FORAMINIFERAL AND ECOLOGICAL PROCESSES IN ST. LUCIA LAGOON, ZULULAND

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St. Lucia Lagoon has a long (20 km) and narrow inlet from the Indian Ocean which leads into a shallow basin 38 km long and 2 to 8 km wide. Volume of runoff flowing into the lagoon varies greatly. During years of low runoff the lagoon water may be strongly hypersaline, and it is hyposaline when runoff is high. Populations of crocodiles and water birds are adversely affected during prolonged hypersalinity.

Assemblages of foraminifera have very low diversity and high dominance of Ammonia Beccarii, *with a slightly more diverse fauna in the inlet and southern part of the basin than elsewhere. Large standing stocks of foraminifera in the southern part of the basin, indicating high organic production, are believed to be a result of re-supply of nutrients from the open ocean. Large standing stocks in False Bay and off the Mkuzi River are believed to be a result of abundant supply of nutrients from runoff water, aided by nutrient enrichment from swamp water in the lower reaches of the rivers. Hypersalinity in the lagoon reflects low runoff, low rate of supply of nutrients, and thus low food supply for the crocodiles and water birds.*

Patterns of foraminifera indicate a net flow of marine water into the lagoon, with constant marine influence in the southern part of the basin and frequently throughout the basin. Water exchange rates with the open ocean are slow due to the long and narrow inlet. Rates of sedimentation based on living and total ratios of foraminiferids are high, except in the middle and lower basin where they are moderate.

INTRODUCTION

Coastal lagoons and estuaries are of considerable importance as potential harbors, as nursery grounds for juvenile fish and shrimp, and as recreational areas. St. Lucia Lagoon is in northeastern South Africa on the Indian Ocean coast of Zululand. The lagoon and surrounding land is a wildlife reserve and sports-fishing area administered by the Natal Parks, Game and Fish Preservation Board. The water area supports several hundred crocodiles (an important endangered species), approximately 500 hippopotami, very large flocks of water birds such as flamingoes, white pelicans and ducks, abundant fish of several species and a large population of shrimp. The South Africans consider St. Lucia and its animal populations to be a valuable national asset which must be preserved.

The water in St. Lucia is a mixture of seawater, supplied through the inlet, and fresh-water runoff from the rivers entering the lagoon and seepage from the porous dunes which border the lagoon. When rainfall and runoff are high the water of the lagoon is hyposaline; the water birds, crocodiles and other water life are abundant and healthy under these conditions. When fresh runoff into the lagoon is low during prolonged periods of low rainfall, the inner lagoon becomes hypersaline; many of the water birds migrate elsewhere, some of the crocodiles become "sick" and many die unless relocated in a more congenial environment.

The purpose of the present study is to use the distributions of living and dead benthic foraminifera in St. Lucia Lagoon to interpret some of the ecological processes operating in the area. It is believed that the results obtained by this method may be useful in several aspects of the management of this lagoonal system.

Ist. Int. Symp. on Benthonic Foraminifera
of Continental Margins
Part A: Ecology and Biology
MARITIME SEDIMENTS Spc. Pub. 1, pp 195-204

DESCRIPTION OF THE AREA

St. Lucia Lagoon is located on the coast of the Indian Ocean in northeastern South Africa between approximately 28°24' and 27°53' S. Lat. and 23°21' and 32°35' E. Long. (Fig. 1). The inlet from the open ocean enters a relatively narrow channel, approximately 200 to 500 m wide, which extends north approximately 20 km (Fig. 2). This inlet channel enters a large basin, called Lake St. Lucia which has an average depth of 2 m or less. The basin is about 38 km long and varies in width from 2 to 8 km. There is a series of low-lying islands which extend out into the basin from the eastern shore and which provide constrictions in the basin. These are, from south to north; Mitchell Island, Vincent Islands, Fanies Island, Lane Island and Bird Island. A shallow lagoon basin is tributary to Lake St. Lucia on the west, called False Bay; this is 21 km long and about 2 to 3 km wide.

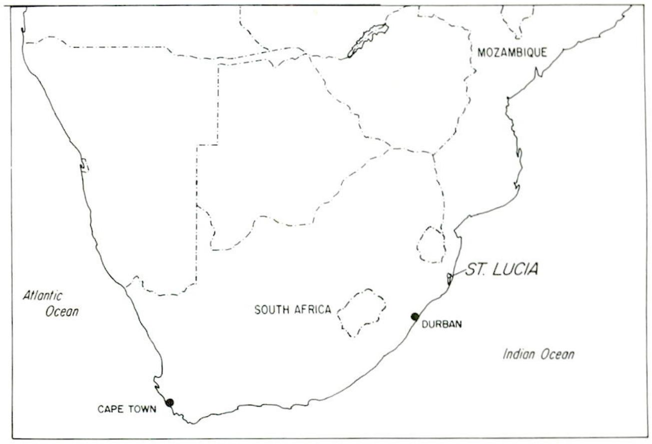

FIG. 1 Location map of St. Lucia.

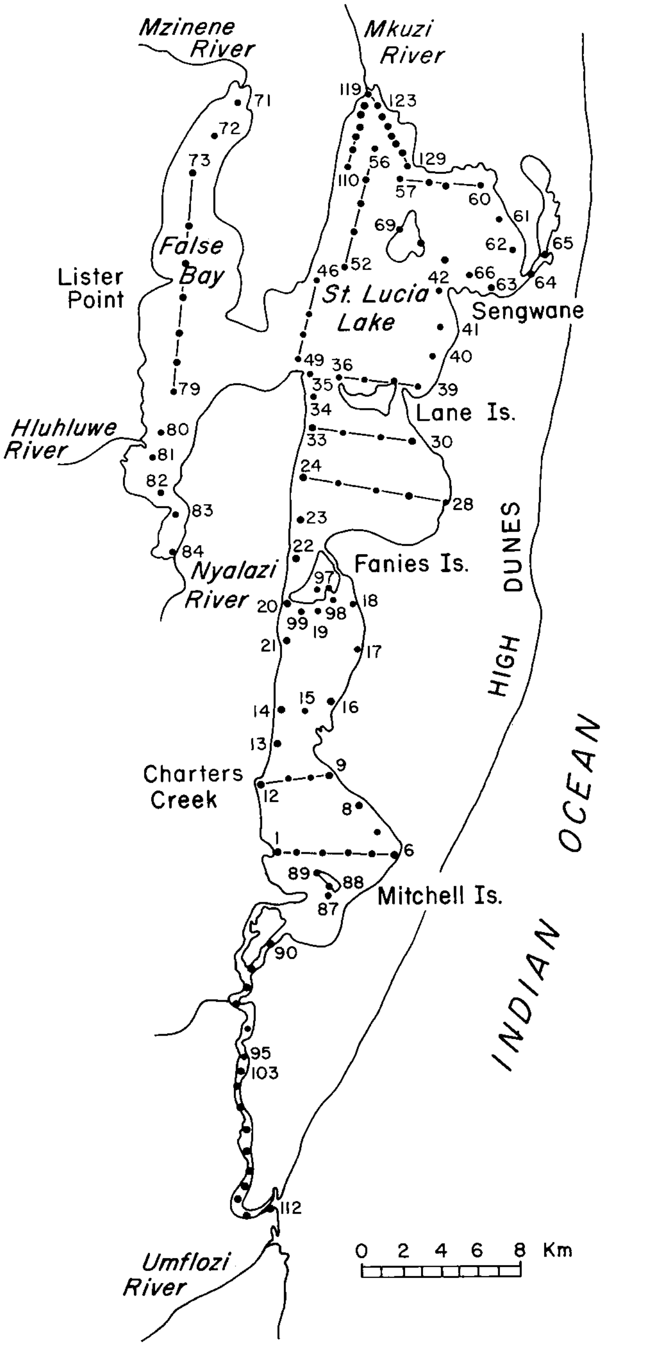

FIG. 2 Outline map of St. Lucia Lagoon showing locations of sediment samples collected in 1973 for foraminifera.

The lagoon is separated from the Indian Ocean by a sandy barrier of forested dunes which are up to more than 150 m high. On the lagoon side of the dunes there are marshy lowlands and some low dunes. False Bay is separated from Lake St. Lucia by two peninsulas of Cretaceous rock; the two basins are connected by a passage 2 km wide. Dunes from an older cycle bound False Bay on the west.

The Mkuzi River flows into the north end of the lagoon. Three small rivers flow into False Bay, the Nyalazi, the Hluhluwe and Mzinene. The Mflozi River enters the ocean approximately 1 km south of the inlet.

The climate of the area is warm subtropical. The average rainfall is about 100 cm/year, but in a very wet year may be as much as 225 cm or as little as 46 cm in a very dry year. The evaporation loss from the lake is estimated as greater than the rainfall, except in a very wet year, and evaporation may be as much as three times the rainfall in a very dry year. Eighty percent of the rain falls during the summer season, October to March.

Samples for forams were collected from approximately 20 stations in May and November, 1972, and from 125 stations in May, 1973 (Fig. 2). Surface sediment samples approximately 10 cm^2 in area and 1 cm thick were collected by taking a short core with a pole sampler designed by R.R. Lankford and J.R. Curray; these were preserved in a buffered formalin solution. Living specimens were identified by staining with rose Bengal.

SALINITY PATTERNS

The geographic and temporal distribution of salinity within the lagoon reflects water exchange with the open ocean and variations in the amount of river runoff flowing into the lagoon. Figure 3 contains plots of monthly surface salinities at four locations in Lake St. Lucia and one in False Bay, as well as water levels at Charters Creek relative to mean sea level for 1970-73. This includes the times when samples for forams were collected. The salinities plotted are near the south end of Lake St. Lucia (Charters Creek), almost midway in the lake (Fanies Island) in the upper lake (Sengwane) the northern end of the lake (Mkuzi River mouth) and in False Bay (Lister Point).

During 1970 and most of 1971 the area was weakly to strongly hypersaline with salinities more than 50 °/oo much of the time and up to almost 100 °/oo in the upper lake. Strongly hypersaline water also was recorded for at least 1 km upstream in the Mkuzi River, and large areas of the Mkuzi swamp dried out. There was a slight decrease in salinity after January 1971, reflecting runoff during the rainy season but salinities remained 50-75 °/oo in the upper lake and False Bay. It was during this period of stong hypersalinity that large numbers of water birds left the area and many of the crocodiles became "sick" and some died in the Mkuzi River area, and some were relocated to the southern lake. Salinities in the long inlet were essentially those of sea water most of the time, with occasional dilution in some places, probably caused by local seepage of ground water.

The considerable runoff in December 1971 and continuing into early 1972 was reflected in a dramatic lowering of salinities. Water at the Mkuzi River mouth was fresh for four months in early 1972 and salinities were low throughout the area, including the inlet, and lake water levels were above mean sea level. Somewhat lower runoff during the 1972-73 rainy season is reflected in

TABLE 1

Occurrences of living (L) and dead (D) species of foraminifera

in percent of the living or dead population

STATION NO.		1	2	3	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	24	26	27	28	29	31	34	35	36	37	38	39	40	41	46	47	48	49	50	51	52	53	54	56	57	64	65	66	67
LIVE POPULATION		57	455	21	396	128	80	0	114	1240	200	340	20	400	120	60	156	60	54	132	110	140	41	27	24	560	75	20	27	78	184	270	24	100	66	40	46	3730	70	170	60	77	0	510	37	178	16	16	54	52
DEAD POPULATION		213	1870	490	1580	620	64	20	90	4600	860	370	1240	9800	7490	1580	1440	1700	300	1650	1850	4370	940	800	40	700	1800	1300	340	900	2000	5100	450	1420	600	530	440	2900	200	1010	800	460	980	5200	208	700	3200	250	200	3200
AMMOBACULITES SP.	L																																																	
	D														X																																			
AMMONIA BECCARII VARS.	L	40	11	100	93	100	75		71	98	40	86	100	75	78	51	100	80	100	85	100	78	93	100	100	99	100	100	81	85	100	100	100	100	100	100	91	99	84	94	100	96		92	94	86	50	50	100	86
	D	96	43	86	92	99	100	66	100	100	100	95	95	91	94	99	99	97	96	90	99	94	94	99	100	97	95	99	95	92	91	95	100	97	94	81	95	97	93	100	97	91	88	90	85	88	96	90	98	88
AMMOTIUM SALSUM	L																																																	
	D																																																	
ARENOPARRELLA CF. MEXICANA	L																																																	
	D																																																	
BOLIVINA SPP.	L	4	5		4				3		5	5			11	33							2							10														2						
	D		1	1	1							1		1						5			1						1	1							1	1	2		1	1		X		1				
CRIBROELPHIDIUM CF. TRANSLUCENS	L		1		1						2															1			4															3						
	D		2	6									2	3	2				3	2	1		1	1		1	1		1	2	2	2			2	1			2					2	8	3	1			4
GAUDRYINA CF. EXILIS	L	4										1																																						
	D		1	1																																														
HAPLOPHRAGMOIDES WILBERTI	L																																																	
	D																																																	X
H. SP.	L																																																	
	D		1																																												1	3		
MILIAMMINA FUSCA	L																																																	
	D																																																	
MILIOLIDS	L	44	83		2		25		26	2	53	8			11	16		20		10		22	5						15	5							9	1	16	6		4		3	6	3	50	50		
	D	4	51	3	7	1						2	3	3	9	1	1	3		8		6	4			2	4	1	3	5	7	3		3	4	18	4	2	4		2	8	12	8	7	8	2	7	1	8
REOPHAX CF. NANUS	L																																																	
	D																																						1											
TROCHAMMINA CF. INFLATA VAR.	L	8																																																
	D							34				2	X																																		X		1	
TROCHAMMINITA IRREGULARIS	L																																																	
	D																																																	
VIRGULINA CF. SPINICOSTATA	L													25																																				
	D																																																	

STATION NO.		68	69	70	72	73	75	77	78	80	81	82	84	85	86	87	88	89	90	91	92	94	95	97	98	103	105	106	107	108	109	110	111	113	114	116	118	120	121	122	124	125	126	127	128	129	60	61	62	63
LIVE POPULATION		4	230	0	51	615	430	2440	250	92	306	200	62	144	133	945	232	192	183	45	58	35	20	10	48	128	67	12	47	81	44	115	110	294	350	144	168	7	26	19	88	274	116	283	60	17	32	42	24	7
DEAD POPULATION		230	1875	700	390	1100	920	2640	1600	560	830	1840	430	5300	2700	960	169	4330	27	35	10	5	18	16	840	26	2	4	7	130	16	49	22	1360	1640	1750	6600	116	50	63	570	510	790	310	170	114	940	1000	2100	48
AMMOBACULITES SP.	L																		2		4																													
	D																1																																	
AMMONIA BECCARII VARS.	L	100	82		92	99	96	98	99	98	97	96	100	94	94	65	85	66	63	33	54	69	45	10	100	88	66	100	52	50	52	29	64	95	98	97	100	100	100	68	96	97	98	96	100	100	100	96	84	100
	D	86	89	90	93	93	95	93	90	90	93	87	79	93	96	69	70	67	77	43	60	40	88	19	98	65	100	100	29	27	55	8	30	81	90	93	93	98	56	67	91	94	92	93	93	86	95	89	91	72
AMMOTIUM SALSUM	L															1					4			10								1																		
	D																													1		2																		
ARENOPARRELLA CF. MEXICANA	L																																																	
	D																							7																										
BOLIVINA SPP.	L		2			1	2				1				6	2	1		6			20	10			3	27		34	27	36	25	12	5		3					2	1								
	D	1	X		2		1	1	1	1	1	X			1		3					20								6	5			1	X	1	1		2		X	1		1	1	1			1	
CRIBROELPHIDIUM CF. TRANSLUCENS	L		10								1	2				9	4		2																1					16										
	D	4	6		1	3	2	5	2	4	1	10	12			3	10	1	23															5	3	1	1	1	10		2	1	2	2	1	3	2	4	1	
GAUDRYINA CF. EXILIS	L																1				7					2	4			4		9	2																	
	D																															6	10																	
HAPLOPHRAGMOIDES WILBERTI	L																																																	
	D																																							8										
H. SP.	L																																																	
	D												2											12															4											2
MILIAMMINA FUSCA	L																																																	
	D																																							2										
MILIOLIDS	L		4		8		2	2	1		1	2		6		22	9	34	14	67	14	11	45	60		5	3		10	10	7	13	18		1						2	1	2	4				4	16	
	D	9	3	10	4	4	1	1	7	5	5	3	7	7	3	20	14	32		14		40	12	12	1	27				42	20	6	60	13	7	5	5	1	20		7	4	6	4	5	9	3	7	7	18
REOPHAX CF. NANUS	L									2							1												2	6		15																		
	D						1					X														4			57	22	20	76	2																	
TROCHAMMINA CF. INFLATA VAR.	L		2													1	1		13					20					2		3	1								16										
	D															8	2			43	40	17		50	1				14			2							6	13		X				1				8
TROCHAMMINITA IRREGULARIS	L																																							10										
	D																																																	
VIRGULINA CF. SPINICOSTATA	L																		2											3		7	2																	
	D																													2																				

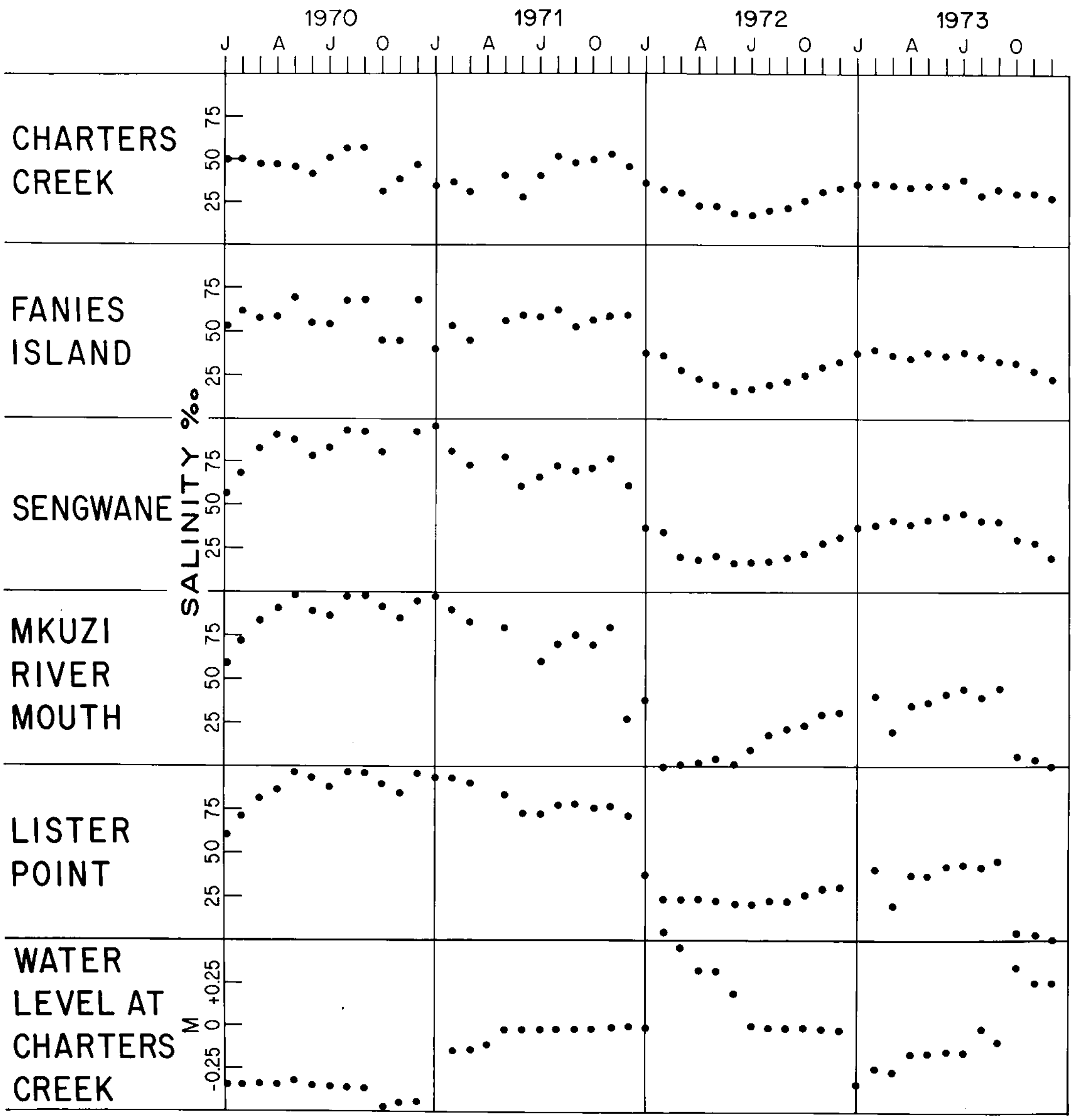

FIG. 3 Salinities at selected locations during 1970-73, and water level in m. at Charters Creek referred to mean sea level.

a salinity increase and lowering of lake levels. Relatively high runoff is indicated for the beginning of the rainy season in late 1973 by a marked reduction of salinities in the inner basin and a rise in water level. Reduced salinities also occur throughout the inlet.

The monthly salinity data for 1970-73 clearly demonstrate the great variations which occur from year to year. This also has been shown by data from the Charters Creek station from 1957-1965 (Commission Report, 1964 - 66). Several years of runoff data of the five rivers which influence salinities in the St. Lucia system show very large variations in the approximate yearly runoff; the extreme ranges of runoff of the Mkuzi River, for example, are an order of magnitude apart (Table 2).

DISTRIBUTION OF FORAMINIFERA

Species

The species in the St. Lucia area appear to be very similar or identical to forms which are well-known elsewhere in similar environments. Established names are used here although there may be some varietal differences from described forms in other areas. The original references to the species are listed along with a readily available modern reference and illustration.

Ammonia beccarii (Linne) vars. *Nautilus beccarii* Linne, 1958, Syst. Nat., ed. 10, p. 710 "*Rotalia*" *beccarii* variants A, B, C, Parker, Phleger and Peirson, 1953, Cushman Found. Foraminiferal Res., Spec. Publ. 2, p. 13, Pl. 4, Figs. 20-22, 25-30.

TABLE 2

Approximate River Runoff in $M^3 \times 10^6$

	Mflozi	Mkuzi	Nyalazi	Hluhluwe	Mzinene
1950-51	232	74	14	31	10
1951-52	267	39	5	6	2
1952-53	362	68	12	13	5
1953-54	301	62	13	17	3
1954-55	871	110	29	38	18
1955-56	950	212	19	35	6
1956-57	1,495	194	53	68	22
1957-58	2,053	369	70	140	42
1958-59	440	106	10	30	4
1959-60	433	106	14	22	5
1960-61	1,134	375	35	66	15
1961-62	264	70	13	15	3
1962-63	1,657	418	34	75	43
1963-64	251	46	16	33	15
1964-65	396	40	15	24	7
1965-66	353	56	17	49	12
1966-67	703	140	13	13	9
1967-68	354	54	6	14	3
1968-69	495		39	24	13
1969-70	288		9	15	3
1970-71	612		19	14	5
1971-72	1,340		81	128	41

Three variants were observed in essentially all samples; since they appear to have no separate ecological value they were not differentiated in counting. This species occurs in all samples. It averages more than 90 % of the live and dead population in most of the area, except in the inlet and the southernmost part of Lake St. Lucia, south and west of Mitchell Island, where it averages about 55 % of the population.

Quinqueloculina seminulum (Linne). *Serpula seminulum* Linne, 1767, Syst. Nat., ed. 12, p. 1264. *Quinqueloculina seminulum*, Parker, Phleger and Peirson, 1953, Cushman Found. Foraminiferal Res., Spec. Publ. 2, p. 12.

Almost all miliolids observed are *Q. seminulum*. This is the second-most abundant species, occurring at almost all stations throughout the area.

Cribroelphidium cf. *translucens* (Natland), 1938, Bull. Scripps Inst. Oceanography, Tech. Ser., v. 4, p. 144, pl. 5, Figs. 3, 4.

This occurs in most of the samples in the basin but was found live at only 9 stations; it was not found in the inlet samples. The retral processes in these specimens vary from prominent to very poorly developed at the same station.

Bolivina cf. *lowmani* Phleger and Parker (1951, Mem. 46, Geol. Soc. Amer., pt. 2, p. 13, pl. 6, Figs. 20a, b, 21.

Bolivina cf. *striatula* Cushman, 1922, Publ. 311, Carnegie Inst. Washington, p. 27, pl. 3, Fig. 10.

These two species occur together and were not counted separately. They occur in all the area, but living specimens are more common in the inlet and lower lake to approximately Fanies Island.

Gaudryina cf. *exilis* Cushman and Bronnimann, 1948. Contribs. Cushman Lab. Foraminiferal Res., v. 24, pt. 2, p. 40, pl. 7, Figs. 15-16.

This is rare and was found in the inlet and on the west side of the lake as far as Charters Creek.

Reophax cf, *nana* Rhumbler, 1913, Ergeb. Plankton-Exped. Humboldt Stiftung, v. 3, pt. 2, p. 471, pl. 8, Figs. 6-12.

Most of the specimens of this rare species were found in the lower inlet, but there was one specimen near Mitchell Island and a few specimens were in False Bay.

Virgulina cf. *spinicostata* Phleger and Parker, 1953, Cushman Found. Foraminiferal Res., Spec. Publ. 2, p. 15, pl. 4, Figs. 16, 17.

This was identified in 4 samples from the inlet and in 2 in the southern lake near Fanies Island.

Trochammina cf. *inflata* (Montagu) var. *Nautilus inflatus* Montagu, 1808, Test. Brit., p. 81, pl. 18, fig. 3, Parker, F.L., Phleger, F.B. and Peirson, J.F., 1953, Cushman Found. Foraminiferal Res., Spec. Publ. 2, p. 15, pl. 3, Figs. 5, 6.

Ammotium salsum (Cushman and Bronnimann). *Ammobaculites salsus* Cushman and Bronnimann, 1948, Contr. Cushman Lab. Foraminiferal Res., v. 24, pt. 1, p. 16, pl. 3, Figs. 7-9.

Miliammina fusca (H.B. Brady). *Quinqueloculina fusca* H.B. Brady, 1870, Ann. Mag. Nat. Hist., per. 4, v. 6, p. 47 (286), pl. 11, Figs. 2a-c, 3.

Parker, F.L., Phleger, F.B. and Peirson, J.F. 1953, Cushman Found. Foraminiferal Res., Spec. Publ. 2, p. 10-11, pl. 1, Figs. 40, 41.

Trochamminita irregularis Cushman and Bronnimann, 1948, Contribs. Cushman Lab. Foraminiferal Res., v. 24, pt. 1, p. 17, pl. 4, Figs. 1-3.

Arenoparrella cf. *mexicana* (Kornfeld). *Trochammina inflata* (Montagu) var. *mexicana* Kornfeld, 1931, Contribs. Stanford Dept. Geology, v. 1, p. 86, pl. 13, Figs. 5a-c.

Assemblages

Occurrences of species in samples collected during May 1973 are in Table 1; generalized distributions are on Figure 4. Distributions of species in the samples of May and November, 1972, show patterns which are similar to the 1973 collection.

1. Inlet assemblage. *Ammobaculites* sp., *Ammotium salsum* and *Rheophax* cf. *nana* were rare only in the inlet. *Gaudryina exilis* was rare in the inlet and the south end of the lake. *Quinqueloculina seminulum* was less common than in the lake, and *Ammonia beccarii* was distinctly less abundant in the inlet and south end of the lake than elsewhere. The presence of *Trochammina* cf. *inflata* var. in the inlet and south end of the lake is attributed to the occurrence nearby of fringing marine marsh. *Bolivina* spp. are common.

2. Lake Assemblage. *Elphidium* cf. *translucens* is common throughout the lake. *Quinqueloculina seminulum* is common and *Bolivina* spp. are common as far north as Fanies Island and rare elsewhere. *Ammonia beccarii* is abundant at all stations.

3. Mkuzi River assemblage. *Haplophragmoides wilberti* and *Trochamminita irregularis* are recorded only from here; these forms are reported from marine marsh in the Gulf of Paria. Other marsh species are *Miliammina fusca*, *Trochammina* cf. *inflata* var. and *Arenoparrella* cf. *mexicana*. *Ammonia beccarii* is abundant and rare forms are *Bolivina* spp. *Elphidium* cf. *translucens* and *Quinqueloculina seminulum*.

4. Marsh. One sample from a small stream on Fanies Island contained *Arenoparrella* cf. *mexicana*, *Haplophragmoides* sp. and *Trochammina inflata*, as well as rare *Ammonia beccarii* and *Quinqueloculina seminulum*.

An overlap of the inlet and lake assemblages occurs at the south end of the lake, south of Mitchell Island and northwest approximately to Charters Creek.

The standing stock of foraminiferids at most stations ranged approximately from 50 to 150 living specimens per sample (10 cm^2/1 cm thick) at the time of the May 1973 collection. At this time there were two areas where significantly larger-than-average standing stocks were collected: (1) in the southern end of the lake around Mitchell Island and extending north to about Charters Creek, and (2) in False Bay where large standing stocks were present at 6 stations. An unusually large living population also was present at Station 48 in the lake off the entrance to False Bay.

Unusually large standing stocks were found during both May and November 1972 (4,000+ and 2700+) at a station in the northern lake just off the mouth of the Mkuzi River. In May 1973 several samples were collected off the Mkuzi mouth in an attempt to define the extend of the high production area. The standing stocks at this location at that time, however, were more than an order of magnitude less than those of the previous year.

The fauna is dominated by *Ammonia beccarii*. In the lake, north of approximately Mitchell Island and in False Bay, this species is 90 % or more of the population at almost all stations. In the inlet and south of Mitchell Island *A. beccarii* averages about 55 % of the fauna. The number of species in the lake north of Mitchell Island and Charters Creek and in False Bay is small, averaging approximately 2 species per station. In the inlet and the southern

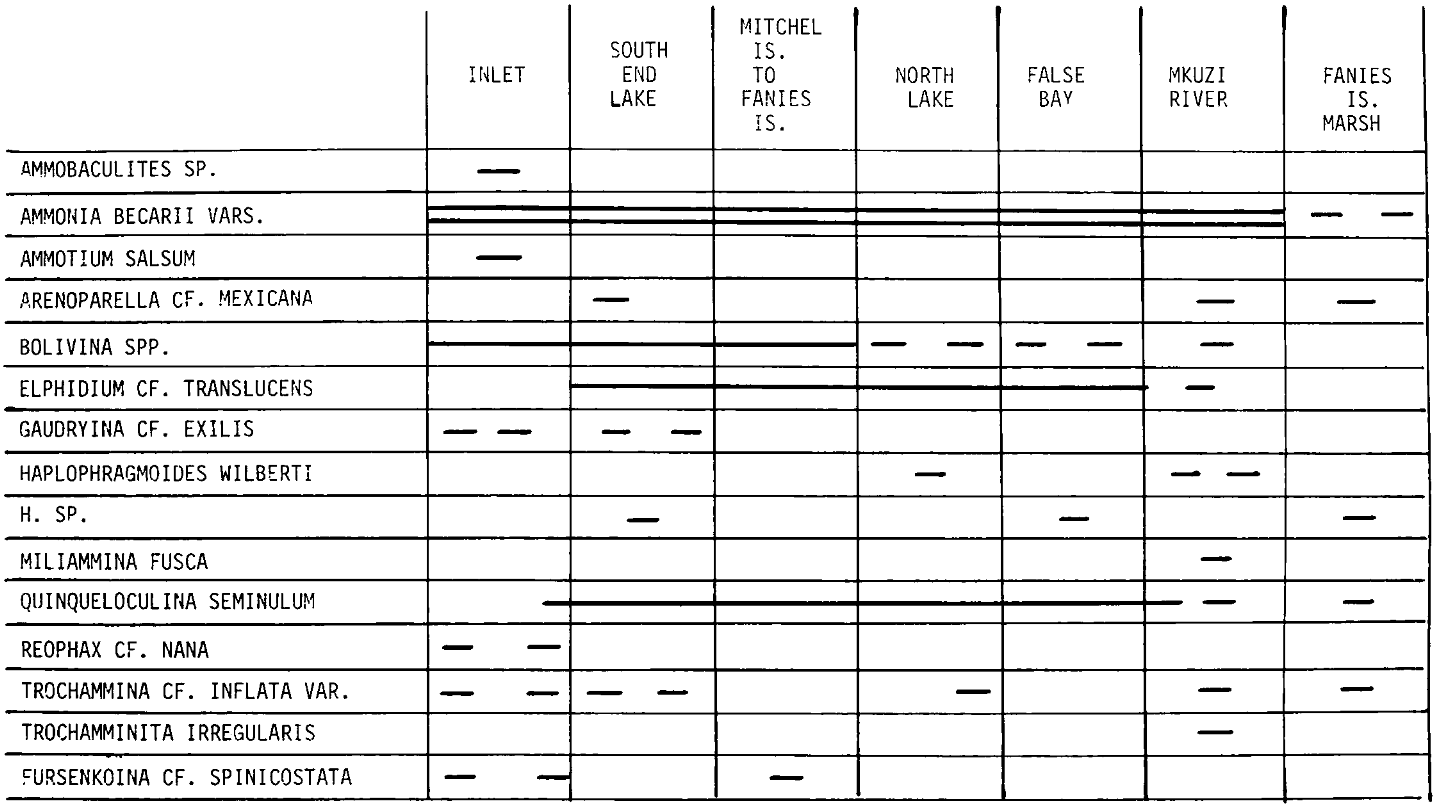

FIG. 4 Generalized distributions of species of foraminifera.

end of the lake the average number of species per station is between 4 and 5. The populations thus have a very low diversity throughout the area, with a somewhat lower diversity north of the southern end of the lake than in the inlet and the southern lake.

ECOLOGICAL INTERPRETATIONS

Water Exchange and Marine Influence

Conditions in St. Lucia Lagoon range from strongly hyposaline to strongly hypersaline due to variation in runoff during the rainy and dry seasons and during relatively wet and dry years. These variations in water conditions are amplified because of the relatively large size of the area and unusually long inlet, which result in a very low rate of exchange of water with the open ocean. As a result the water in the lake, except at the southern end, is essentially trapped there except during times of large floods when the lagoon may be partly or entirely flushed. The water in the lake and False Bay is thus ecologically distinctive.

Foraminiferal assemblages reflect these conditions, and since their tests accumulate in the sediments they leave an integrated record of environmental conditions over the period of time represented by the sediment sample. The living assemblage reflects conditions when they were collected and (or) those during the very recent past. In the present samples the living and dead populations are essentially the same in composition, with some exceptions.

The unusually high dominance by *Ammonia beccarii* and very low diversity of the fauna reflect the great range in environmental conditions in St. Lucia Lagoon, especially in the area north of Mitchell Island to Charters Creek. The lower dominance and higher diversity of the fauna in the inlet and southernmost lake appear to reflect the greater stability of water conditions in that area. This is verified by the small ranges in salinity in comparison to the northern area. It is obvious that *A. beccarii* can survive and reproduce under a large range of water salinity with such efficiency that it may even restrict the presence or abundance of other forams. It is not known whether this species lives in the nearshore open ocean as it does in many other areas, but it is likely that it does, based on its abundance in the living population throughout the inlet.

The limit of the influence of more or less ecologically unaltered marine water extends into the southern end of the lake as far as Mitchell Island and approximately to Charters Creek on the west side of the lake much or most of the time. This is based on the northward limit of *Gaudryina exilis*, *Reophax nanus* and *Virgulina* cf. *spinicostata*, which in other areas are open-ocean forms. In addition, living *Bolivina* cf. *lowmani* and *B. striatula* are more abundant in the lower lake and inlet than elsewhere in the lake. According to F. Joubert (personal communication), resident scientific officer of the Natal Parks Board at St. Lucia, the southern end of the lake also is the northern limit of observed tidal effect. The faunal evidence indicates that consistent marine influence is mostly on the west side and central part of the southern lake. This is verified by abundant salinity data furnished by the Natal Parks Board.

The distribution of *Bolivina* cf. *lowmani* and *B. striatula* indicates that there is frequent marine influence as far north as Fanies Island. Occasional marine influence, however, occurs throughout the area, based on distribution of the same species in low frequencies throughout the basin. This appeared to be the situation in May, 1973, judging from the high salinities throughout the lake and False Bay. Hypersaline water was recorded in the channel of the Mkuzi River several times in 1970-71 when hypersaline water filled the entire basin (Fig. 3).

There appears to be a net transport of water through the inlet from the ocean into the basin. This is based in part on the widespread distribution within the basin of the two open-ocean species of *Bolivina*. It is also based on the restriction of *Elphidium* cf. *translucens* to the basin and its absence in the inlet, except at the northernmost station in the inlet. It is further verified by water-level records at Charters Creek where the lake levels were near, or below mean sea level most of the time during 1970-73 (Fig. 3). It seems likely that there is occasional flushing of the basin during times of very high water, when the water level in the lake is known to be above mean sea level. Such flushing may not be sufficiently severe or prolonged to cause migration of *E. translucens* into the inlet. This is in apparent contrast to the occurrence of a closely related lagoonal species of *Elphidium* in the nearshore zone off San Antonio Bay, Texas (Phleger 1956). The long and narrow inlet at St. Lucia apparently acts as a filter to prevent rapid outflow during high lake levels, as well as restricting the rate of flow of sea water into the basin. The presence of forams in the Mkuzi River for at least 1 km upstream indicates that there is invasion of water of lagoon origin into this area, and this is verified by salinity data from this station. The surface water of the river at this location was fresh when the samples were collected. Living *Ammonia beccarii* and *Elphidium* cf. *translucens* were found in the river sediments. Other species of this fauna are marsh forms, indicating that the river bottom has the ecology of a marine marsh, although it is surrounded by a fresh-water marsh dominated by plants of *Phragmites*.

Significance of Standing Stocks

The standing stocks of forams per unit area and volume are useful approximations of relative organic production. The largest standing stocks have been found in hypersaline lagoons, such as Laguna Madre, Texas (Phleger 1960), Laguna Madre, Mexico (Ayala-Castanares 1968) and Laguna Ojo de Liebro, Mexico (Phleger and Ewing 1962), and near river effluents where they enter coastal lagoons (Phleger and Lankford 1957) or the open ocean (Lankford 1959). Organic productivity measurements have shown that rates of carbon fixation are high in at least two areas of large standing stocks of forams (Phleger and Ewing 1962, Thomas and Simmons 1960).

This is generally a highly productive area based on comparisons of sizes of standing stocks with other lagoonal areas. The basin as a whole is like a hypersaline lagoon with a net flow of ocean water into the area, and it is a hypersaline lagoon in fact during some years. Under such conditions there is a constant re-supply of inorganic nutrients because of a constant re-supply of ocean water. In addition, the rivers which flow into the lake bring a supply of nutrients and soil extract which enhances production rates.

Another factor contributing to high organic production probably is nitrogen fixation by blue-green algae in the extensive fresh water and marine marshes which border much of St. Lucia lagoon and the rivers which flow into it. According to Mague (in press) "the blue-green algae contribute significantly to the processes of (di)nitrogen fixation in nature ... Blue-green algae are particularly abundant in tropical lakes where profuse blooms are sometimes manually collected in nets and baskets for use as a green manure". These nitrogen-fixing algae also are abundant in marshes according to Mague. Recent work has indicated that nitrate is probably the limiting factor in organic production in marginal marine environments (Goldman *et al* 1973).

The unusually high standing stock of forams off the effluent of the Mkuzi River in May and November, 1972, can be explained in part by the supply of soil extract to the inner lagoon. Soil extract contains plant nutrients and numerous trace materials important in plant gorwth, and is a desirable ingredient of phytoplankton culture in the laboratory. The Mkuzi flows through extensive marshes in its lower reaches and a part of the river delta. There is no easily discernible principal river course in much of this area and it appears that the river filters through the marsh. It seems likely that the river water accumulates nitrogen compounds which were fixed by the blue-green algae in the marsh. A large population of crocodiles lives in the lower river, indicating a large supply of fish which is necessary for their food. A high basic organic production is therefore indicated.

The small standing stock of forams off the mouth of the Mkuzi in May 1973 was at tne end of a "rainy season" when the rainfall and consequent river runoff were considerably less than in 1971-1972; the river was lower and there was less apparent river flow than was observed at the same time in the previous year. Large numbers of the foraminifera off the river effluent appeared as if they had recently died; they had small fragments of cytoplasm inside the tests. These samples were interpreted as indicating that a large standing stock had recently been produced; the most likely cause of death is believed to have been lack of food. The most reasonable explanation for the small standing stock in 1973, compared with 1972, is a reduction in food supply from that of the previous year when there was much more rainfall and river runoff.

The inlet supplies inorganic nutrients to the southern end of the lake from seawater with probable enrichment from the nitrogen-fixing blue-green algae in the extensive marine and freshwater swamps which border the long inlet. Fresh nutrients are supplied to this area on each flood tide. The rate of water exchange between the southern end of the lake and the central and northern sections is very slow. As a result most of the inorganic nutrients are used near the point of their introduction in the southern lake. This also occurs off the mouth of the Mkuzi River where the area of high production is near the efflent.

The high standing stock in False Bay probably is due to enrichment by runoff from the three rivers which flow into the area. The deltas of the Mninene and Hluhluwve rivers have large marshes which probably enrich the runoff water. There are large old dunes on the western side of False Bay which provide a significant reservoir of ground water. Seepage from the reservoir may contribute a considerable amount of ground water to False Bay. There is considerable seepage from the modern dunes on the eastern side of St. Lucia Lake, as evidenced by lakes and swamps in the lowlands on the western side of these large dunes.

The "sickness" of the crocodiles in the upper lagoon and the departure of many water birds during prolonged dry periods appears to be due to a sharply reduced supply of fish which are the principal food for many water birds and crocodiles. The low fish population under such conditions has been attributed to the high salinities which prevail in the inner lake. It is suggested here that the principal basic cause is a reduced supply of inorganic nutrients which are necessary for the organic production of plants at the beginning of the food chain, and that salinity is not the principal ecological factor. The hypersalinities reflect the reduced supply of fresh water to the lagoon and thus also reflect the reduced supply of nutrients such as phosphate, nitrate and other trace materials contained in the runoff water. It is expected that organic production in the southern lake will remain at about the same level during high runoff and low runoff season, due to a constant re-supply of inorganic nutrients by tidal action, and this was observed in the standing stocks of forams in this area in 1972 and 1973.

Recent studies have indicated that nitrogen may be the key growth-limiting nutrient in many coastal marine waters (Goldman *et al* 1973). This suggests that the nitrogen-fixing algae may be of primary importance in maintaining organic production levels in St. Lucia Lagoon. It is believed that the greatest concentrations of the blue-green algae are in the marshes which border the area, especially the lower reaches of the rivers. It may not be proper management, therefore, to modify the courses of the rivers so that they bypass the marshes in an attempt to increase rate of flow, as has been suggested for the Mkuzi River. Such modification may reduce the total supply of nitrogen compounds to the lagoon and result in a reduction of organic production in the Mkuzi estuary and the northern lake.

The mouth of the inlet to the open ocean frequently is very restricted in size and may close completely. The adjacent effluent of the Mfloze River provides abundant sand to the nearshore zone which is available to waves and longshore currents to choke the inlet. It is obviously essential that free circulation be maintained between the open ocean and the lagoon through the inlet to: (1) maintain the organic production rates within the southern lagoon, (2) provide free access to the lagoon for juvenile fish, post-larval shrimp and other organisms and (3) provide a mechanism for disposal of metabolic and decomposition wastes.

SEDIMENTARY PROCESSES

St. Lucia Lagoon is in an ancient river valley cut during one or more interglacial intervals and now essentially filled with sediment. The barrier originally was a ridge of sandstone on the seaward side, Pleistocene or Pliocene in age, which is the base on which the dunes of the present cycle are placed. This ridge of sandstone can be followed from about 7 km north of the inlet of St. Lucia to beyond the northern boundary of the basin. It appears that the lagoon filled rapidly with sediment as soon as sea level reached a position so that the sediment-laden river runoff was impounded. Cores recently drilled in the basin contain 20 to 30 km of Holocene sediment; this suggests that deposition in the basin began 9000 to 11,000 years BP (Curray 1961). Since sea level was about at its present position (approximately 3,000 yr BP) the basin has been reduced in size by filling, primarily at the northern end associated with the delta of the Mkuzi and in the south associated with the Mflozi delta area.

Relative rates of deposition of the surface sediment can be estimated by the percent of the total population of foraminifera in surface sediment samples of equal thickness (1 cm) which were alive. Large percents suggest relatively rapid deposition and small percents suggest low deposition. This is based on the assumptions: (1) that the forams are produced at an approximately constant rate, and (2) that there is no significant post-mortem transport or destruction of empty tests. The data in St. Lucia suggest the following: (1) the highest rates of deposition are in the inlet from the open ocean to south of Mitchell Island; (2) rapid deposition occurs in False Bay and on the Mkuzi delta, but not so rapid as in the inlet; (3) depositional rates in most of the St. Lucia basin is relatively slow, except for a few km north of Mitchell Island, on the eastern edge of the basin and on the islands sampled.

Depositional rates suggested by this method are much higher in St. Lucia Lagoon than in Terminos Lagoon, an area in southern Mexico which has seasonal rainfall and high runoff from three rivers flowing into the lagoon (Ayala-Castanares 1963). Termir s Lagoon has two, short and wide inlets. The ı.off bypasses the lagoon and exits through one et and deposits most of its suspended sediment the continental shelf. The runoff flowing into .. Lucia, on the other hand, has only delayed access to the open ocean because of the filtering effect of the very long and narrow inlet. This results in deposition of most of all of the sediment brought in by the Mkuzi, Mzinene, Hluhluwe and Nyalazi Rivers in the lagoon basin. The fast sedimentation in the inlet probably results from Mflozi runoff brought into the inlet by the flood tide. Much of the sediment brought in by the Mkuzi runoff is deposited in the large reed swamp through which this river filters. It seems likely that St. Lucia Lagoon is filling more rapidly with sediment than some other lagoons where much of the sediment is by-passing their basins.

The lagoon is being segmented by cuspate spits which have formed low islands. These cuspate spits are mostly on the eastern side of the St. Lucia basin where there is an abundant supply of sand from the dune barrier, except an additional one on the west side opposite Mitchell Island where there also is abundant sediment from adjacent lowlands. It has been suggested that these have developed by wave action within the lagoon because it is aligned sub-parallel to the strong prevailing winds (Orme 1972). Shallow auger holes were made on Mitchell and Fanies Islands. The upper sediment is a mud similar to that which occurs at most places within the lagoon. This is underlain by a clean sand similar to the sands on the eastern shore at a depth of about 1 m. It appears that the surface mud is being deposited during time of flood when the water level in the lagoon is high and the silt and clay is trapped by the reeds which cover the islands.

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