LITERATURE CITED

GOODBODY, I.
1961. Mass mortality of a marine fauna following tropical rains. Ecology *42* (1).

MORI, S.
1950. Characteristic tidal rhythmic migration of a mussel, *Donax semigranosis* Dkr. and the experimental analysis of its behavior. Zoolog. Mag., Tokyo. *59* (4).

TURNER, H. J., JR. AND D. L. BELDING
1957. The tidal migrations of *Donax variabilis* Say. Limnol. & Oceanog. *11* (2).

YONGE, C. M.
1949. On the structure and adaptions of the Tellinacea, deposit-feeding Eulamellibranchia. Phil. Trans. B. *234*.

Physical Parameters of Maracaibo Estuary and Their Ecological Implications

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Abstract

The system formed by Lake Maracaibo and the Gulf of Venezuela is the site of a new flourishing fish industry, and at the same time the route for oil tankers. Alterations in the estuary to improve navigation could permanently damage the fishery.

Studies are being made in our laboratory to determine the physical parameters of this estuary. The yearly distribution of organisms and chlorinities, and the circulation of masses of water have permitted the separation of several ecological regions. Effects of substratum and tidal system are being studied. We hope to predict how alterations in the physiography will reflect on the hydrography, indicating how the distribution of organisms will be altered.

INTRODUCTION

THE OBJECTIVE OF THIS PAPER is to present some of the recent research on the physical parameters in the Maracaibo estuary and their bearing on the distribution and reactions of the communities. This is part of a project done for the Instituto Nacional de Canalizaciones.

Lake Maracaibo (Fig. 1) is the second largest estuary on the southern part of the Caribbean, the Orinoco River being the largest. The fresh water of Lake Maracaibo mixes with the sea water of the Gulf of Venezuela in Tablazo Bay. In the southern part of the bay Lake Maracaibo discharges through the Maracaibo Strait. The Limon River discharges into the northwestern part of Tablazo Bay..

The Maracaibo area is the site of most of the oil industry in Venezuela and tankers continually cross the water of the bay. To facilitate navigation,

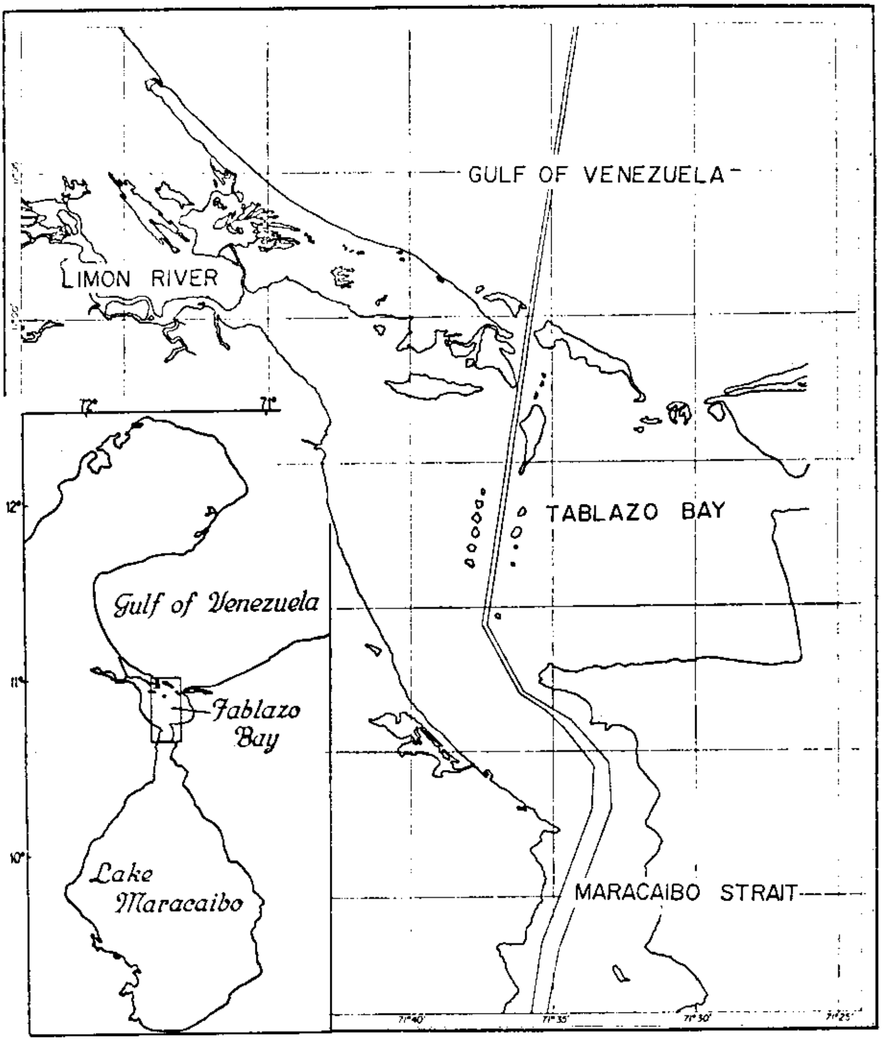

FIG. 1. Geographical position of Lake Maracaibo and Tablazo Bay.

a channel, whose minimum depth is 12 m, was dredged in 1956. Several additional hydraulic works are under study to protect the dredged channel and reduce the intrusion of sea water which increases corrosion of the pipelines.

At the same time, the Gulf of Venezuela and Lake Maracaibo are the site of the shrimp industry, the most valuable fishery of the country today with a production of 3.8 million kg in 1963. There is also a smaller production in the estuary of several eurihaline fishes, like mullet *(Mugil)* 850,000 kg; weakfish *(Cynoscion maracaiboensis)* 3.1 million kg; snook *(Centropomus)* 700,000 kg; oyster *(Crassostrea rhizophorae)*; and a local clam *(Polymesoda arctata)*.

The present investigation was designed to determine the effect of the channel on the biota and to ascertain what possible effects other proposed hydraulic works could have. Since a hydraulic model of the estuary is under study, we have attempted to determine the physical parameters and the reactions they produce on the communities. With these data, we can determine on the model the variations in the parameters and gain some idea of what changes will be produced.

We have concentrated on the hydrographic characteristics which are more liable to change if dikes or other structures are introduced in the estuary. The physical parameters so far studied are: (a) tides, (b) electrolytes, (c) chlorinity, (d) oxygen, (e) sediments, and (f) movement of masses of water. Littoral and shallow water organisms were sampled regularly throughout the year and the composition of the phytoplankton and zooplankton was analyzed during the rainy and dry seasons.

RESULTS

TIDES: Analyses were made of the last three years' records of five tide gauges regularly spaced throughout the estuary. The tidal range diminishes progressively throughout the five tide gauges from 110 cm at the mouth to 40 cm in Maracaibo. This decrease follows a regular law of the form:

$$A = N e^{-kD}$$

Where A is the tidal amplitude in cms at a given point, N is the value in cms of A for $D=0$, k is the damping coefficient in cm^{-1} and D is the distance measured from the first tide gauge in cm. This equation allows us to predict the tidal amplitude at any point, if the distance from the first tide gauge is known.

The water level fluctuates throughout the year in all tide gauges (Fig. 2). These seasonal fluctuations follow the general pattern of other localities on the Venezuelan coast. However, in the tide gauge located in the center of the bay, there is an anomaly from July to November in the years under study. The slope of the water throughout the bay is 1 cm/km.

From these data on tidal amplitude, we can calculate the exposure of the tidal zone to the air. The records of the tide gauges are integrated in 5 cm intervals and the per cent exposure obtained for the various levels. The plot of percentage exposure against levels gives a discontinuous function that could be defined by two straight lines with an inflection point. We have obtained the equations $Y = (8.765 + 80x + 1424)/A + 0.27A - 8.7$ and $Y = 0.57x + 1.88A + 6.44$ which give the percentage exposure of the levels referred to the mean water level above and below the inflection point. The only value required in the calculation is the tidal amplitude A, which we have shown is a function of the distance from the mouth of the estuary.

Since the water level changes seasonally, corrections should be applied for each month of the year. This method can be applied under similar conditions in other estuaries and bays to obtain the percentage of exposure in 24 hours for any surface due to tidal action. Now we are studying exposure due to wave action. We will attempt to correlate the theoretical values obtained with the settlement of organisms in test panels.

CHEMISTRY OF WATER: The conservative elements Cl, SO_4, HCO_3, Mg, Ca, K, Na, and some of the trace metals F, Fe, Si, NO_3, NO_2, were determined in various regions of the estuary. If total salts in each sample is plotted against the chlorinity of the sample, the regression line differs from the regression line

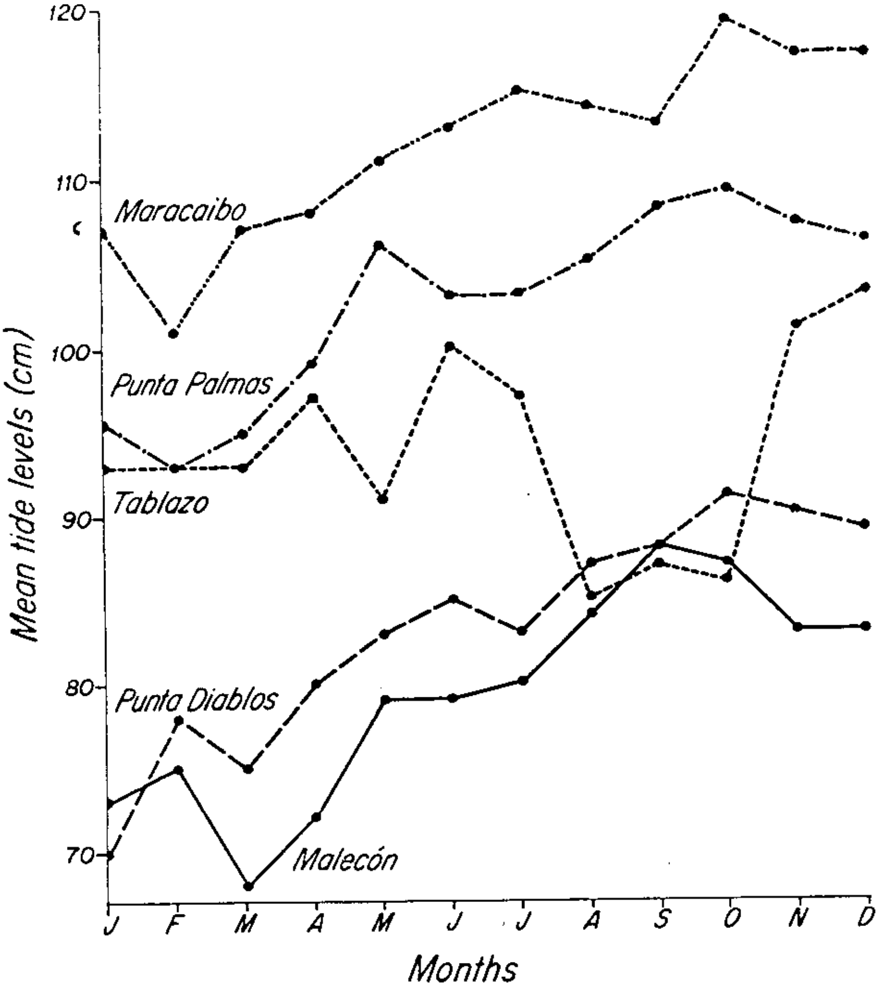

FIG. 2. Seasonal fluctuations in mean water level.

used for the relationship salinity-chlorinity in sea water, namely, $S = 1.805.\mathrm{Cl} + 0.03$. The value of the slope in our equation is 1.802 and the y-intersect is 0.7. The equation is useful in obtaining total concentration of electrolytes when the effect of the chlorinities on the physiology of the organisms is taken into account. It is worth mentioning here that the values for calcium do not exceed 1.50 mg/liter. Chlorinity was sampled monthly from 25 fixed stations and from several occasional stations. In different portions of the estuary, the curves representing chlorinity throughout the year differ in the amplitude of the changes and in the extreme values reached (Fig. 3).

The chlorinity changes drastically with the dry and wet seasons in Limon

River, while in Maracaibo Strait the changes are very small. The shape of these curves is due partially to the width and shape of the channels.

The shape of these curves is important if "ionic stress" is taken into consideration. A poverty of invertebrates is associated with the violent changes in Limon River, while a rich fauna is present in Maracaibo Strait. In the organisms in which there is an active transport of electrolytes, the ionic regulation requires supplementary expenditure of energy. The work required for the active transport of a gram-molecule of an ion, from a lower to a higher concentration, can be expressed by:

$$W = zRT \cdot \ln - C_1/C_2$$

W is the work expressed in calories; R is the perfect gas constant; T is absolute temperature; C_1 and C_2 are concentrations of the internal and external media respectively.

If zRT are constant, and assuming that C_2 does not change, the work is a function of the external concentration of electrolytes and the curves presented

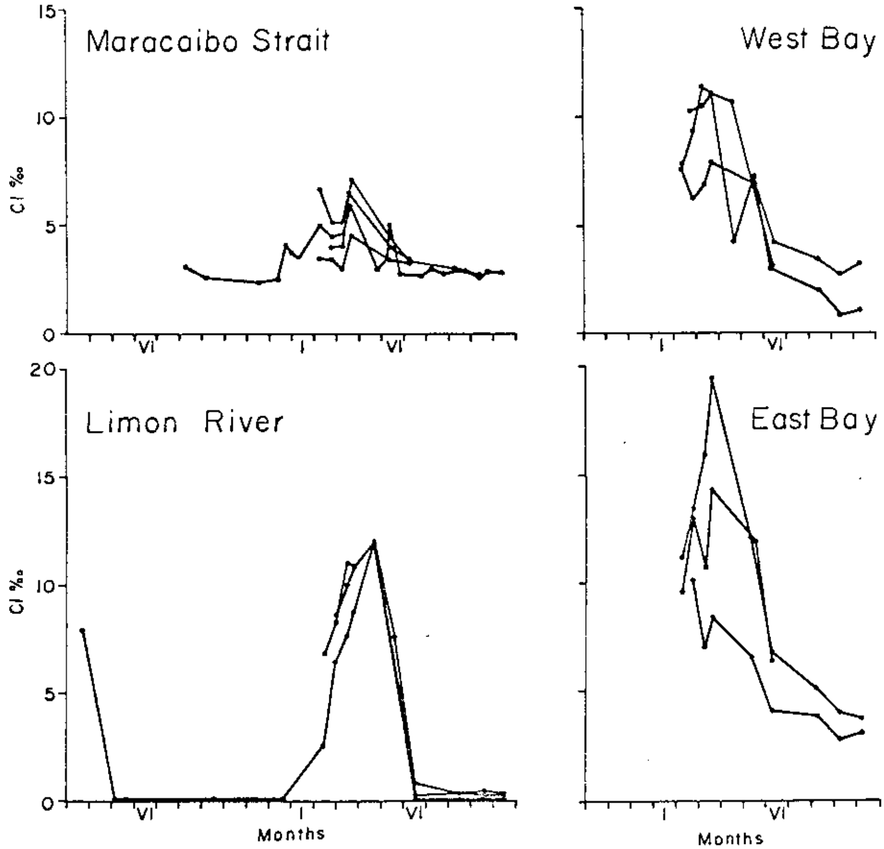

FIG. 3. Seasonal fluctuations in chlorinities in various areas of Maracaibo estuary.

in Fig. 3 can be taken to represent the work required to perform ionic regulation. These violent changes in ionic stress could account for the poverty of the fauna in some regions of the estuary.

OXYGEN: Measurements of dissolved oxygen were made during two months of the year to discount the possible existence of anaerobic areas within the estuary that will account for peculiarities in distribution. The values of saturation were higher in Maracaibo Strait than in the Limon River, although not even in the mangrove was there a depletion of oxygen (83.9% to 98.2%).

Within the bay the saturation values were sometimes as high as 119.4%. This fact could be due in part to the heavy blooming of phytoplankton that takes place during the wet season.

SEDIMENTS: During the dredging operations, new islands have been formed that clearly differ from mangrove forested areas in the grain size composition. These islands are usually colonized by mangrove in two or three years. To determine the effect of the changes in texture of the substrate on the burrowing organisms, especially on fiddler crabs *(Uca)*, we have correlated the distribution of different types of sediments with the distribution of these crabs. Recently deposited beaches, whose texture corresponds with beaches inhabited by *U. leptodactyla*, can be colonized by all the species present in the estuary, but *U. leptodactyla* can live only in a substratum of this texture. In this sense, we can consider *U. leptodactyla* a pioneer species.

We are still following this line of research, studying the effect of thixotropy and organic carbon content of the sediments on the distribution of the species.

MOVEMENT OF MASSES OF WATER: Due to the peculiar physiography of the estuary, the circulation of water within the estuary is very complex. This has important consequences on the distribution of plankton and of eggs and larvae of the invertebrates colonizing the estuary. At the beginning of this research we attempted to trace the masses of water, but this was impossible

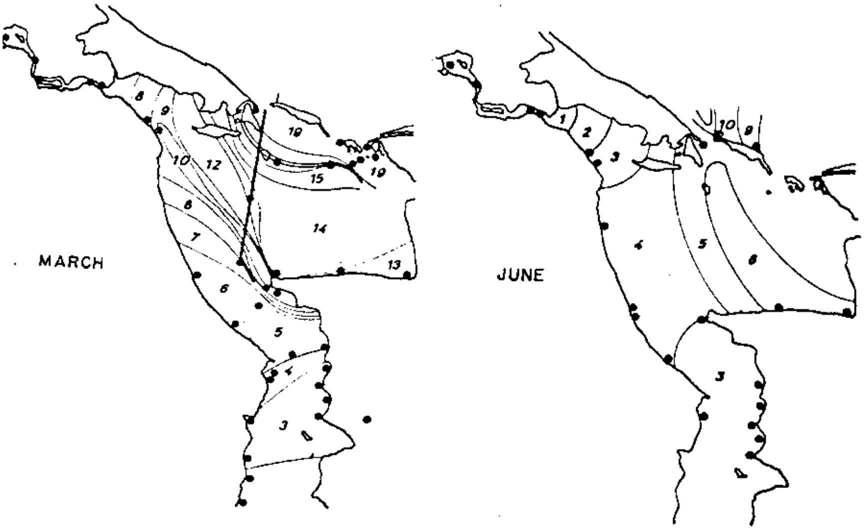

FIG. 4. Surface isohalines in March and June.

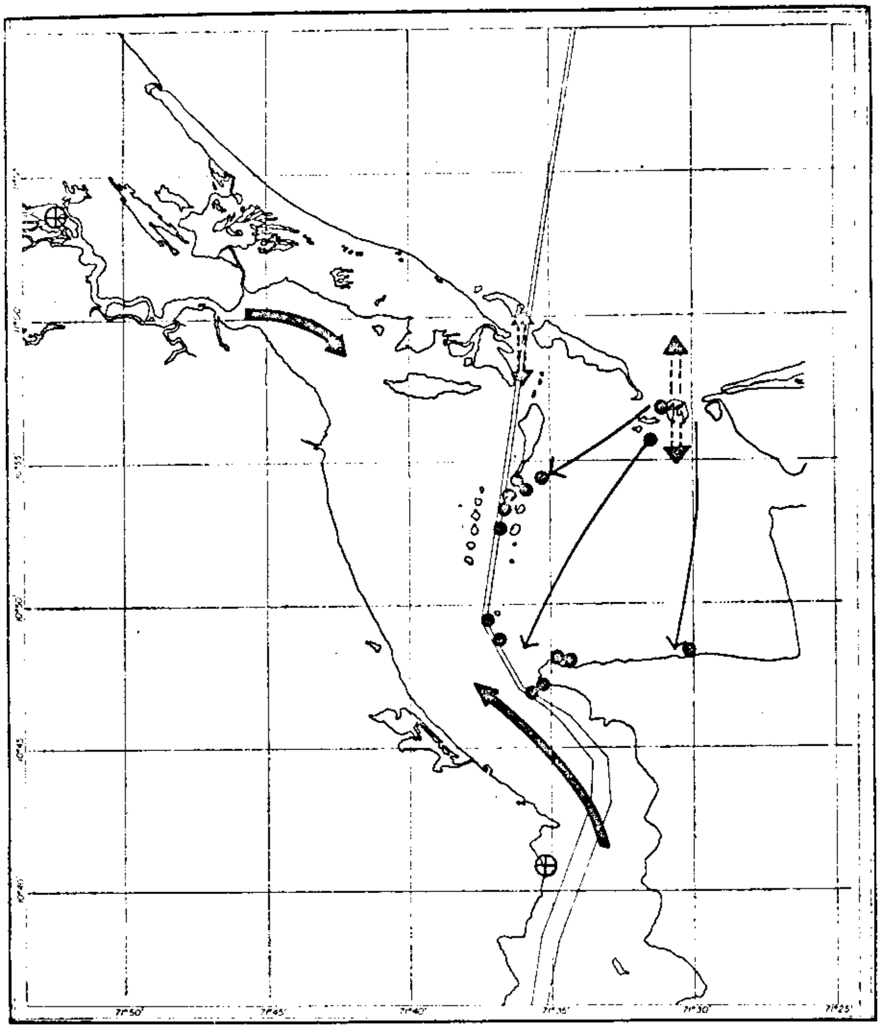

FIG. 5. Distribution of *Stomolophus meleagris.*

with the facilities available. The problem is at present under study by the Massachussetts Institute of Technology and the Instituto Nacional de Canalizaciones, with the probable use of rhodamyne-b as a tracer.

We have, however, made some observations that could shed some light on the problem. First of all, consider the distribution of surface isohalines during the wet and dry seasons (Fig. 4). During the dry season, the water of the channel is circulating northward and mixing with high salinity water, but at the same time there is an intrusion of sea water on the east portion of the bay that raises its salinity to that of sea water. There is also a penetration of high salinity water up the Limon River. This situation lasts four months. During the wet season, the intrusion of sea water on the east side and up the Limon River is reduced. The peculiar situation during the dry season could be due to strong trade winds. This theory is strengthened by the distribution of medusae (*Stomolophus meleagris*) on a windy day of the dry season (Fig. 5). These organisms clearly originated in the sea and can only penetrate through one of the mouths of the estuary. They are freely moved by the water at a depth of 20 cm, being thus equivalent to the study of the distribution of "drift bottles."

DISTRIBUTION OF ORGANISMS: The aquatic plants and invertebrates were sampled regularly throughout the year. These data were compared with the distribution found in a survey made in 1956. In the intervening time, the navigation channel was dredged. No major changes seem to have taken place

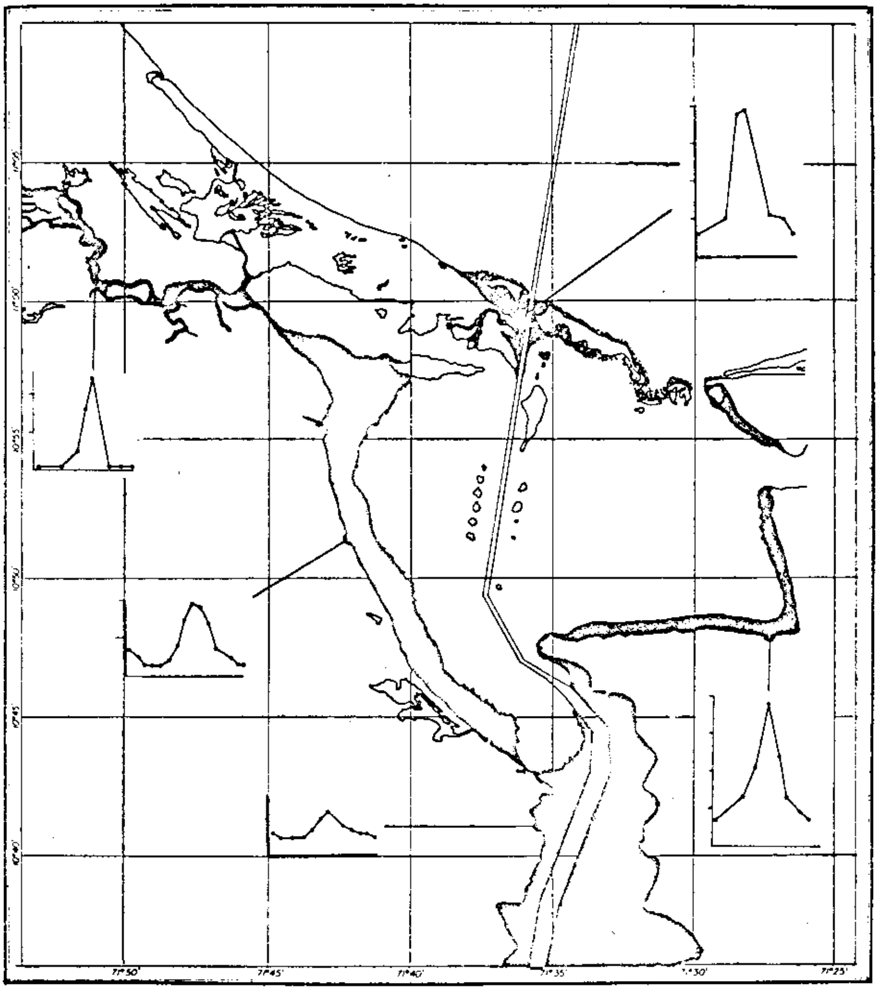

FIG. 6. Ecological areas in Maracaibo estuary.

in the biota since the channel was deepened, with the exception of the northern coast of the Zapara Island, located at the mouth of the estauary. Species there have changed from estuarine to marine, and marine invertebrates like *Donax, Tivela, Siphonaria pectinata, Tetraclita squamosa stalactifera, Mennipe nodifrons*, and *Eriphia gonagra* have been established.

We have used the data on distribution of salinity and species to determine limits of tolerance for invertebrates. Of 31 invertebrates examined, 10 range between 2 and 20‰ Cl, 13 between 2 and 10‰ Cl, and 8 between 10 and 20‰ Cl.

The uneveness of the distribution throughout the estuary was evident. Of 23 common species of invertebrates in the estuary, 19 are present in the Maracaibo Strait throughout the year, while at an equal distance from the mouth, Limon River has only 7.

The composition of plankton undergoes changes throughout the year. During the rainy season it is composed almost entirely of fresh-water forms with a few brackish water representatives. From June to October, there is a heavy bloom of phytoplankton, mainly *Anabaena spiroides* and *Microcystis viridis*, and the surface water takes on the appearance of a thick soup. During the dry season, there is an invasion of neritic plankton that follows the same path reported for medusae. The forms that withstand the dilution of the estuary are mainly *Sagitta serradodentata, S. enflata*, and *Lucifer faxoni* that penetrate even to Maracaibo Strait.

SUMMARY AND CONCLUSIONS

Due to its complex physiography, the estuary of Maracaibo departs from the idealized situation. Many different conditions are present in a relatively limited space, offering an excellent opportunity for comparative studies.

There are five distinct regions within the estuary (Fig. 6) characterized by the shape of the changes of the annual salinities. These changes have a bearing on the mechanisms of adaptation of regulating organisms and determine sharp distinctions in the composition of the fauna, as shown, for example, for Limon River and Maracaibo Strait.

If marginal dikes to the channel are built or if some portions of the bay are separated from the rest by terminal dikes, the effect that these hydraulic works will have on the biota will largely depend on the relation that each region of the estuary has with the adjacent ones. I think the study of this relationship should be the next logical step in this research. At the same time, more data are needed on the effect of reactions of the communities to the physical parameters.