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PRELIMINARY RESULTS OF THE STUDY OF METEOROLOGICAL EFFECTS ON THE PRODUCTIVITY OF THE PANAMA BIGHT

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RESUMEN

Se analizan parámetros característicos de aspectos meteorológicos, oceanográficos, químicos y biológicos, a fin de observar en forma integrada los efectos meteorológicos en la productividad del Golfo de Panamá. Se observan grandes variaciones estacionales en todos los parámetros analizados, lo cual hace a esta área un lugar ideal para este estudio. La posición de la zona de convergencia intertropical parece ser el factor meteorológico limitante principal en la productividad biológica del área. Utilizando como primer aproximación un modelo multiplicativo donde se consideran efectos radiativos, térmicos y dinámicos se obtienen buenos resultados de simulación.

ABSTRACT

Characteristic parameters of meteorological, oceanographical, chemical and biological aspects are analyzed, with the purpose of observing in an integrated form, the meteorological effects in the productivity of the Panama Bight. Large seasonal variations are observed in all the analized parameters, making of this area an appropiate place of this study. The intertropical convergence zone position looks to be the main limiting meteorological factor in the biological productivity of the area. Using as a first approximation a multiplicative model, where radiative, thermodynamic and dynamic factors are considered, good results of simulation are obtained.

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INTRODUCTION

The existence of the life on the earth is sustained over a thin air, water and soil layer with a size of a thousandth of the earth diameter and it principally depends of two factors: the nutrients with its recycling process and the energy flux (which has its origin in the sun) flowing only in one direction.

The marine biological production is affected –directly or indirectly– by the solar energy (in a radiative, thermodynamic and dynamic form). In reference to the radiative effect it intervenes directly in the marine vegetals growth (phytoplankton) through the photosynthetic production process, due to which the plants are able to store the incident solar energy; this energy lays in a potential form and lately it suffers a slowly conversion to kinetic energy that allows the life in the ecological communities; the plant components are converted in others by the herbivorous, and its time these are converted in others by the carnivorous and at the end of this process the decomposers (which complete the chemical cycle) return the nutrients to the ecological system for use them again.

The solar energy that flows through the system is not destroyed but transformed (first thermodynamic law) and one part of it is used to support the life in each biological production level. A great part of it is degraded from an energy form capable to realize reactions and work to less useful forms and it returns to the environment as heat which is impossible to use again, in accordance to the second thermodynamic law.

In the thermodynamic level, through the temperature, the solar radiation plays an important role in the photosynthesis, and in the kinetic of the enzymatic processes associated to it.

The thermodynamic level with the earth rotation produces the dynamic level formed by the basic system of the atmospheric circulation that influences on the dynamic of the water masses and on its vertical and horizontal movements, these factors control the bioproductivity of the oceans in all the world, transporting with themselves the nutrients to the upper ocean layers, where the greater amounts of light produce the ideal conditions for the phytoplankton production. Is important to notice that the richest fisheries areas are localized in or near where are produced or concentrated a great quantities of organic material (upwelling, current interfaces, gyrations, etc.) As the ocean is not without movement, the productivity fluctuates in these areas, and this fluctuations affect the abundance of the species. Is necessary a better knowledge of the meteorological effects over the oceanic productivity, in order to isolate those effects of the dependent causes of the fisheries.

The joined actions of these three levels of solar influence (radiative, thermodynamic and dynamic) favours the development of the oceanic life, and any anormaly produced by whichsoever of them will be detected in the productivity.

We try to develop, in the present paper, a procedure to know the effects of the three levels in the ocean productivity due to its obvious importance in the exploitation of the marine resources and taking in consideration that besides exists a conscience and a desire, each time greater, to finish with an epoch of economic anarchy, and consistent with the verification of the finite limits of the resources (including the oceanic resources), all of these is taking to the begining of another epoch in where the use and profitting of biosphere mecanism will have to be done in a more prudent and rational manner.

Furthermore, this study is not realized with the only economic finality to know the ideal conditions of the places for development and aggregation of the species in order to obtain a maximum utility with a minimum effort, but it can be usefull too as an auxiliar in the research of the dynamics of the fisheries population, being able in this way to avoid the possibility of extinction in the available resources.

The Panama Bight was choosen, in this first intent, for its ideal meteorological and oceanographical conditions for this kind of study, besides to have the more important condition that is the available information of this region, obtained by several authors and research centers. Forsberg (1969), Stevenson (1970).

2. THE MODEL

2.1. *Effects of the radiative level*

In order to know the solar effects in the radiative level on the ocean production, and to be able to formulate a mathematical relation between incident radiation and photosynthetic production in a time t and a z depth, the next behavior characteristics must be reproduce; a.) a lineal relation for lower intensities of illumination, b.) maximum values of production for an optimum illumination, c.) inhibition for greater values of illumination (Vollenweider, 1965).

As a first approximation, the basic equation used and chose also for several researchers including steele (1965) and which fundaments and basis for its use are given by Ryther (1956) will be considered

$$P(z,t)=p_m(I_z/I_m)\exp(1-I_z/I_m) \ , \qquad (1)$$

where P_m is the maximum observed rate of reproduction, I_z is the illumination into the water for a depth z and I_m is the level of radiation where the maximum reproduction is localized.

In order to relate the light amount I_z in a z depth being able to produce photosynthetic processes, with respect to the incident global radiation I_i on the sea surface, we will make the next assumptions:

a.) From the solar energy incident on the water surface only a 6% is lost due to reflexion effects. Budyko (1963).

b.) For the upper layer there is a mixing layer where the nutrients are not a limiting factor and with enough turbulence to produce a uniform distribution of plankton.

c.) The amount of solar energy useful for the photosynthetic production was determined reducing the total radiation by a factor of 0.2 to eliminate the non photosynthetic energy (Sverdrup, 1953), since the energy with wave lengths greater or minor to 4 200 to 5 600Å–range representing approximately a 20% of the total energy– are completely absorbed in the first meter of water depth.

d.) The coefficient of the light extinction (η) is constant with depth, in other words, it is considered as an optically homogeneous layer. Maybe this can not be valid for the first meters of the surface, nevertheless, the mistake can be negligible for greater depths. Sverdrup (1942), Jerlow (1951).

If I_i is the incident global radiation on the oceanic surface, then the energy that goes through this surface can be write it as

$$I_w = (1-\alpha) I_i \quad , \tag{2}$$

where α is the albedo of the fraction of radiation reflected by the oceanic surface. Then the quantity of effective energy for photosynthetic production will be given by:

$$I_e = 0.2(1-\alpha) I_i \quad . \tag{3}$$

The illumination for any depth z, will be given by:

$$I_z = I_e e^{-\eta z} = 0.2(1-\alpha) I e^{-\eta z} \quad , \tag{4}$$

where $\eta = 1.7/D$, is the extintion coefficient of the blue light of greater importance in the chlorophyll a production, and D is the depth of the secchi disk, Poole and Atkins (1929), Riley (1949), Parson *et. al.* (1965).

Substituting equation 3 into equation 4 and integrating over a mixed layer of h depth we obtain the mean reason of the reproduction, given for the expression

$$\bar{p}_I = \frac{p_m}{\eta h}\left[\exp\left\{-\left(a\frac{I_i}{I_m}\right)\exp(-\eta h)\right\} - \exp\left(a\frac{I_i}{I_m}\right)\right] \quad , \tag{5}$$

where $a = 0.2\,(1-\alpha)$

2.2. Effects of the thermodynamic level

Applying the conservation principle of the energy through the first law of the thermodynamics to the considered mixed layer and neglecting the thermic effects due to the currents and mean winds, as well as another due to the turbulent effects, we obtain in accordance with

Adem (1963, 1964) an expression to calculate the anomalies of the oceanic temperatures of the region.

$$\frac{h P C_v}{2}\frac{\partial T_s}{\partial t} = E_s - G_2 - G_3 \quad , \tag{6}$$

where $\frac{h P C_v}{2}\frac{\partial T_s}{\partial t}$ is the energy storage in a mixing layer of depth h, ρ the density, C_V the specific heat of the ocean. E_s the radiation excess T'_s is the temperature anomaly of the layer, G_2 and G_3 the loss of thermic energy by vertical turbulent transport of sensible heat from the ocean to the atmosphere and for evaporation, respectively. And where the excess of radiation will be given like Adem (1963) as

$$E_s = F_{12} + \epsilon F'_{12} + F_{13} T'_m + \frac{F_{13}}{2} \beta H' + F_{14} T'_s + (Q+q)_o \left[1-(1-Y)\epsilon\right](1-\alpha) \quad , \tag{7}$$

where T'_m is the anomaly of the temperature of the mean troposphere, ϵ is the cloudiness in fractional form, β is the thermic gradient that is constant, $H' = AT'_m$ is a deviation of the tropospheric height H_o of 11 km $(Q + q)_o$ represents the possible radiation received of a clear sky, γ is the regression coefficient given by Budyko (1963) and F_{12}, F'_{12}, F_{13}, F_{14} and A are coefficients given by Adem (1963, 1968).

If we substitute equation (7) into the equation (6) and resolving, we obtain:

$$T'_{s_{i+1}} = \frac{1}{D_s}\left\{ F_{12} + F'_{12}\epsilon + F_{13}\left(1+\frac{\beta A}{2}\right)T'_m + (F_{14} + D_s)T'_s + (Q+q)_0\left[1-(1-\gamma)\epsilon\right](1-\alpha) - G_2 - G_3 \right\} , \tag{8}$$

where $D_s = \frac{h\rho C_V}{2\Delta t}$ and $T'_{s_{i+1}}$ is the oceanic temperature of the next month.

Considering that the effect of temperature is similar of the light, it can be use a similar equation as equation (4), like

$$P_T(t) = P_m(T_z / T_M) \exp(1 - T_z / T_M) , \tag{9}$$

where T_M is the temperature that corresponds to the maximum photosynthetic production that was observed, and T_Z is the temperature of the considered layer and equal to $T_{S_O} + T'_{S_{i+1}}$ where T_{S_O} is the observed mean monthly temperature.

2.3. Effects of the dynamic level

The perturbations in the photosynthetic productivity in an acuatic ecological system are usually caused by fluctuations in the physical factors. The rate on the change of the phytoplanktonic population can be expressed as a difference of energy accumulation (which is the photosynthetic rate by population unit) and an energy of dissipation (given by the rate of respiration and pasturing). Sverdrup (1953), Cushing (1959a, b) Murphy (1962) had shown that the quantity of net photosinthesis is affected by the amount of radiation, the mixed layer depth and the water turbidity, besides it can be observed, based in an energy balance that the depth of the mixed layer can limit the production, when it makes that the photosynthetisers spend a great time of their life in profundities in where there is not enough light, these authors called critical depth to the depth of mixing where the production by unit of surface was exactly balanced by the respiration, in other words, a situation where the net production is zero. On the contrary, Patten (1968) explains that any natural system can be adjusted when the parameters are changed from its system, in such a way that the net production of the community is always positive for a water column completely mixed, without taking in consideration what deep it can be.

From the data of the mixed layer depth of Fig. 4 we can observe that for a minor mixing depth layer corresponds to a greater photosynthetic production, which gives a greater credit to the first of the indicated considerations.

Considering a lineal proportionality we can use the maximum rate of upwelling –vertical movement– provider of the necessary nutrients for the photosynthetic production in order to find the expected nutrients values where the rate is given by Wyrtki (1964) as:

$$\omega = \frac{Q}{\rho C(T_o - T_D)}, \tag{10}$$

where T_o is the temperature of the mixed layer that was taken on a depth of 10 meters, T_D is the temperature of the ascending waters, temperature that was taken on a depth of 150 meters and Q is the total heat interchange on the surface.

For the dynamic level, we use as a first approximation, the final effect, in other words, the quantity of the nutrients (magnitudes of ω) that are present as a result of all the effects that appear in this level, considering that the effect is similar to the others levels.

2.4. Total effects

The total effects of the three considered levels, in where the meteorological effects act on the oceanic productivity, are principally based on the consideration that the effect of presence or abundance of the characteristic parameters (illumination, temperature and nutrients) of each level (radiative, thermodynamic and dynamic) acts in an independent form, that is why the combiner effect can be written in a multiplicative form adjusting the data to an expression like $C\, p_I^{\alpha_1}\, p_T^{\alpha_2}\, p_N^{\alpha_3}$ in accordance to Powell's (1964) and Jorgensen's and Steeman Nielsen's (1965) procedures, where, C, α_1, α_2, and α_3 are the fitting constants.

2.5. Relation between the primary production with other superior levels

The relation between the primary production with other superior trophic levels is considered as a clasic case of the interaction: predator-prey, where the predation or pasturing is proportional to the concentration of food, this consideration was used in Lotka-Volterra's equation, using an expression as:

$$\frac{\partial P_o}{\partial t} = bP_o - f_1(P_o)H_e + \frac{\partial}{\partial x} K \frac{\partial P_o}{\partial x}$$

$$\frac{\partial H_e}{\partial t} = f_2(P_o)H_e - f_3(H_e) + \frac{\partial}{\partial x} K \frac{\partial H_e}{\partial x} , \tag{11}$$

where P_o is the population of plants, H_e the herbivorous population, b is the growth rate of the plants for unitary density and K is the eddy lateral diffusion, for all of it we used the Schaefer (1954) and Usher and Williamson's procedure (1974), with delays of two months in the abundance of the predatores with respect to the preys for the case of the interaction phytoplankton-zooplankton and a direct relation for the zooplankton with another superior species.

3. *Meteorological, Oceanographycal, Chemical and Biological data of the studied area*

With the purpose to know the main characteristics of the studied area we will analyze the observed values in an horizontal, vertical and punctual form in order to be able to realize an integration of all the parameters that intervene in the three levels in which the meteorological effects influence on the oceanic productivity, analyzing first at all the incident radiation for the radiative level, the temperature for the thermodynamic level and the upwelling movements for the dynamic effects. Forsberg (1969) has shown that the major transport of nutrients are due to upwelling effects originated by the winds of the region.

3.1. Data in horizontal form

In Fig. 1, the superficial mean winds are shown for November and February-March periods, averaged over squares of one degree, it can be observed, in general, south winds for November, while for the other period the predominant winds will be from the north.

In Fig. 2 we have the surface temperature, the mixed layer depth, the phosphate at 30 meters and the chlorophyll *a* of the surface (it was used as an indicator of the primary productivity) for two periods from Nov. 18 to Dec. 1st., 1965 and for Feb. 17 to March 6, 1966, respectively, observing for the second period colder regions (of temperature), more intense temperature gradients, the mixed layer less deep and more quantities of phosphate and chlorophyll *a*, all this is an indication of the existence of the upwelling effects.

3.2. Data in vertical form

In Fig. 3 the average values are shown with vertical distribution of the temperature, the salinity, the anomaly of the potential density, the nitrates, silicates, phosphates and disolved oxygen for the periods from May 21 to June 4, 1965 (tenuous continuous line) from August 19 to 30, 1965 (drawn in outline) from November 18 to December 1st., 1965 (dotted line) and from February 6 to March 6, 1966 (continuous line).

Notice that the values are closer to the surface (continuous line) during the months (Feb-March) with northerly winds and mayor primary production, this points out the importance of the disposition of the nutrients –transported by the upwelling effects– on the superior oceanic part with the most abundance of solar radiation.

3.3. Data on punctual form

In Fig. 4 we have montly mean values of meteorological parameters (radiation, position of the intertropical convergence zone (ZCIT), north winds, air temperature on surface (T_a) and precipitation), oceanographycal (temperature of the surface water (T_s), water temperature to 20 meters depth (T_{20}) and depth of the mixing layer), chemical (phosphates, nitrates, carbon fixation and chlorophyll *a*) and biological (zooplankton and abundance index of tuna fish expressed by the capture by unit of effort).

It can be observed that exist two periods clearly defined of the studied parameters.

a.) The maximum values of incident solar radiation exist in the first months of the year, with the ZCIT position in the south of the studied area which generates the maximum values in the northerly winds producing cold waters that point out the effects of the vertical movements (upwellings) and of a shallow mixing layer, this provides a maximum of nutrients and joined with the maximum of radiation produce a maximum of carbon fixation and chlorophyll *a* production.

b.) The rest of the year, there is fewer radiation and the ZCIT position is localized to the north of the studied area producing southerly winds which brings humidity and produce strong precipitations stabilizing the considered layer and desapearing the upwelling movements, with its consequences like depression in the nutrients quantities and the later poor carbon fixation and chlorophyll *a* production.

Furthermore, it's interesting to observe the coincidence in the maximum production of zooplankton and another species, like the tuna fish. These maximum presents a delay of two months in relation with the maximum abundance of the phytoplanktonic biomass (chlorophyll *a*).

RESULTS AND CONCLUSION

Panama Bight area presents two characteristic periods in its oceanic productivity. One period of greater abundance at the begining of the year (February-March) and other period of poor productivity during the rest of the year. The limiting factor in the regional productivity are the absence of nutrients in the euphotic zone, since the dynamic effect of vertical transport of the upwelling disappear when changes the sense of the predominant winds (from north at the begining of the year to the south the rest of the year) when the ZCIT position changes. So, we can see that the ZCIT position is the limitative meteorological factor in the ocean productivity for our studied area, so it is not only an important factor in the regional climatology but also the one that on a dynamic action level is the activator (south position) of the biological productivity in this area. A stabilization effect on the superior oceanic layer is produced by the presence of rains, and these rains influence too over the destruction of the vertical turbulent movements.

The phytoplanktonic biomass simulation, based of a multiplicative model following Jorgensen and Steeman Nielsen (1965) and Powell's procedures (1964) where it is considered that the three influence levels (radiative, thermodynamic and dynamic) are independent and similar to a Steele's expression (1965), gives good results, as it is shown in Fig. 5 where continuous lines represent the observed values and the crosses curve represents the calculated values by the model.

The procedure followed to calculate the effective photosynthetic radiation for the radiative level, the oceanic temperature for thermodynamic level obtained by Adem's procedures (1963, 1964, 1968) as well as the given by Wyrtki (1964) in relation with the vertical movements which provides the nutrients for the dynamic level, gives good results in the calculation of the desire parameters for each influence level. The abundance of superior throphic levels is well adjusted into a simulated predator-prey model like Lotka-Volterra's type, using a two months delay in the predators for the phytoplankton-zooplankton relation and a direct relation in the density relation of zooplankton against the anchovy captures and the tuna fish density (capture by unit of standard effort). We can observe greater divergences for the anchovy case possibly due to the fact that in these were only used the captures, while in the case of tuna fish it was used and abundance index, what is more realistic for the relations used.

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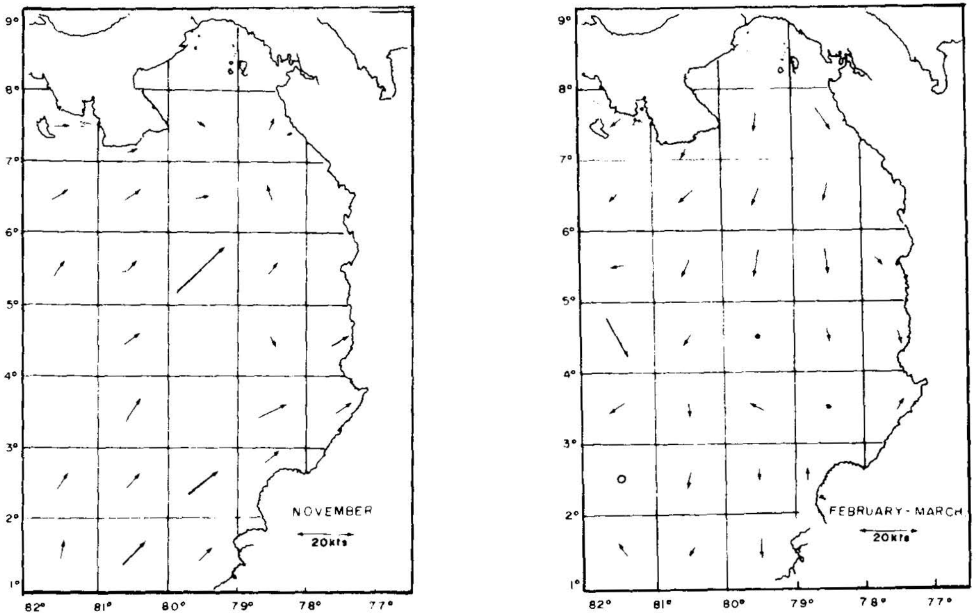
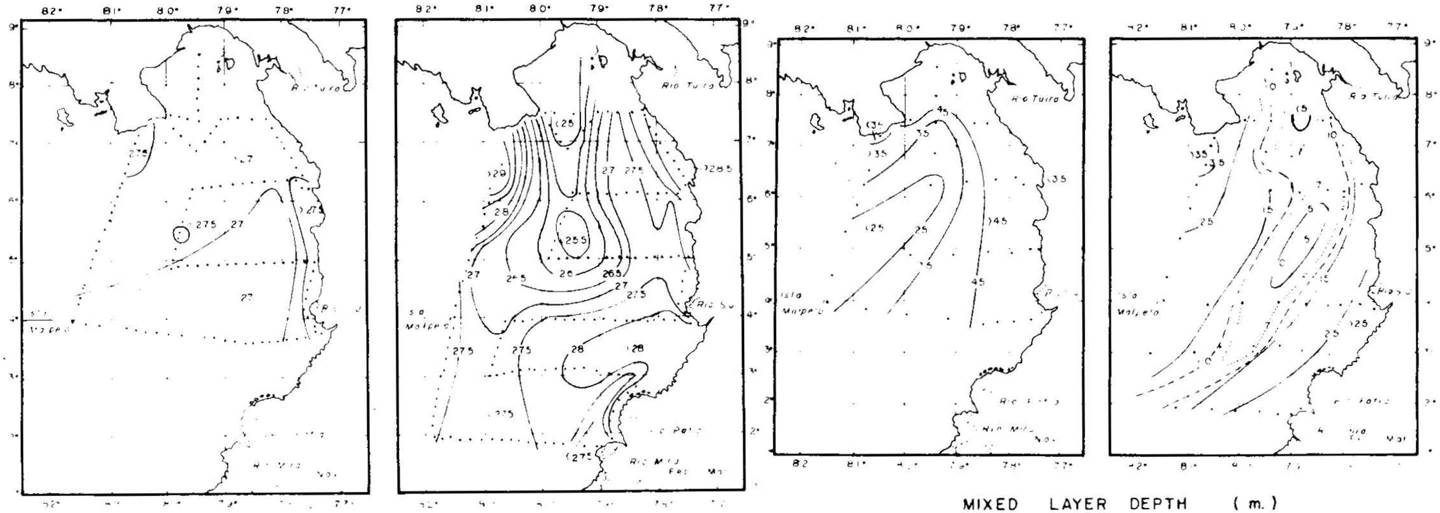
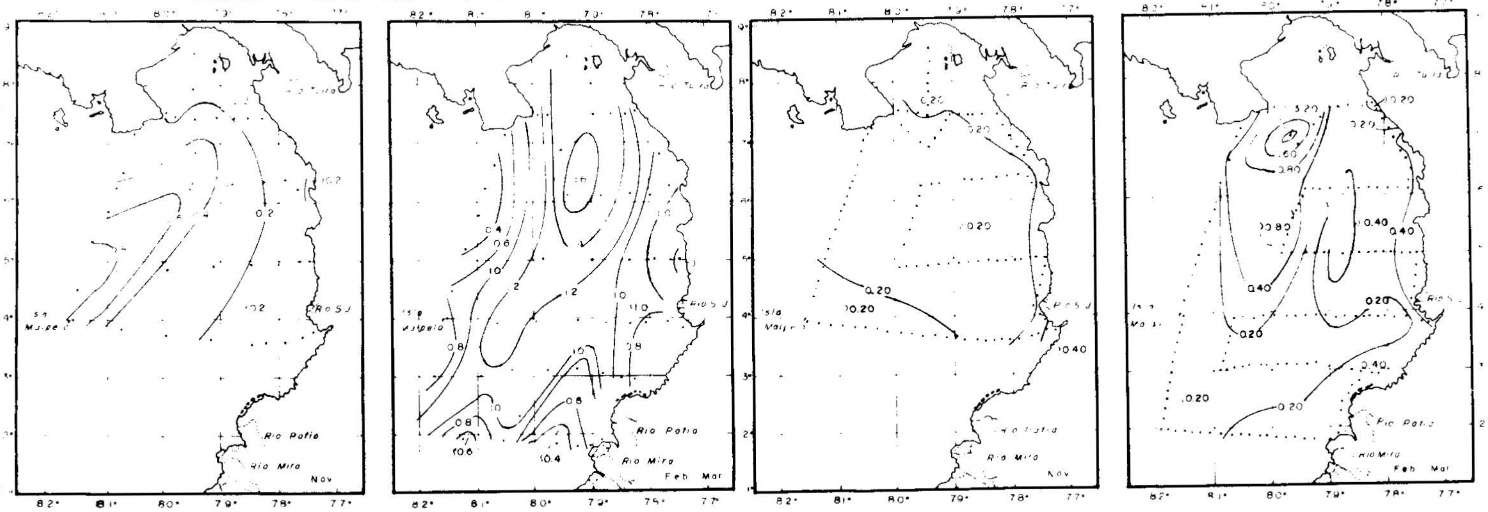


FIG-1 SUPERFICIAL MEAN WINDS, AVERAGED FOR ONE DEGREE SQUARES. STEVENSON (1970)



SURFACE TEMPERATURE (°C)

MIXED LAYER DEPTH (m.)



INORGANIC PHOSPHATE - PHOSPHORUS AT 30m. (mg.-at./L)

FIG: 2

SURFACE CHLOROPHYLL a (mg./m³)

FORSBERGH (1969)

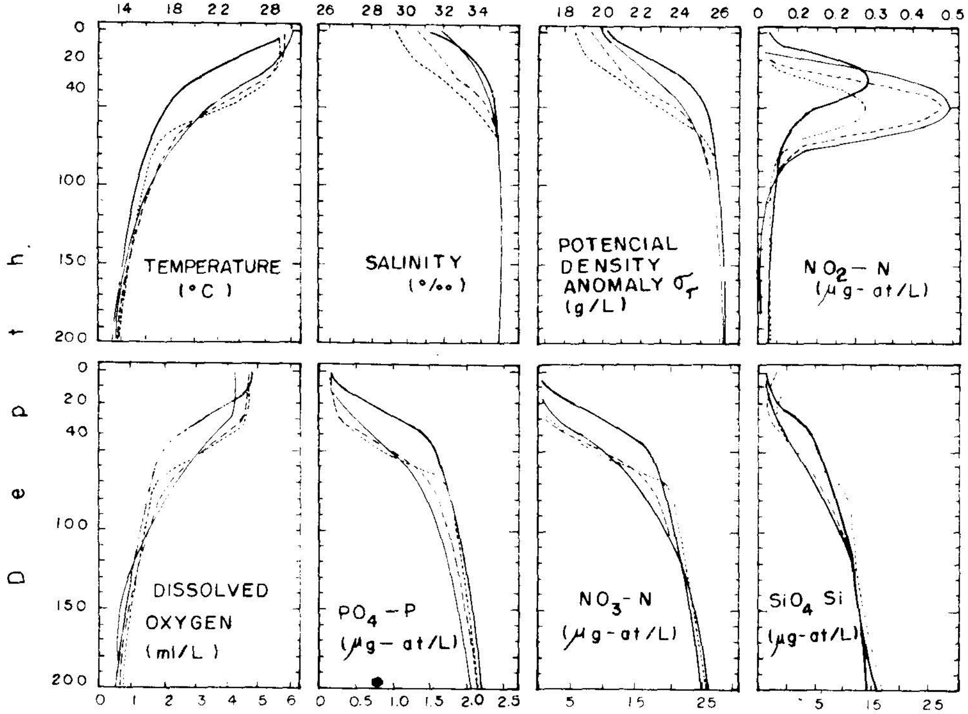


Fig. 3 MEAN VERTICAL DISTRIBUTION OF PHYSICAL AND CHEMICAL PROPERTIES AT STATION OF THE PANAMA BIGHT. FORSBERGH (1969)

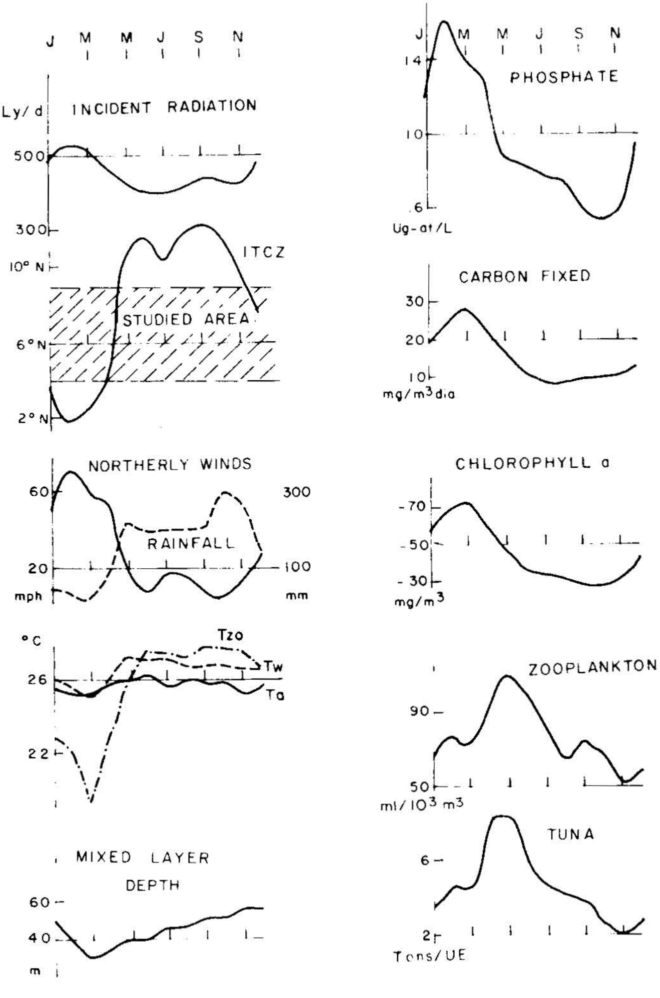


FIG-4 Montly mean values at Panama bight of the radiation, of the intertropical convergence zone,(ITCZ) of the Northerly Winds, rainfall, the ocean temperature at 20 m depth (T20), the sea surface temperature (Tw), the temperature of the air, the mixed layer depth, Phosphates, Carbon fixed, Chlorophyll a, Zooplankton and the abundance index of Tuna (tons by unit of effort (U E))

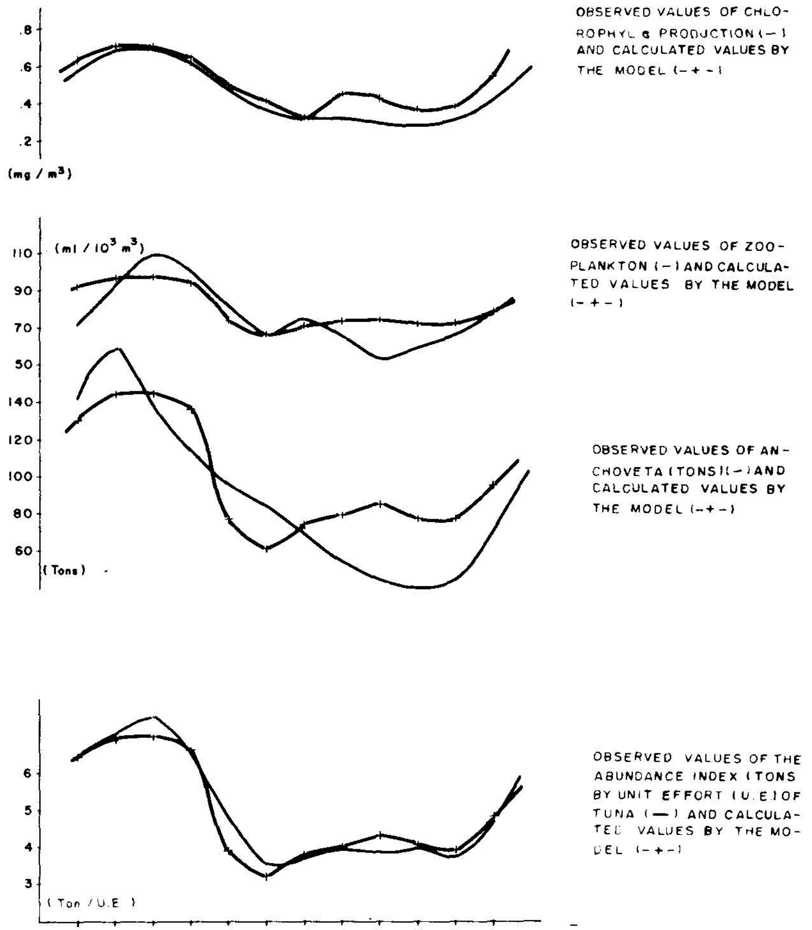

.8
.6
.4
.2
(mg / m³)
OBSERVED VALUES OF CHLOROPHYL a PRODUCTION (–) AND CALCULATED VALUES BY THE MODEL (–+–)
110
90
70
50
(ml / 10³ m³)
OBSERVED VALUES OF ZOOPLANKTON (–) AND CALCULATED VALUES BY THE MODEL (–+–)
140
120
100
80
60
(Tons)
OBSERVED VALUES OF ANCHOVETA (TONS) (–) AND CALCULATED VALUES BY THE MODEL (–+–)
6
5
4
3
(Ton / U.E)
OBSERVED VALUES OF THE ABUNDANCE INDEX (TONS BY UNIT EFFORT (U.E) OF TUNA (—) AND CALCULATED VALUES BY THE MODEL (–+–)
J
F
M
A
M
J
J
A
S
O
N
D

FIG-5

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