . . . Type X
(may be aberant Type V eggs)

29A Ellipsoidal; 1.0 x 0.8 mm; no oil droplet; yolk granular; chorion translucent, granular looking. . . . . . . .Type AB
(probably Engraulidae)

29B Spindle shaped, 2.3 x 0.4 mm; 1-2 oil droplets; yolk homogenous; chorion transparent to prismatic. . . Scaridae, Scarus sp.

Appendix B

A Key to the Larval Fishes of Lameshur Bay

Key to the Yolk-Sac Larvae of Lameshur Bay

1A Anus not yet formed 2

1B Anus formed 9

2A Oil droplet(s) present in yolk. 3

2B No oil droplets in yolk 6

3A 1-4 oil droplets. 4

3B Several minute oil droplets; about 25 myomeres; surface of yolk sac appears granular . . .βF
(resembles embryos seen in Type X eggs)

4A Oil droplet(s) centrodorsally located. 5

4B One oil droplet posteriorly located. . . .ββ

5A 1 oil droplet; yolk homogenous. . .βδ

5B 1-4 oil droplets; yolk with a large inclusion of different optical density, in transmitted light inclusion more transparent, in reflected light more opaque than rest of yolk. .

6A Yolk homogenous 7

6B Yolk granular in appearance; 16 post yolk-sac myomeres. . .βC

7A No pigment anyplace, TL less than 1.0 mm. 8

7B No pigment anyplace, TL 1.1-1.3 mm; 10-13 post yolk-sac myomeres. . . β5

8A 0.9-1.0 mm TL . . . .βA
(resembles embryos seen in Type Z eggs)

8B 0.8 mm TL . . . .βe

9A Gut simple; one melanophore under stomach; 1 melanophore on nape with scattered melanophores on top of head; 2 melanophores on dorsal margin of caudal peduncle . . . U

9B Gut looped; no pigment anywhere. . . . . Bothidae 1

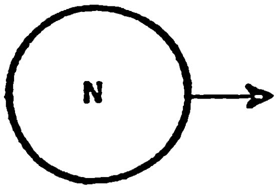
APPENDIX C

ENERGY SYMBOLS

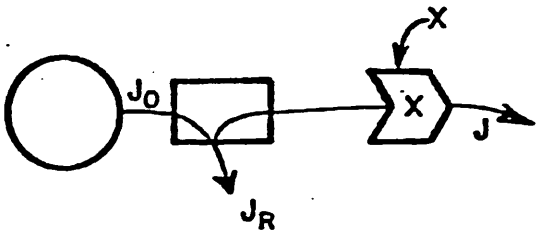
APPENDIX C

SYMBOLS USED IN MODEL DEVELOPMENT

The symbols used in diagrams of models are those of the enery circuit language developed by H. T. Odum. Each symbol has both a verbal meaning and an exact mathematical equivalent which can be found in Odum (1971a, 1972a).

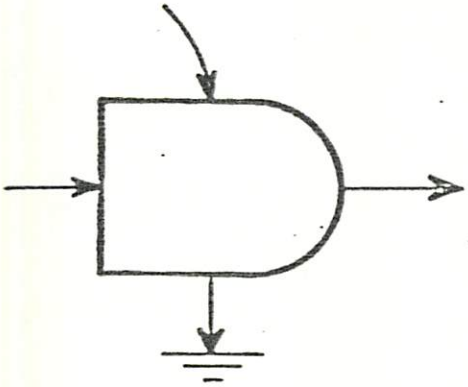


Forcing Function. An external source of energy with or without materials whose driving forces are independent of model behavior. Program can be constant, sinosoidal, etc. and is controlled from outside the model.

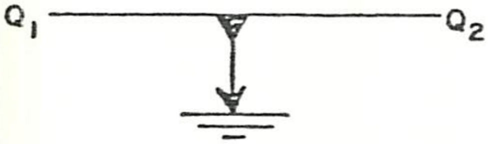


Flow Limited Forcing Function. An external source of energy with or without materials whose input can be a limiting factor due to interactions within the model.

$$J_r = J_o - kJ_rX;\ J = k\left(\frac{kJ_o}{1 + kX}\right)(X)$$



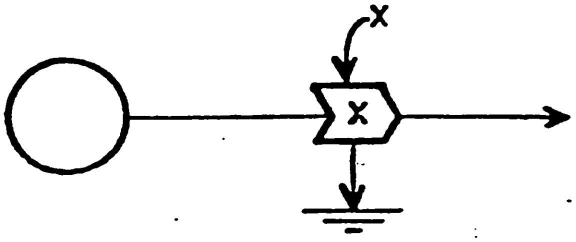
Production and Regeneration Module. A group module representing an interactive production process and storage. Normally used to depict green plant photosynthesis. On a regional scale the module represents the production and consumption of entire ecosystems (P/R). Details of relationships in a particular model are shown within the group symbol.



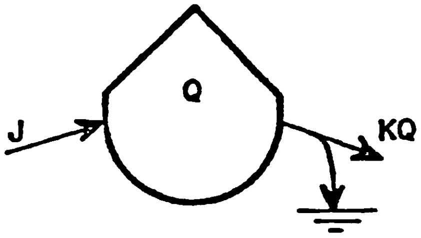
Pathway. Shows a flow of energy with or without materials which is proportional to a quantity in storage or external sources at each end ($J = k(Q_1 - Q_2)$). The heat sink represents energy losses due to frictional forces and backforce along the pathway.

Adding Junction. Shows the intersection of two pathways capable of adding. Arrow indicates direction of flow and absence of any backforce.

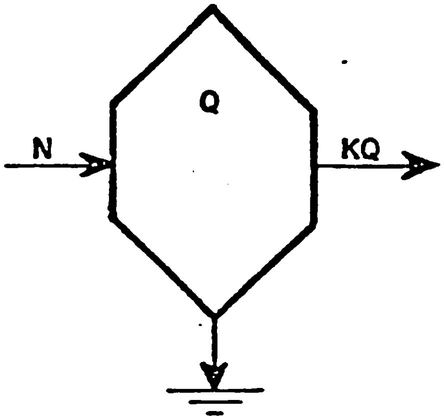
Money Pathway. Dashed line indicates a flow of money with arrow indicating direction.



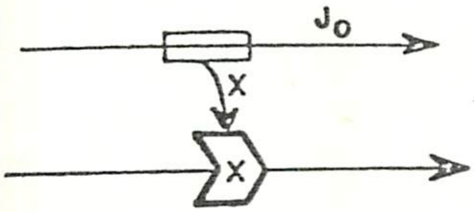
Forcing Function. An external source of energy with or without materials whose input is determined by some variable within the model (X). Inflow can only be limited by the variable with which the forcing function interacts.



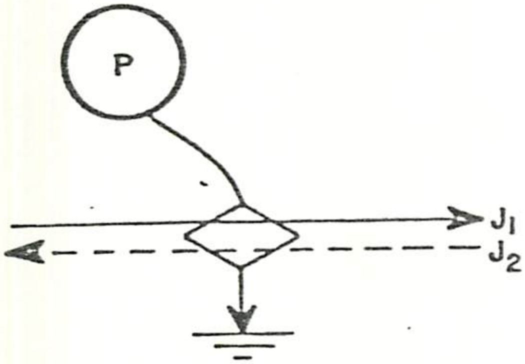
Storage Module. Represents a storage of energy of materials within a system where a quantity is stored as the balance of inflows and outflows ($\frac{dQ}{dt} = J - kQ$) and where outflow includes depreciation.



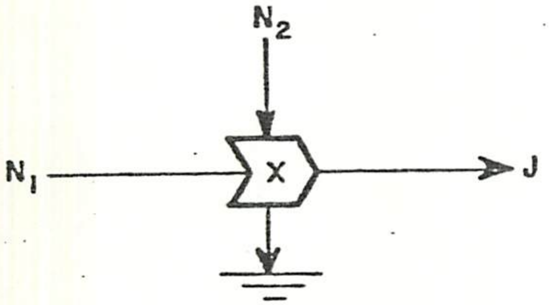
Self-Maintaining Consumer Model. A group module which represents a consumer unit including a combination of a storage module and at least one multiplier where energy stored in one or more places in the module is fed back to do work on processing input energy to that unit; response is autocatalytic if the above features are included. The group symbol is often used to organize model components. When used in this way, it does not imply additional pathways beyond those actually shown.



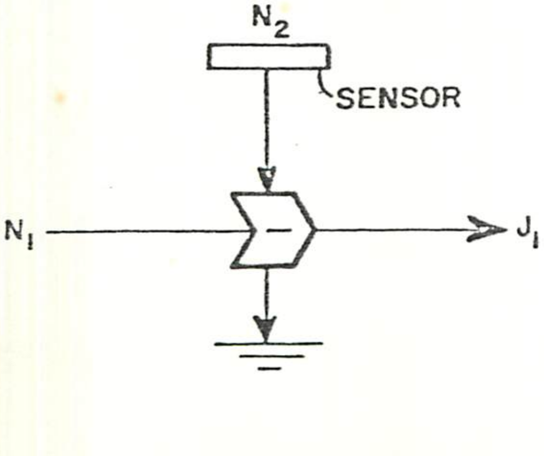
Force from a Flow Symbol. Flow rate of one pathway (J_0) delivers a force X that is proportional to the sensed flow and derives its energy from it.



Price Transactor. Symbol indicates an economic transaction with price (P) the ratio of money flow to energy flow (J_2/J_1). Price may be constant or may vary in a variety of ways. Heat sink indicates the energy cost of maintaining transactions.



Multiplicative Workgate. Symbol indicates intersection of two pathways coupled to produce an outflow proportional to the product of the forces driving both flows. General response is a limiting factor type ($J = kN_1N_2$).



Drag Action Workgate. Symbol indicates an intersection where an increase in one flow has a retarding effect on the output flow ($J = kN_1(1 - kN_2)$). Sensor symbol indicates there is no appreciable loss from N_2 in this interaction.