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A SUSTAINABLE SHRIMP MARICULTURE INDUSTRY FOR ECUADOR

Edited by Stephen Olsen and Luis Arriaga







International Coastal Resources Management Project

The University of Rhode Island

Red Tide and Shrimp Activity in Ecuador

Marea Roja y la Actividad Camaronera en Ecuador

Roberto Jiménez

Resumen

El fenómeno llamado **"marea roja"** usualmente es causado por una explosión monoespecífica en la producción del fitoplancton, pudiendo ocurrir también con actividad del zooplancton y origina una coloración del agua que puede ser verde o rojo-amarillento. Mareas rojas causadas por dinoflagelados como <u>Gymnodium breve</u> y <u>Gonyaulax catenella</u> son tóxicas para peces e invertebrados. Otros organismos como el ciliado <u>Mesodinium rubrum</u>, no son tóxicos para la fauna marina.

Desde el comienzo de las investigaciones en 1969, han ocurrido 28 incidentes de mareas rojas. Una marea roja descrita por el autor, causada por <u>M. rubrum (Cyclotricnium mernieri)</u>, en el Golfo de Guayaquil, en mayo de 1973, produjo alta fertilidad en el área con concentraciones de clorofila de 93,7 mg/m³, similar a los casos asociados al fenómeno de El Niño de 1976.

En abril de 1980, una extensa área de marea roja ocurrió en el Golfo de Guayaquil (Canal de Jambelí), causando mortalidad en los peces. El organismo responsable fue <u>Gonyaulax monilata</u>. Entre 1980 y 1981 fueron registrados siete casos de mareas rojas causadas por <u>Mesodinium rubrum</u>, a lo largo de la costa del Ecuador. En noviembre de 1981 un caso de discoloración de las aguas, típico de la marea roja, fue determinado en el Estero Salado, debido a la diatomea <u>Skeletonema costatum</u> que alcanzó concentraciones de 100'000.000 células/l y altas concentraciones de clorofila (más de 100 mg/m³).

El autor presenta un resumen de las características de diversos casos de marea roja observados en el período 1980-86 en aguas ecuatorianas.

El bombeo de agua con marea roja a las piscinas ha causado altas tasas de mortalidad en el camarón. También, el uso de altas concentraciones de fertilizantes ha originado un florecimiento excesivo de algas, habiéndose informado concentraciones de <u>Nitzschia</u> mayores que 1'200.000 células/litro, lo cual causa mortalidad en el camarón por anoxia. También se ha observado frecuentemente la proliferación de filamentos de algas azules, resgistrándose en algunas piscinas camaroneras cifras mayores que 75'000.000 de filamentos por gramo de sedimento. Mediante estudios de contenido estomacal se ha verificado que el sabor del camarón cambia y que tiene olor rancio, cuando se alimenta con esta alga.

El documento concluye en la importancia del control de las poblaciones de plancton en las piscinas camaroneras y de la vigilancia de las poblaciones de camarón, especialmente después del florecimiento de las algas, lo cual puede indicar una anoxía potencial y problemas de mortalidad.

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Introduction

The so-called "red tides" are spectacular phenomenoma in the oceans of the world. Red tide is usually caused by a monospecific (single species) explosion in phytoplankton production, though water coloration can also occur with activity of zooplankton and may actually be green or yellowish-red. Also, referred to as sea decoloration or hemotalasia in scientific literature, these brightly colored areas in the sea can appear in clusters or singly and last for days, weeks or months.

Red tide phenomena, caused by dinoflagellates like *Gymnodium breve* and *Gonyaulax catenella*, are toxic to fish and invertebrates. Other red tide organisms, such as the cilliary photosynthetizer *Mesodinium rubrum*, are not toxic to sea fauna.

Red Tide Awareness

Towns located near the South American coast have frequently used local names for these phenomena, "sea purge" in Galicia; "tidal wave" in Peru: "el turcio" in Venezuela.

In Ecuador the media has begun to refer to these disturbances as "red tide," which is a readily identifiable way to offer information to fishing communities when such phenomena occur along the Ecuadorian coast. Previously, most of the data pertaining to the organisms that cause the red tides came from Chile, and was based on information obtained from fishermen.

Incidents and Effects of Red Tide - 1969-1979

Twenty-eight red tide incidents have occurred in Ecuador (Figure 1) since marine phytoplankton research began (Table 1) in 1969. For example, two red tides associated with *Mesodinium rubrum* occurred in the Gulf of Guayaquil in February 1968. This paper's author described a red tide also caused by *Mesodinium rubrum (Cyclotricnium mernieri)* in the Gulf of Guayaquil in May 1973. This particular incident produced high fertility in the area with chlorophyll concentrations of 93.7 mg/m³ similar to those associated with El Niño phenomena of 1976. In November 1978 a red tide was observed in the open sea near the Port of Manta, associated with accumulation of *radiolarian* colonies (genus *Collozoum*).

Another red tide caused by *Cochlodinium catenatum* occurred in July 1979, south of the Gulf of Guayaquil. *C. catenatum* is a "naked" dinoflagellate with complex morphological characteristics. It is frequently present in chains of eight cells; 4 and 16 cell chains are not uncommon. The concentration of *C. catenatum* in the red tide area reached 1,900,000 cells on the sea surface, with its concentration significantly reduced with depth. This phototropic characteristic of the organism was reflected in the high daily primary production rate (about 5,000 mg c/m³) near the surface in the red tide area.

Despite efforts to culture the specie using various mediums, the organism did not survive for more than a few days.

Incidents and Effects of Red Tide - 1980-1986

There were several major red tides in 1980. In April of that year, an extensive area of red tide occurred in the Gulf of Guayaquil (Canal de Jambeli), turning the sea oxide red in color and causing high fish mortality. Microscopic analysis confirmed that the organism responsible was the dinoflagellate *Gonyaulax monilata* that is frequently associated with high fish mortality. The highest concentrations (988,000 cells/1) were found at 5 meter depths, while the surface showed 600,000 cells/1, and concentrations greatly decreased at 10 meters. The greater concentrations at the surface were favored by a stable water column with surface temperature between 26.8^o and 27.2^o, contrasted to 21.0^o recorded at 10 meters.

In general, these red tide phenomenoma are associated with strong sunlight exposure, a significant contribution of riverine an drainfall water and stability of the water column. All these elements were present when the red tide occurred in Canal de Jambeli in 1980. This red tide persisted for a short time.

Also, in April 1980, a large expanse of red tide occurred in the Galapagos caused by *Mesodinium rubrum* and *Prorocentrum gracile* with concentrations of 21,300,000 cells/1 and 2,340,000 cells/1, respectively. There was a high fish mortality rate, mainly south of Isabela and Canal Bolivar, with hundreds of dead fish reaching the beach near Puerto Villamil. This was the first reported red tide in the Galapagos Islands. Finally, in August 1980 in Valdivia, there was a red tide caused by *Noctiluca scintilans* and *M. rubrum* (Jimenez, in print).

Between 1980 and 1981 seven red tides caused by *Mesodinium rubrum* were recorded along the coasts of Ecuador, during cruises on board the B/1 **Tohalli** of the Instituto Nacional de Pesca. In all events recorded, high cell concentrations caused discolorations of the sea, and the high chlorophyll values detected in the red tide areas caused increased fertility. The effects of this high fertility can be significant for trophic pellagic chains.

Red tides were present in the Gulf of Guayaquil and in the northern part of Puna in November 1981. The patches were narrow and quite long and were caused by high concentrations of *Prorocentrum* sp.). Accumulations of the organisms were more significant in areas where there were greater concentrations of detritus and organic materials, with high photosynthesis fixation of 7.918 mg c/m³. The cells and detritus particles resembled macroscopic organic conglomerates.

In November 1981, in the Estero Salado, the Instituto Nacional de Pesca recorded a significant change of water color to brownish-red, typical of red tides. The organism causing this discoloration was the diatom *Skeletonema costatum*, that attained extraordinary cell concentrations of 100,000,000 cells/1, with high concentrations of chlorophyll a (more than 100 mg/m³). Another organism observed during this phenomenon was *Gymnodinium*. The phytoplankton causing the discoloration was formed by sea cells due to high tide influence that increased the Estero Salado's salinity to 28.1 ppt.

A high intensity red tide was observed in the Guayas River in September 1982. The color was a strong dark brown caused by *Gyrodinium stratum* that reached concentrations of 93,000,000 cells/1. The affected area was about 50 km long from the northern part of Guayaquil to off Puna Island in the Gulf of Guayaquil. The red tide persisted for over one month. At this time, the negative effects of pumping discolored water into shrimp ponds was first noted. Although *Gyrodinium stratum* is not toxic, such high concentrations within the ponds caused anoxia and subsequent shrimp mortality. Thousands of shrimp died, according to shrimp farmers, though exact figures could not be obtained since the shrimp biomass within the ponds is not usually estimated until harvest time. Also, shrimp mortality is difficult to determine since dead shrimp are generally eaten by other shrimp.

In August 1984, in Estero Bajen in the estero Salado, a red tide caused by *Mesodinium rubrum* reached concentrations of 70,000,000 cells/1 with 4,000 mg/m³ of chlorophyll a. This incident was reported by shrimp farm owners. On this occasion, high shrimp mortality occurred due to low oxygen levels in the water, mainly at night. As in other instances, the recommendation was for frequent water changes to prevent proliferation of the organism in the closed pond systems.

A red tide occurred in Estero Salado in September 1984. This incident was not as intense as that in the Guayas River in 1982, and disappeared in a few days.

In February 1984, along the coast of Ecuador, a red tide caused by *Mesodinium rubrum* covered a 1000 mile long area between Funtilla de Sta. Elena and Cato pasado. The organism was dispersed over an area greater than 200 square miles. The denser patches showed concentrations of up to 7,600,000 cells/1 and 140 mg/m³ of chlorophyll a. These high cell concentrations were also associated with a near coastal bloom which created increased productivity of Ecuadorian coastal waters. In February and March 1985, there were red tide reports in the Gulf of Guayaquil and Galapagos, caused by *M. rubrum*.

Between February 1985 and February 1986, there was a high density, nontoxic red tide in the internal estuary of the Gulf of Guayaquil, associated with *Prorocentrum maximum*. It persisted for 12 months in Estero Salado, causing no problems to shrimp farms since the higher cell concentrations were located in the center of the Esteros and not in nearshore water used for water changes by the shrimp farms. Due to strong currents predominant in the area, most of the organisms causing the red tide swept to the external part of the Gulf where they did not thrive, probably because this specie prefers estuarine waters. Though it was suspected that the large amounts of organic material from this organism can cause a reduction of the oxygen content at sub-surface levels in the water column, it was observed that the oxygen concentrations near the bottom were similar to those found on the surface, as indicated below:

Location	Date	Depth in Meters	Oxygen/ml/L	T ^O C
Estero Corvinera	23-07-85	2	3.88	24.7
	(09h30)	6	3.60	24.4
Estero Calaco	17-02-86	2	4.53	29.1
	(16h18)	18	4.66	29.0
Estero Corvinera	19-02-36	2	5.05	28.6
	(11h00)	9	4.99	28.4

Some other species caused red tides in the inner part of the Gulf of Guayaquil in 1985, but their intensity was lower, i.e. *Scrippsiella trochoidea* with concentrations of 3,150,000 cells/1; *Gymnodinium sp.* with maximum levels between 3,250,000 cells/1 and 9,750,000 cells/1; with concentrations of 1,300,000 cells/1.

In March 1986, in the coast of Manglaralto there were red tides of *M. rubrum* associated with *Gonyalaux monilata* in significant concentrations. A number of hatcheries are located in this area and significant mortality of hatchery-reared postlarvae occurred, paralyzing operations of eight facilities for 30 to 45 days.

In April and May of 1986, this *M. rubrum* red tide moved to the Gulf of Guayaquil, but the toxic organism *G. monilata* was not present. Later on, in June 1986 extensive red tides were reported in the Gulf of Guayaquil in Engunga, caused by *M. rubrum* and *Ceratium dens*, which reached concentrations of 2,200,000 cells/1 and 840,000 cells/1, respectively.

Impact of Red Tides on Shrimp Mariculture Operations

Many shrimp farms of the affected zone pumped red tide contaminated water to their ponds, with resultant high shrimp mortality rates. The highest concentration found in the ponds were:

Species	Concentration		
Mesodinium rubrum	3,900,000 cells/1		
Ceratium dens	675,000 cells/1		
Prorocentrum gracile	450,000 cells/1		
Scrippsiella trochoidea	90,000 cells/1		
Microflagellates	225,000 cells/1		

It is important to state that many shrimp ponds use high concentrations of fertilizers that cause excessive algal blooms. Concentrations of *Nitzschia* have been reported at more than 1,200,000 cells/1, which causes mortality of shrimp due to anoxia. Also, ammonia levels of 50 ug/l have been recorded.

Problems arising from proliferation of filaments of blue-green algae have occurred frequently. In some ponds, up to 75,000,000 filaments/gm of sediment have been recorded. Through studies of stomach contents of shrimp, it has been verified that when shrimp feed on these algae, the flavor of the shrimp is changed and they have a musty odor. Although significant proliferation of blue-green algae has been observed among the plankton of open Ecuadorian waters, this type of algae also reproduces quite easily in closed systems such as shrimp ponds.

Finally, sampling in shrimp ponds shows that, depending upon the environment, phytoplanktonic forms frequently cause red tide phenomena within the ponds. Those blooms affect the growth and mortality of shrimp due to excessive numbers of planktonic organisms or toxics released by the cells. In conclusion, it is important to the shrimp industry to improve their control over plankton populations in shrimp ponds and to monitor shrimp populations from pond seeding to harvest, especially after algal blooms which indicate potential anoxia and mortality problems.

Year	Depth in meters	Location	Organism	Cells/Litre
1931	2	Sta. Elena-Esmeraldas	ciliado?	
1968	2	Golfo de Guavaquil	Mesodinium rubrum	
1973	5	Golfo de Guavaguil	Mesodinium rubrum	
1976	3	Golfo de Guavaguil	Gymnodinium splendens	
1976	4	Pta. Sta. Elena	Ceratium deflexum	
1978	9	Manta	Collozoum sp.	
1979	7	Punta Pavana	Cochlodinium catenatum	1.900.000
1980	4	Canal de Jambeli	Gonvaulax monilata	988.000
1980	8	Valdivia	Mesodinium rubrum	14,755,000
1980	8	Valdivia	Noctiluca scintilans	
1980	4	Islas Galapagos	Mesodinium rubrum	21,300,000
1980	4	Islas Galapagos	Prorocentrum gracile	2,340,000
1981	3	Isla de la Plata	Mesodinium rubrum	4,367,000
1981	8	Golfo de Guayaquil	Mesodinium rubrum	3,000,000
1981	9	Isla Puna	Prorocentrum sp.	49,330,000
1981	9	Estero Salado	Skeletonema costatum	100,000,000
1982	9	Rio Guayas	Gyrodinium striatum	93,000,000
1984	9	Estero Salado	Gyrodinium striatum	440,000
1984	8	Estero Salado	Mesodinium rubrum	70,000,000
1984	2	Pto. Lopez	Mesodinium rubrum	7,600,000
1985	3	Isla Galapagos	Mesodinium rubrum	
1985	2	Golfo de Guayaquil	Mesodinium rubrum	
1985	2 - 12	Estero Salado	Prorocentrum maximum	283,000,000
1985	6	Estero Salado	Scrippsiella trochoidea	3,150,000
1985	2	Estero Salado	Mesodinium rubrum	1,500,000
1985	8 y 11	Estero Salado	Gymnodinium sp.	9,750,000
1986	3	Manglaralto	Mesodinium rubrum	3,000,000
1986	3	Manglaralto	Gonyaulax monilata	90,000
1986	4 - 5	Golfo de Guayaquil	Mesodinium rubrum	23,100,000
1986	6	Golfo de Guayaquil	Ceratium dens + M. rubru	m 840,000

 Table 1

 Recorded red tides in Ecuadorian waters

Figure 1. Locations of red tide outbreaks in Ecuadorian waters during 1982.



Oceanographic Characteristics Off the Coast of Ecuador

Características Oceanográficas frente a la Costa del Ecuador

Emilio Cucalón

Resumen

En el presente trabajo se resaltan las principales características oceanográficas prevalecientes frente a la costa de Ecuador, su variabilidad estacional e interanual. Se presentan algunas evidencias de como variaciones ineranueales de baja frecuncia en las concdiones ocieanográficas de la región, El fenómeno de el Niño, inducen cambios significativos en la compsocipo y distribución de aguans de lasmás importantes pesquerías, provocando el descalabro de unas y foreciendo el desarrollo de otras. Asío por ejemplo, durante el desarrollo del último fenómeno de El Niño en 1982-83, la pesquría de peces pelpagicos de gran importancia comercial como macarela (Scomber japonicus), sardinas (Sardinops sagax, Estremeres teres) y pincahagua (Opisthonema spp.) fue drásticamente reducida, mientras que la pesquería del camarón alcanzó nivles nunca antes registrados.

Se destacan, además, otros tipos de variabilidad interanual de característica y frecuencias diferentes a las de El NIño, las cuales podrían también estar relacinadas ocn fluctuaciones en algunas pesquierías. Tal es el caso del "Frente Ecuatorial" que durante el invierno de 1985 estuvo más al norte de su límite usual, originando que las aguas costeras sean 2ºC más frías que lo esperado. En este año las capturas totales de los pequeños peces pelágicos (macarela, sardinas) superó el millón de toneladas, constituyen así un record en estas pesquerías.

Summary

The main seasonal and interannual variations in oceanographic characteristics off the Ecuadorian coast are presented in this paper. In addition, some evidence is presented as to how low frequency interannual variations in the oceanographic conditions of the region (El Niño) induce significant changes in the composition and distribution of important fisheries, causing the collapse of some, and favoring the development of others. For example, during the development of the last El Niño phenomenon in 1982-83, the pelagic fisheries of great commercial importance, such as mackerel (*Scomber japonicus*), sardines (*Sardinops sagax, Etrumeus teres*) and pinchagua (*Opisthonema spp.*), were drastically reduced, while the shrimp fishery reached record levels. Other kinds of interannual variability besides those of El Niño, which could likewise be related to fluctuations in some fisheries, are also presented.

Introduction

All the seacoast countries around the world recognize the vital necessity of increasing their knowledge about how the variations of oceanographic conditions influence the composition, distribution and abundance of the living resources of the sea, so they can be administered reasonably as a sustainable food resource. The oceanic region along the coast of Ecuador presents great variability, both in physical environment and living resources, a factor that has an important impact on the economy of the country.

Since any phenomenon that affects water temperature, currents and other ocean characteristics, will likewise affect annual abundance or distribution of many species of fish and crustaceans, it is crucial that resource managers have as complete an understanding as possible of the relationships between living resources and environmental conditions.

Study Area

The study zone is an area of the eastern equatorial Pacific Ocean situated immediately off the coast of Ecuador. This area, which extends latitudinally from $1^{\circ}N$ to $3^{\circ}20'S$, is a transition zone between the tropical and subtropical regimes. To the north, the Panama Bight is defined as the area of the eastern tropical Pacific Ocean that lies between the Isthmus of Panama (about $9^{\circ}N$) and Punta Santa Elena (about $2^{\circ}S$), and extends from the coasts of Panama, Colombia and Ecuador to about $81^{\circ}W$ longitude (Figure 1). This area is characterized by warm (>25°C), low salinity (<34.0 ppt) tropical water. To the south, off Peru, the subtropical water is cold (<22°C) with high salinity (>35.0 ppt) because of the Humboldt Current (or Peru Current), which is strongly influenced by coastal upwelling. Between these two water masses lies a transition zone called the equatorial front, which displays marked seasonal variations and is identified by intense surface thermo-haline gradients.

Seasonal Variability: Circulation and Associated Hydrography

The area is characterized by two clearly differentiated seasonal periods: summer (January-April) and winter (July-October). The remaining months are considered transition periods between these two seasons. More than 95 percent of the annual precipitation falls during summer (Stevenson, 1981).

In summer, a narrow, southward coastal flow of warm (25^o-27^oC), low salinity (33.0-33.8 ppt) water from the Panama Bight is evident along the coast of Ecuador to approximately 2^o-3^oS (Figures 2 and 3). This tropical surface water is also characterized by low-nutrient concentrations, and its flow may be defined as a response of the local circulation to seasonal variations of the wind field in the region. The summer meridional winds that blow parallel to the coast weaken, whereas the northeast trade winds blowing across Central America strengthen, increasing the meridional transport of water across the equator.

This flow is indicated on several maps as the El Niño Current (the Holy Child Current), not to be confused with the El Niño phenomenon. This current develops each year during the summer months, and is responsible for the presence of warm waters along the coast of Ecuador during this period. On the other

hand, the El Niño phenomenon describes a large scale ocean atmospheric anomaly (Pacific Ocean), characterized by the aperiodic influx of unusually warm surface water (29^o-30^oC) in the southeast Pacific Ocean, particularly off Ecuador and Peru.

Ordinarily, during the summer, the position of the equatorial front is quite unpredictable, since it may be formed weakly and moved to the south off Peru, or may be completely absent. To the south, in the Gulf of Guayaquil, the surface temperature varies between 26^o and 28^oC. The isohalines tend to be orientated longitudinally, varying from 26.0 ppt in the inner part of the Gulf to 34.0 ppt in the outer, due to the river discharges into the estuary during this season.

The vertical distribution of temperature presents a sharp, shallow thermocline (maximum vertical temperature gradient) between approximately 10m and 20m depth, associated with the seasonal increase of solar heating and the weakening of the meridional winds during this time. The thermal gradient reaches values of up to 10° C/5m depth in some areas. In general, the water column is well stratified.

In winter, the presence of the intense equatorial front is the most important oceanographic feature. The front is identified by surface thermo-haline gradients between approximately 1°S (25°C-33.6 ppt) and 2°S (19°C-35.0 ppt) (Figures 4 and 5) and extends down to 30-40m depth. The seasonal position of the front is determined by a balance between the force of the Humboldt Current (induced by the meridional winds) and the horizontal hydrostatic pressure gradient generated across the front. Thus, any change in the strength of the wind in the region will produce a latitudinal displacement of the front.

During winter the subtropical surface water is displaced to the north relative to its summer position, in response to strengthening meridional winds and the Humboldt Current. To the south, in the Gulf of Guayaquil, the presence of relatively cold (21⁰-23⁰C) and saline (34.0-34.8 ppt) surface water indicates that river discharges into the estuary are lowest because it is the dry season.

Also at this time, the distribution of temperature and salinity throughout the water column presents strong thermo-haline gradients from 30m to 50m depth below a surface mixed layer. This mixed layer displays seasonal variations associated with the force of the meridional winds, being normally evident during winter.

The cold and saline water on the southern side of the equatorial front is also characterized by high nutrient concentrations. This water corresponds to the mixture between the subtropical surface water from the Humboldt Current and the underlying equatorial subsurface water which upwells to the surface south of 2°S. This upwelling process brings cold and nutrient-rich subsurface water up to the surface, giving rise to a higher productivity of the phytoplankton, which through successive links in the ocean food chain ultimately reaches the major fish populations.

Interannual Variability: The El Niño Phenomenon

Occasionally and quite unpredictably, extensive areas of the southeast Pacific Ocean, particularly off Ecuador and Peru, are subjected to an aperiodic influx of unusually warm surface water, commonly referred to as the El Niño phenomenon. These invasions of anomalously warm water, coming mainly from the north and/or from the west, produce dramatic changes in the local meteorological, oceanic and biological regimes. In this century, major El Niño events were recorded in 1925, 1929, 1939, 1941, 1953, 1957-58, 1965, 1972-73, 1976, and 1982-83.

During El Niño, warm water accumulates along the coasts of Ecuador and Peru and the upwelling of colder water seems to weaken. Fish stocks practically disappear, drastically reducing the catches of the fishing fleet and causing many marine birds, dependent on fish for food, to die of starvation. For example, during the 1972-73 El Niño event, the Peruvian anchovy (*Engraulis ringens*) catch dropped from over 10 million metric tons (m.t.) in 1970 and 1971, to approximately 4.5 million m.t. in 1973 (Caviedes, 1975). Also, the population of guano birds fell from 6.5 million in 1971, to 1.8 million in 1972 (Vildoso, 1976).

Moreover, the coastal areas suffer torrential rainfalls due mainly to an abnormal southward displacement of the intertropical convergence zone of the winds (ITCZ) during El Niño years. Disastrous floods cause severe damage to the crops of the region. The financial consequences of these events are catastrophic for the local fisheries, and the economic repercussions are adversely felt throughout the affected countries.

During the development of the last El Niño phenomenon (October 1982-July 1983), the entire coast off Ecuador was covered by very warm waters, up to 28^o-30^oC (Figure 6), and there was a remarkable increase in the stability of the water column that isolated the surface layer from the nutrient-rich water

below the thermocline. In fact, the thermocline was depressed to depths four times greater than normal, 80-100m. Since the major supply of inorganic nutrients to the euphotic zone is in water below the thermocline, it is clear that any process depressing the thermocline away from the surface layer, where there is enough light for photosynthesis, will necessarily reduce productivity (Barber and Chavez, 1983).

Another important feature observed during the development of the 1982-83 event, was the existence of a surface mixed layer. In normal conditions, there is no surface mixed layer in summer, however, during 1983, this layer was evident up to 30m depth. Because light decreases exponentially as a function of depth, the depth of the surface mixed layer determines the quantity of light that can be captured by the phytoplankton for the synthesis of organic material; less amount of light will be available to the phytoplankton as the surface mixed layer deepens. In this way, the supply of both nutrients and light was significantly reduced as El Niño progressed.

The subsequent decrease in phytoplankton productivity caused considerable disturbance to organisms of higher trophic levels, such as zooplankton, ichthyoplankton and fish. Small pelagic fish including mackerel, sardines and pinchagua did not spawn at normal rates, greatly reducing usual abundance (Garcia, 1983). The total catch for these fisheries dropped from over 180,000 m.t. during the first quarter of 1982 (prior to El Niño), to approximately 43,000 m.t. during the same period in 1983, and consisted almost exclusively of mackerel (Jimenez and Herdson, 1984).

The 1982-83 El Niño phenomenon had a great socio-economical impact on the coastal region of Ecuador, caused by a tremendous increase in rainfall, flooding and landslides, damage to transportation facilities, huge agricultural losses, in addition to disturbance of many coastal fisheries. The only commercially important sea resource that benefitted from the anomalous oceanographic conditions prevailing during this event was the shrimp fishery. The total catch reported by the shrimp fleet in 1983 increased by more than 200 percent relative to the previous years (Figure 7, McPadden, 1985).

Other Interannual Variations

Other kinds of interannual variability in ocean characteristics can also be related to fluctuations in some fisheries. For example, during winter 1985, the equatorial front was located further north than its normal limits, to about latitude 0^{0} (Figure 8). This shift in the front was associated with a strengthening of the Humboldt Current, which pushed its cold and saline waters further north than its usual limits, causing Ecuadorian coastal waters to be 2^{0} C colder than expected for this time of the year. The total catch of small pelagic fish (mackerel, sardines) was over 1 million m.t. in 1985, the highest annual catch ever registered (Figure 9). Sardines (*Sardinops sagax*) constituted 70 percent of the catches, surpassing mackerel for the first time (Maridueña, 1986).

In another instance, the advance of cold and saline subtropical water of the Humboldt Current towards the coast of Ecuador was observed in March 1986 and not at its usual time in May or June. This created important changes in the oceanographic conditions of the region, giving rise to the presence of waters 2^oC colder than expected for the season (Figure 10). This anomaly in the physical environment coincided with the presence of quantities of valuable Peruvian anchovies in Ecuadorian waters for the first time (Maridueña, personal communication). Considering the close relation between the distribution of these small pelagic fish and the circulation of the water masses in the region, long-term monitoring of such oceanographic changes could be invaluable.

Conclusion

The economy of Ecuador is strongly influenced by its fisheries, so that a better understanding of the climatic, ecological and economic implications of the variability in the oceanographic conditions of the region would provide a very important guide for long-range economic planning. Undoubtedly, the living resources of the sea respond directly and indirectly to these variations in their physical environment, as evidenced by past fluctuations in the composition and distribution of some of the most important fisheries. How and to what extent do these changes in the oceanographic conditions determine fluctuations that can cause the collapse of some fisheries and/or favor the development of others? Are these interannual variations of local or regional character? Do they occur more or less often than the El Niño phenomenon? These are some of the questions that have to be answered in the future to make management of Ecuador's living marine resources more successful and economically dependable.

Figure 1.- Area of the eastern tropical Pacific Ocean showing the different water masses involved in the study zone.



Figures 2 and 3.- Surface distribution of temperature (°C) and salinity (ppt) in February-March 1981, respectively.





Figures 4 and 5.- Surface distribution of temperature (^OC) and salinity (ppt) in August 1981, respectively

Figure 6.- Surface distribution of temperature (°C) in February 1983, during the development of the El Niño phenomenon.

Figure 8.- Surface distribution of temperature (^OC) in July 1985.

Figure 9.- Total annual catch of the small pelagic fish (mackerel, sardines, pinchagua) during the 1964-1985 period (source: Maridueña, 1986).

Figure 10. Surface distribution of temperature (^OC) in March 1986.

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