Ecologic Observations on an Estuarine Environment at Fanning Atoll[1]

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ABSTRACT: Salinity variations observed in an inlet and tidal flat on Fanning Atoll ranged from 7.8 to 42.3 ‰. Water temperatures varied from 25.1° to 39.7° C. Daytime oxygen concentrations indicated that water at all stations was supersaturated. There are numerous estuaries on Fanning. Although distinct physical regions may be recognized within the estuaries, the distribution of organisms over these regions was found not to be comparable from estuary to estuary. Most of the fauna of the estuarine environment on atolls appears to be derived from euryhaline, high intertidal, or supratidal species of the lagoon shore.

STANDING OR FLOWING BODIES of freshwater are rare on atolls because of the high permeability of the soil. The basal groundwater body of porous island structures is of the Ghyben-Herzberg type (Cox, 1951; Arnow, 1954) and, excepting regular but damped tidal oscillations, daily and seasonal fluctuations in precipitation account for gross changes in the head or level of the groundwater above sea level. Freshwater or brackish water pools that form, do so in depressions extending below the water table. Although the factors that determine the degree of mixing of seawater and freshwater in the Ghyben-Herzberg lens are complex (see Cox, 1951), all water added to the lens through rainfull and not subsequently withdrawn and transpired by plants eventually emerges along the shoreline as brackish water. Brackish water outflow along the seaward shore is probably inconsequential in the ecology of the shoreline since the mixing of the brackish water with seawater before it emerges is promoted by two factors: substantial wave action and coarse sediments. Along the lagoon shore, however, where sediments tend to be fine and wave action is reduced, estuarine conditions may result with the outflow of brackish water from the aquifer. The distribution of these low salinity environments is dependent on local topographic and geologic features and the magnitude and duration of the rainfall recharging the aquifer. In addition, lagoon organisms may also be subjected to increases in salinity resulting from evaporation in shallow shoreline water. The data necessary to assess both the extent to which wide variations in salinity along lagoon shores occur and the importance of such variations in the ecology of the lagoon have not been reported.

In January 1970, as part of a team surveying the biota of Fanning Atoll (Line Islands), I made a series of physical and biological observations in lagoon areas liable to incursion by brackish water. Many of these environments also regularly become hypersaline relative to ocean water. The short period of time over which the data were collected and the nonquantitative nature of the biological observations allow only a characterization of the estuarine environments.

Certain properties of Fanning Atoll tend to enhance variations in the salinity of the water along the lagoon shores. The islands of the atoll nearly enclose the lagoon and hence lagoon water mixes only slowly with open ocean water (Gallagher et al., Pacific Science, this issue). The lagoon, for the most part, is shallow; relative to the land area, the tidal flats are extensive (see Fig. 1). The total area of Fanning Atoll is 33,207 acres, with the lagoon comprising 28,800 acres. Almost half of the remaining 4,407 acres are "salt flats" (Zipser and Taylor, 1968). The mean annual rainfall at Fanning is 81 inches (based on 41 years of data provided by the New Zealand Meteorological Service, 1956). The rainfall is spread over much of the

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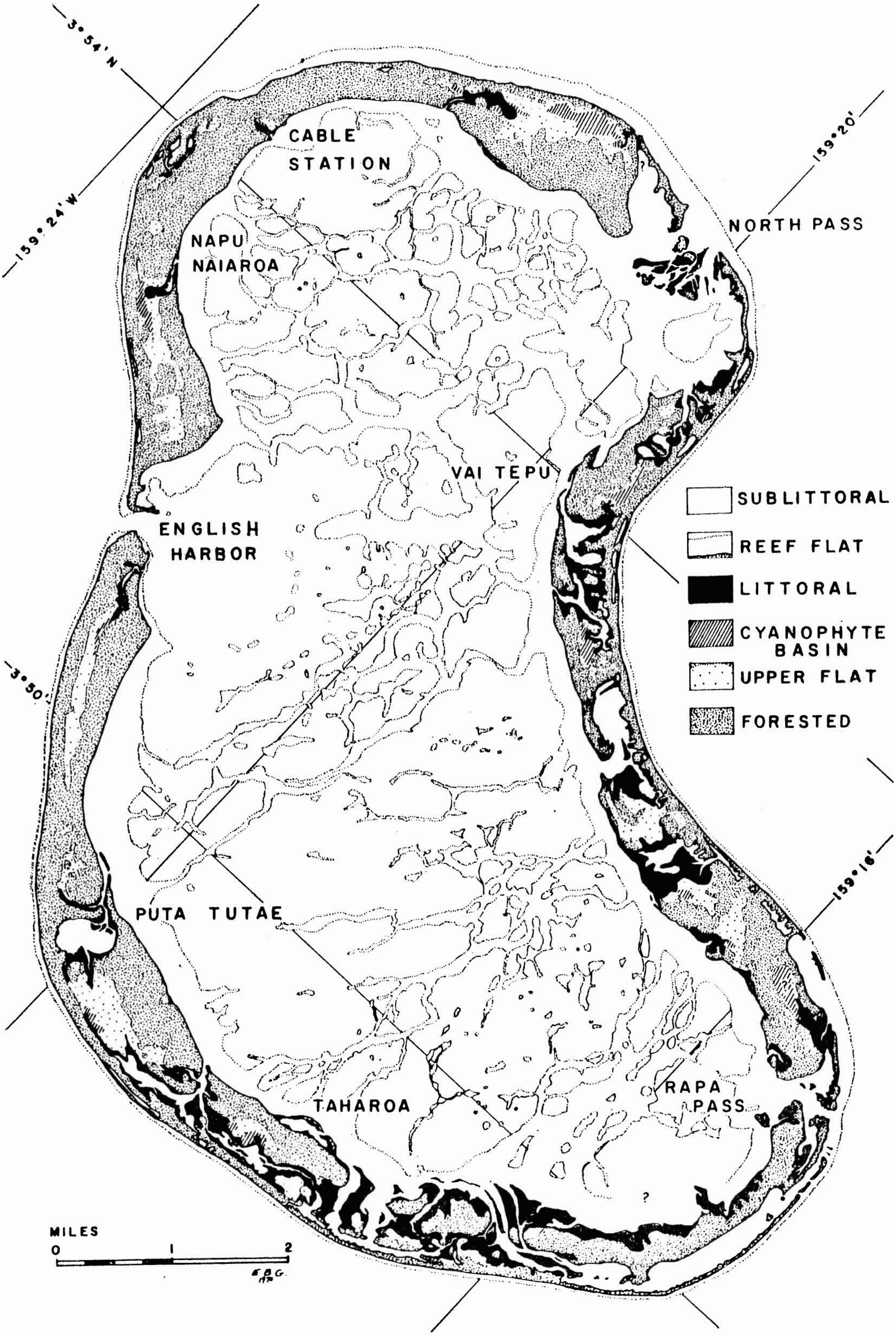

FIG. 1. Environments associated with estuarine conditions on Fanning Atoll.

year, although the months of September and October constitute a dry season (when the monthly mean is about 2.9 inches). Droughts occur occasionally. The islands of the atoll are large, and this fact, combined with the generally ample rainfall, indicates that well-developed Ghyben-Herzberg lenses may be expected.

Although all shallow water along the lagoon shore may decrease in salinity during rainy periods and increase in salinity during conditions that enhance evaporation, variations in salinity (and temperature as well) are accentuated in the tidal and subtidal inlets and channels dissecting the islands of the atoll. These "extralagoonal" bodies of water may be termed estuarine in a broad sense; that is, they are regions of often steep and variable gradients in salinity, temperature, and tidal currents. Three conditions seem important in producing and maintaining estuarine conditions in the inlets: (1) a generally restricted flow of water between the estuary and the lagoon, (2) the association of extensive tidal flats with the estuaries, and (3) intimate contact with the Ghyben-Herzberg lens of the surrounding island structure. The relative degree to which each of these features exists along any part of the shore determines the magnitude of the response of the particular body of water to variable rates in precipitation and evaporation.

Figure 1 depicts shoreline- and estuarine-associated features at Fanning as interpreted from aerial photographs and ground surveys. The dotted line, which marks the outer margin of the seaward and lagoon reefs, is based on the lagoon slope in the lagoon and the line of breakers on the outside of the island ring.

ESTUARY AT NAPU NAIAROA

The estuary at Napu Naiaroa was selected for detailed sampling because its proximity to my residence at the Cable Station allowed regular monitoring of physical conditions, and because it appeared to typify over a well-delimited area those features of the salt flats and estuaries observed on other parts of the atoll. Figure 2 shows the Napu Naiaroa estuary and the station locations.

Several physically distinct regions of the estuary may be distinguished. The main body of the estuary is an inlet tending roughly NNW–SSE, with its mouth narrower than its head. Sandbars partially block the mouth of the estuary enclosing a portion of the lagoon reef flat (a sand shoal along the lagoon shore) against the island shore (Stations 1 to 4) and I term this region the "enclosed shore." The shoreline of the inlet above the bridge (Stations 5 to 12) is a tidal flat of variable width dissected by tidal channels. At the head of the inlet a branching main channel (Stations 20 to 40) drains numerous smaller channels covering a more extensive tidal flat ("lower flat"). The latter tidal flat is covered with hard-packed sand, although sediments on the channel bottoms are fine silt. Sediments of the inlet bottom and inlet tidal shore are less consolidated than those of the tidal flat southwest of Station 20, and walking is difficult along the inlet shore.

The tidal channels are unusual in a number of respects. Their pattern (Fig. 3) is vaguely dendritic and individual channel courses are only slightly sinuous. Often many channels run roughly parallel to each other in a herringbone pattern. Close to the main channel or the inlet the channel pattern is anastomotic. The width of the flat between each channel is approximately the same as the width of the channels (about 1 to 2 meters), although the interchannel distance increases as the channels narrow toward the upper end of the flat. The main channel and much of the course of the smaller channels are subtidal; the interchannel flat is intertidal. Isolated pools of water remain in the upper reaches of some of the channels as the tide recedes.

The "upper flat" consists of a high intertidal basin, the "cyanophyte basin" (named for the mats of blue-green algae that predominate here) and an extensive supralittoral flat on which a sparse growth of grass occurs. Channels are absent on the "upper flat," although there is some indication of them in aerial photographs of the cyanophyte basin. Coarse gravel forms a reticulate pattern in low ridges on the dry flat. Christophersen (1927) mentioned these "polygon fields" in the Line Islands and included an excellent photograph from Christmas Island (Christophersen, 1927, Plate I-*A*). The phenomenon producing the reticulate

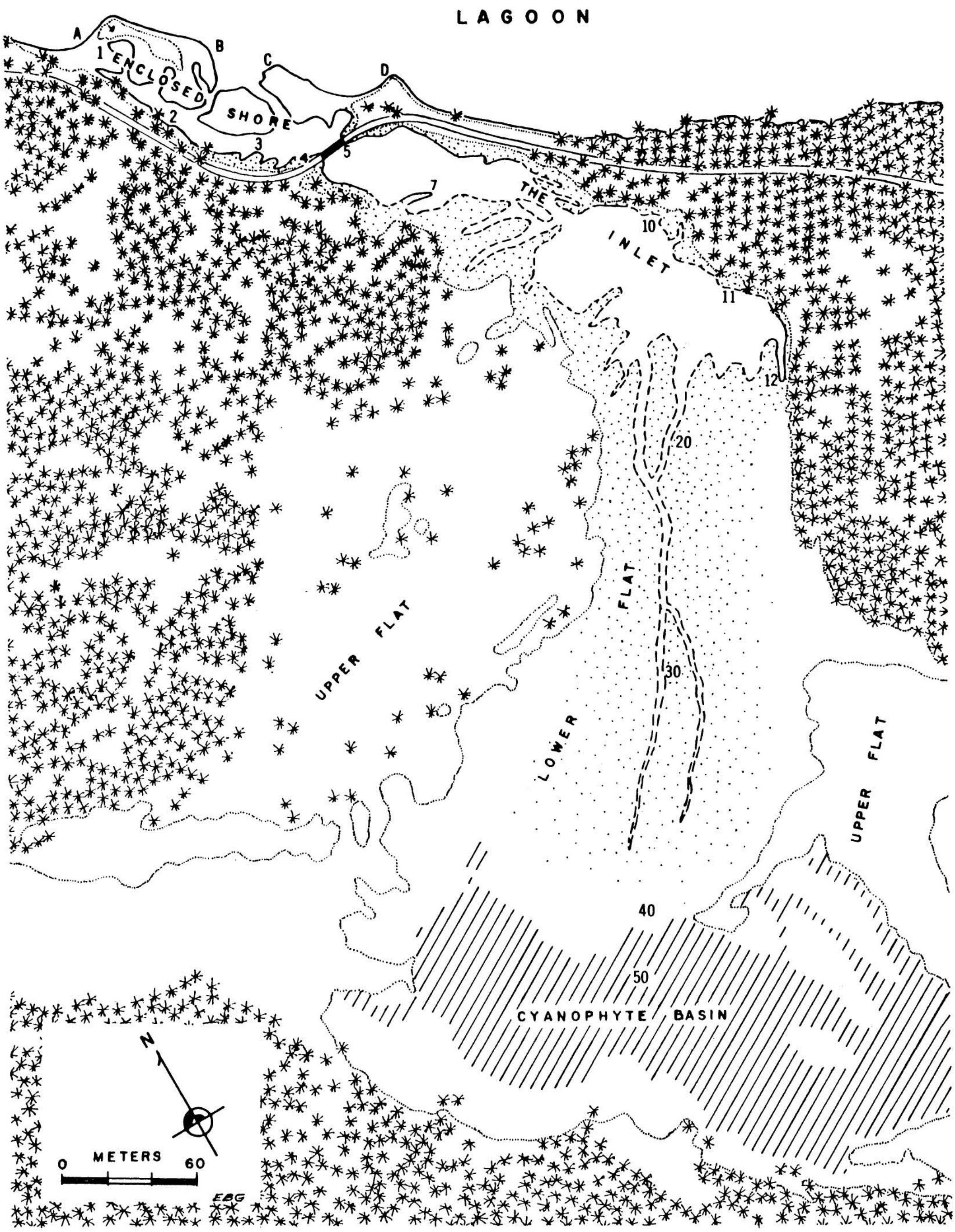

FIG. 2. Map of Napu Naiaroa study area based on ground survey and aerial photographs. Scale is approximate. Broken line of shoreline indicates extensive channel development; stippling indicates distribution of *Uca;* diagonal lines delimit cyanophyte basin; dotted line shows margin of grass cover. Sampling stations designated by numbers and letters.

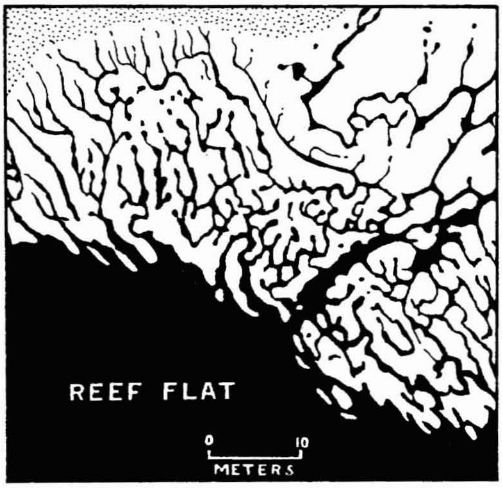

FIG. 3. Diagram of tidal channels based on low-level aerial photographs. Scale is approximate. Area is not Napu Naiaroa.

pattern was not limited to dry flats; the polygons occur also intertidally in sheltered areas. The cyanophyte basin is a shallow depression in which water collects and evaporates, at times producing a highly saline environment.

Physical Data

Salinity and temperature measurements were made at most Napu Naiaroa stations once or twice daily from January 14 to January 18. Salinity was measured in the field with an AO refractometer, but on one occasion water samples were collected and salinity determined in the laboratory with an inductive salinometer. The salinities determined by the latter method were used to check the refractometer readings. In addition to the temperatures taken concurrent with the refractometer readings, a maximum-minimum thermometer was set out (at Stations 5, 20, and 30) for three 24-hour periods. Oxygen concentration was measured at several stations using the Winkler method. All of the salinity and temperature data collected are tabulated elsewhere (Guinther, 1970).

Salinities measured at Napu Naiaroa during six sampling periods are presented in Fig. 4 as ranges, rather than as discrete values. The tide record is presented to indicate the relative height and condition of the tide prior to and at the time of sampling, although mean datum was not established.

The amount of rainfall occurring in the vicinity of the estuary is an important factor in determining the salinity of the estuary water. Accurate rainfall records were not kept for the period of study at Napu Naiaroa, but days on which rainfall occurred were noted. A few days prior to our arrival on Fanning (Jan. 3), heavy rainfall fell on the atoll, but very little precipitation occurred during the period from January 3 to January 15. Some rain fell for a brief period on January 13. Salinities in the estuary on the morning of the 14th were close to those on the lagoon flat fronting the estuary (36.6‰). Salinities in the estuary decreased slightly from the mouth to the cyanophyte basin: 37.6‰ at Station 4 to 34.7‰ at Station 50. Hyposaline water (relative to that of the lagoon) was found at Stations 1 and 12. Salinities measured in the afternoon of the 14th were higher at all stations. Water at Station 50 increased in salinity to 37.6‰ as a result of evaporation. The salinity at Station 1 increased to 36.2‰ (from 31.7‰), but this increase probably reflects addition of lagoon water on a rising tide.

The salinity readings obtained on the morning of the 15th were similar to those of the day before. No rain fell during the night of the 14th to my knowledge, but low-salinity water was found at Stations 1, 12, and 40 on the 15th. There was no standing water on the cyanophyte basin. Rain fell on the evening of the 15th, but, despite the rain, salinity values on the flat were higher than the lagoon on the morning of the 16th. The hypersaline water detected may have had its origin as tidal water flowing onto the cyanophyte basin and there picking up deposited salts. The high tide of the early morning hours on the 16th could have accomplished this mixing. During the afternoon of the 16th, following the flow and ebb of the tide, salinity values again approximated those of the lagoon except the cyanophyte basin where they remained high (42.3‰) and at Stations 1 and 12 where they remained low (32.7‰ and 33.5‰, respectively).

January 17 was marked by rain falling throughout the morning and overcast skies all day. Salinities over the entire estuary were very low by afternoon, the lowest values measured in shallow water on the flat at Station 30 (8.3‰) and Station 40 (7.8‰). The lagoon water on

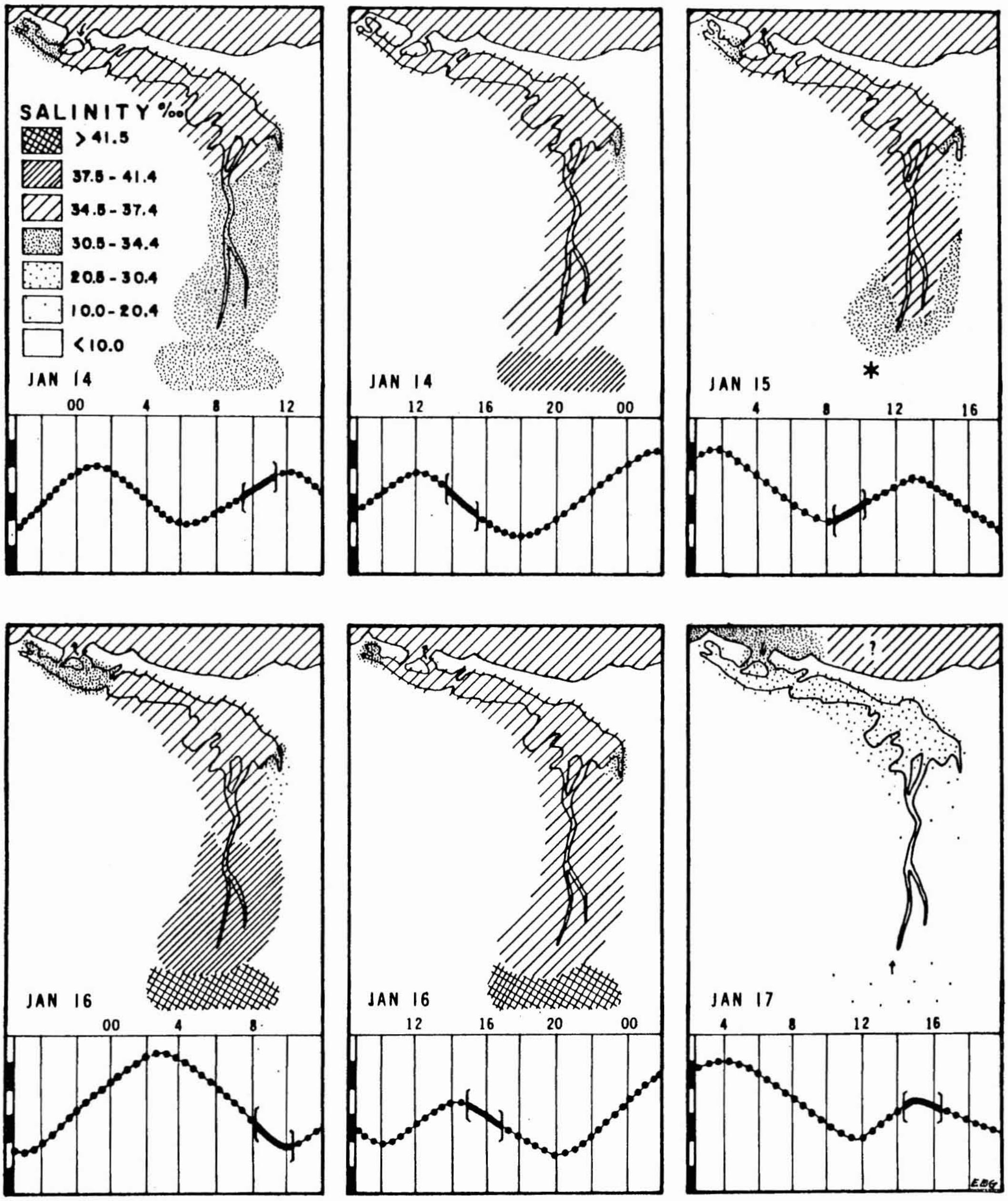

FIG. 4. Salinity values measured at Napu Naiaroa estuary between January 14 and January 17, 1970. Time of day of sampling period is indicated by brackets along tide record. Tide record is from gauge located at Cable Station (lagoon) and adapted from Gallagher et al. (1971). Vertical scale on tide curve marked in 10-cm intervals; time of day indicated across the top of horizontal axis. Asterisk indicates no standing water present. Arrows indicate observed direction of water flow during sampling period.

the reef flat fronting Napu Naiaroa had a salinity of 32.2‰, but it was not determined if this value was representative of shallow areas along the lagoon shore away from the estuary mouth.

Exceptionally low salinities were recorded at Stations 1 and 12 on the 17th. It became apparent that these two stations were located near regions where underground brackish water enters the estuary, probably as runoff from the Ghyben-Herzberg lens. On the 16th, 20 refractometer readings were made in the enclosed shore and a low salinity (12.7‰) seepage area no more than 1 or 2 meters in diameter was detected along the shore between Stations 1 and 2. The steepness of the salinity gradients in this area was demonstrated by the fact that the salinity at Station 2, 20 meters away, was 34.7‰ at this time. The salinity values obtained along the lagoon shore at Station *A* (near Station 1) were generally lower than those obtained at Stations *B, C,* and *D.*

Air temperatures, measured during the day at Station 1, varied from 27.2° to 30.0° C over the period from January 14 to January 17. Water temperatures were a few degrees to nearly 10 degrees higher than ambient air temperature. The lagoon water temperature, taken at Station *D,* varied from 26.1° to 36.4° C. At Station 11, an isolated and mostly shaded pond, the water temperature ranged from 27.4° to 39.0° C. In the cyanophyte basin (Station 50) the highest temperature recorded was 36.6° C. The highest temperature observed in the estuary was 39.7° C, measured in a channel at Station 10 on January 16. Water temperatures measured around 2100 hours on January 18 were all above the daytime lows cited above, indicating a slow cooling rate after dark. The air temperature at that time was 27.8° C. The maximum-minimum thermometer values obtained are given in Table 1. The low of 26.1° C recorded at Station 5 was the water temperature at 1500 hours on the 17th when the thermometer was retrieved. The lowest temperature observed was 25.1° C at Station 50 on Jan. 17.

Samples for determining dissolved oxygen were collected during the morning of the 15th at three stations and the afternoon of the 16th at three stations. The calculated data are presented in Table 2. All of the values obtained indicate supersaturated solutions. No samples were taken at night, but a distinct odor of hydrogen sulfide was most noticeable on the flats after dark. Digging in the sediments of the estuary revealed that hydrogen sulfide was being produced just below the surface during the day as well.

TABLE 1

MAXIMUM-MINIMUM THERMOMETER VALUES

STATION	DATE SET OUT	MINIMUM AND MAXIMUM TEMPERATURES RECORDED
30	Jan. 14–Jan. 15	28.6°–36.1° C
20	Jan. 15–Jan. 16	28.3°–33.9° C
5	Jan. 16–Jan. 17	26.1°–33.9° C

Faunal and Floral Distributions

The lagoon reef flat fronting Napu Naiaroa extends for a considerable distance out into the lagoon as a gradually sloping, sublittoral shelf. The bottom sediments are a fine white sand with occasional chunks of larger carbonate material. A sparse growth of the alga *Ectocarpus* sp. occurred on these chunks. Schools of mullet (*Mugil* spp.) ranged offshore and occasionally entered the estuary. On the lagoon face of the sandbars, as along the lagoon beaches, the ghost crab *Ocypode ceratophthalmus* (Pallus) made its burrow. Between Stations *A* and *B,* on top of the sandbar, several young plants, including *Cocos nucifera* Linn., *Messerschmidia* (*Tournefortia*) *argentea* (Linn.), and *Sesuvium portulacastrum* Linn., were established.

The enclosed shore (behind the sandbars) was shallow and much of the bottom was ex-

TABLE 2

DISSOLVED OXYGEN DETERMINATIONS

STATION	TIME	DATE	O_2 CONCENTRATION (ml O_2/liter)
5	0900	Jan. 15	4.42
5	1220	Jan. 15	6.41
20	1010	Jan. 15	5.90
30	1020	Jan. 15	5.81
5	1500	Jan. 16	5.89
11	1545	Jan. 16	5.79
30	1600	Jan. 16	6.64

posed at low tide. Schools of young *Tilapia mossambica* (Peters) and young mullet of at least two species (one is *Mugil engeli* Bleeker) were common in the enclosed shore. At high tide some of the more typically lagoon fishes (Lutjanidae, Diodontidae) could be seen under the road bridge (Stations 4 and 5). Small (12 to 18 inches) reef blacktip sharks (*Carcharhinus melanopterus* Quoy and Gaimard) were common visitors to the estuary from the lagoon reef flat. Near Station 1, living on the silty bottom, was a goby (*Oxyurichthys lonchotus* Jordan and Evermann) and a palaemonid shrimp. The fishes of the estuary inlet and main channels included large *Tilapia mossambica,* several species of mullet, and the milkfish *Chanos chanos* Jordan and Evermann.

A few specimens of the snail *Cerithium breve* Quoy and Gaimard were found near Station 4 on sand. The small nerited snail *Neritina bensoni* (Recluz) occurred on the lower rocks of the roadway fill at Station 4, and some individuals of the supratidal species *Nerita plicata* Linn. were found wherever emergent solid substrate occurred (Stations 3, 4, 5, and 7). The latter species grows to a large size in the quiet waters of the estuary at Napu Naiaroa. One other supratidal snail *Littorina scabra* Linn. was rare but has a distribution similar to that of *Nerita plicata.*

The most striking inhabitant of the estuary shore was the black and red fiddler crab *Uca tetragonon* (Herbst). These crabs lived in densely populated colonies, particularly concentrated on the interchannel flats. Their overall distribution at Napu Naiaroa is shown in Fig. 2, but the crabs were most abundant from Station 5 to beyond Station 20. The grapsid crab *Metopograpsus thukuhar* (Owen) is a high intertidal form which may burrow into mud, but is most abundant in rocky areas. This crab seemed to be limited to the enclosed shore and inlet shores, and, in general, lived slightly higher up the shore than did *Uca.* If chased, however, *Metopograpsus* may seek refuge in occupied *Uca* burrows.

The most evident terrestrial animal at Fanning Atoll was *Cardisoma carnifex* (Herbst), a land crab. This crab was most numerous at Napu Naiaroa within the shaded coconut groves, some individuals burrowing close to the shore where shade was available. At night these crabs became active (although many are "out" during the day) and ranged over much of the estuary shore. Sluggish, moribund individuals found in shallow burrows in the middle of the flats may have been caught in the open at sunrise far from protective shade. At night two species of terrestrial hermit crab (*Coenobita*) also became active and could be seen foraging along the estuary shore and upper flat (*C. brevimanus* Dana) and on the lagoon beaches and enclosed shore beaches (*C. perlatus* M. Edw.). Although the shore crab *Metopograpsus* was active at night on January 20, *Uca* was conspicuously absent above ground after dark.

A very diverse fauna occurred at Station 7, a low rocky spit (man-made?) extending out into the inlet. Animals found here include *Metopograpsus thukuhar, Nerita plicata,* and *Littorina scabra.* Under the rocks an isopod (Trichoniscidae?), a collembolid, and an oligochaete were common.

The only vascular plant growing on the lower flat was *Sesuvium portulacastrum* Linn., a fleshy, bright green herb found most extensively along the main channel from Station 20 to beyond Station 30. A tiny beetle (Carabidae) and a gammarid amphipod (Talitridae) were common on the lower flat between the channels, but the distribution of both extended onto the upper flat. In the channels a palaemonid shrimp was particularly abundant, as were young *Tilapia.* Nest sites of the *Tilapia* were made occasionally in these channels, although most of the nests were found along the inlet shore. Considerable transport of sand from the channel wall occurred as the bowl-shaped nests were constructed, and it would appear that in this manner these fish contributed to the shaping of the channels. Both *Tilapia* and *Gambusia* sp. are introduced species at Fanning, but at Napu Naiaroa *Gambusia* (mosquito fish) was found only in an enclosed pond (Station 11) that is inundated at higher high tides. The pond contained, in addition to *Gambusia,* several brooding *Tilapia,* numerous palaemonid shrimp, and, on occasion, land crabs. The bottom sediment of the pond was a yellow-brown color, differing markedly from the white to grey sediment of the nearby channels, and possibly reflecting the exclusion from the pond of bottom-feeding mullet.

The transition between the lower and upper flat was gradual. The degree of relief between the channels and the interchannel ground decreased until the channels were no longer discernible. The tufted grass growing over much of the upper flat may have been the same species as the bunchgrass *Lepturus repens* (Forster) Brown which covered the ground under the *Cocos* trees, although the growth habit of the grass was different in the two areas. On the flat the plants were shorter, less leafy, and far apart. On the slightly higher ground of the coconut groves the grass was larger and closer together. The grass around the *Cocos* in January had greener leaves and fewer dry portions than did the grass on the open flat.

In the zone of transition between upper and lower flats the small mesogastropod *Assiminea nitida* Pease was particularly abundant but active only at night. A terrestrial isopod (*Tylos latreilli* Audouin and Savigny) occurred here. Each grass plant of the upper flat harbored a small spider which constructs a simple "web" of only two or three threads.

The cyanophyte basin differed markedly from both the grass-covered upper flat and the channeled lower flat. The basin was actually a series of shallow depressions which retained water that came onto the flat at higher high tides. The sediment in the basin was vertically layered with color bands of yellow, pink, and green. The depressions in the basin were coated with a red to purple, cartilaginous material. Both the convoluted cartilaginous layer and the sediments beneath it contained a mixture of species of blue-green algae, including *Schizothrix* spp. and *Anacystis dimidiata* (Kuetzing). A similar algal mat was described at Raroia Atoll (Newhouse, 1954). No animals were collected from the cyanophyte basin.

Several species of shorebirds frequent the upper and lower flats. A list of the birds sighted on Fanning during the expedition is given by Gordon (1970).

OTHER ESTUARIES ON FANNING ATOLL

The division of Napu Naiaroa estuary into regions is based on physical features and the regions are easily recognized in the field. Tidal and supratidal flats, inlets, and tidal "lakes" are common features on Fanning Atoll (Fig. 1), and each estuary is structured much as that described for Napu Naiaroa, although the relative extent of the regions (e.g., enclosed shore, inlet, upper and lower flat) varies. It seems reasonable to assume that differences between the regions are the result of tide-related phenomena and differences in substrate elevation. For example, the size and location relative to the estuary proper of the enclosed shore could be determined by both longshore and estuarine tidal currents. The extent of the lower flat and the form of its channels were the result of the interaction between ground slope and tidal transport of currents. The transition between the lower and upper flat occurs, and is probably determined by, the level of higher high water.

Although the distribution of physical regions is largely determined by tidal factors, biological distributions over the estuary are determined, in addition, by factors such as temperature and salinity. The biota of each physical region at different estuaries can vary because the relative degree of the three conditions responsible for enhancing variations in salinity and temperature differs from estuary to estuary. The following biological distributions may thus be explained in terms of the above hypothesis.

Cerithium breve showed a very scattered distribution at Fanning. It was rare at Napu Naiaroa, present on rocks in the enclosed shore at Vai Tepu, and abundant on both sides of the sandbars of the enclosed shore at Taharoa. The snails were found at several locations in the upper channels of the Vai Tepu estuary on January 6, but on January 15 they were absent at this location except for one group on some rocks in the middle of a main channel nearby.

Living specimens of *Rhinoclavis asper* Linn. were not found at Napu Naiaroa, although shells of this cerithiid gastropod occurred there. The snail was common in the enclosed shore and on the reef flat fronting the estuary at Vai Tepu. A few individuals were also seen in the inlet of this estuary. No living *Rhinoclavis* was found in the expanded inlet at Puta Tutae, but empty shells did occur in the fine bottom sediments.

Uca had a wide distribution at Napu Naiaroa, but was less abundant or rare along channels in some parts of the estuaries examined elsewhere on Fanning. *Sesuvium portulacastrum* showed a variable distribution, but most often occurred close to the channels or inlets. At Napu Naiaroa it was also found with *Cocos* and *Messerschmidia* on the sandbar at the estuary mouth, and at Vai Tepu it occurred intermixed with the open-flat form of *Lepturus repens.*

The predatory gastropod *Natica robillardi* Sowerby appeared to be common in the inlet and enclosed shore of the Vai Tepu estuary, but it was not collected elsewhere. A small, unidentified anemone (these are rare in the lagoon at Fanning) occurred in the expanded part of this estuary as did a swimming crab, *Thalamita integra* Dana.

In each estuary the daily and seasonal ranges over which physical parameters (e.g., temperature, salinity) varied were probably not parallel. Conditions in some estuaries at Fanning reached extremes for sufficiently long periods to exclude for a time many of the residents of the body of water. The expanded inlet or "lake" at Puta Tutae contained an enormous number of empty shells of *Cerithium breve* in the muddy bottom sediment. In addition, shells of *Rhinoclavis, Pupa* sp., *Nassa serta* (Bruguiére), and two species of tellinid clams were present. Many of these species were more typical of the sandy lagoon reef-flat, but transport of the empty shells to the inlet seems improbable. The salinity of the Puta Tutae inlet on January 5 was 6.5‰. *Tilapia* and a few *Cardisoma* were then the only inhabitants in the lake. Shells of *C. breve* in particular were common on Fanning in channel sediments and as drift on the flats. Local "freshwater" kills may therefore occur regularly, affecting the populations of this snail and perhaps the populations of other low-salt-tolerant species as well.

DISCUSSION AND CONCLUSIONS

Many of the organisms living under estuarine conditions at Fanning are widespread in the Indo-West-Pacific. Although their occurrence on atolls has often been noted (Banner and Randall, 1952; Morrison, 1954; Morton and Challis, 1969; and others), salinity values taken concomitant with the collections are seldom given in the literature and presumably are not made. Often the author may describe an area as "brackish" if there appears reason to suspect freshwater influx. Doty and Morrison (1954) described on Raroia Atoll a series of inter-island channels, some closed by sediments at the seaward end only and others closed at both ends. In one of the completely closed ponds were recorded the cyanophyte mats described by Newhouse (1954), while in others occurred *Cerithium breve, Neritina bensoni,* a palaemonid shrimp (*Palaemon debilis* Dana), and mullet. The closed inlets at Raroia must be ecologically similar to the estuaries at Fanning, whereas the fauna in the Raroia inlets open at least to the lagoon resembles the Fanning Lagoon channels at North and English harbor passes. Lagoon-oriented inlets at Fanning tend to be estuarine, whereas, pools isolated from the ocean side only by the coarse, shingle berm are marine. In one such pond, separated from the ocean by a 4-meter-high shingle berm and inhabited only by *Littorina coccinea* Gmelin, *L. undulata* Gray, *Nerita plicata, Assiminea nitida, Truncatella* sp., and *Melampus* spp., the salinity was 35.2‰.

Brackish water influence on the distribution of lagoon organisms is probably not uncommon on most atolls with extensive island development. On many atolls the presence of "mangroves" (see Macnae, 1968; Morton and Challis, 1969) indicates regions corresponding to the estuaries at Fanning. Plant species having a mangrove life-form, however, have not been reported from Fanning Atoll.

The lagoon shore, complicated by inlets, channels, and sand spits, is a region where freshwater influx may be localized sufficiently to produce estuarine conditions. The inhabitants of areas subject to regular depressions in salinity on atolls must be euryhaline species *par excellence.* It is suggested that the intermittency in the occurrence of hyposaline water (relative to the lagoon) will preclude species adapted only to brackish water or freshwater (stenohaline organisms of low salinity environments). Salinities over most of the Napu Naiaroa estuary varied from hypersaline to nearly freshwater during the short period of observations. I would conclude, as does Morrison (1954, p. 5), that "such [environments] offer a habitat in which only a few low salt tolerant species . . . flourish." Most of the estuary inhabitants at Fanning are either migratory forms (most of the larger fish excluding *Tilapia*) or high intertidal forms. The latter group of organisms is subject to freshwater inundation by rainfall on any shore. Those high intertidal and supratidal species adapted to quiet water situations, typical of lagoon shores, constitute the best candidates available for populating the estuaries on atolls.

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