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The Gulf of California as a Large Marine Ecosystem

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ABSTRACT

Large marine regions characterized by unique bathymetry, hydrography and productivity, within which marine populations have adapted reproductive, growth, and feeding strategies constitute large marine ecosystems (LME) (Sherman and Alexander, 1986). The Gulf of California a semi-enclosed sea off the western coast of Mexico qualifies as a LME as it presents physical and biological characteristics not found in the adjoining Pacific. This area sustains the largest commercial fishery in the country which is the sardine fishery. The sardine population resident in the Gulf of California has coupled its reproductive and migration strategies to the environment of this region. Fluctuations of the sardine stock in the Gulf of California are caused by environmental changes and human activities within the Gulf. This paper presents the major physical and biological components of the Gulf of California and identifies the major source of change for the sardine fishery found in this LME.

1) INTRODUCTION

Oceanic areas sharing certain characteristics such as continuous topography, ocean currents and temperature variations are bound to support interrelated populations of fauna and flora that will be affected by seasonal environmental changes throughout the years. The interrelationship between the non-living and biological components of these areas allow them to become large marine ecosystems (LME). Sherman and Alexander (1986) have defined LMEs as relatively large regions of the world ocean, generally on the order of 200,000 square kilometers, characterized by unique bathymetry, hydrography, and productivity within which marine populations have adapted reproductive, growth and feeding strategies.

These authors, among others, have postulated that if the biological and physical characteristics of such systems are adequately monitored in the long term, the sources of pattern disruptions can be accurately identified as natural or man-induced. Today, virtually all ecosystems on earth are being impacted by human activities. As the world population grows and the demand for food and living space increases, human impact on nature will inevitably increase.

Over the years, ocean uses have increased from the traditional transportation and fishing activities to a diverse set of activities ranging from ocean mining to waste disposal. In the past, management of marine areas has been mostly focused on single processes and managerial strategies applied to single species, mainly commercial ones. The study of all major biological and physical interactions within a established ecosystem seeks to grasp a better understanding of fluctuation patterns affecting the system.

By long term monitoring of key physical, chemical and biological processes, natural variability patterns can be successfully identified and human impact can be more accurately measured, thus a LME becomes a manageable entity. A comprehensive management approach based on the total ecosystem model is emerging today as a new rule of customary international law (Belsky, 1990).

A major shift that management of natural resources has undertaken in the past decades is the acknowledgment that no longer can one look at a single process or species individually. For example, when determining stock abundance of a commercial species its trophic interaction with other species must be considered in order to obtain reliable estimates (Bax and Laevastu, 1990).

Sherman (1990), identifies 18 LMEs throughout the globe, all of them encompassing the 200 mile Exclusive Economic Zone (EEZ). It is within the EEZs that over 95 % of the world fish catch occurs today. Therefore, the importance of monitoring the impact of changes brought upon the system in this area by human or environmental causes cannot be overlooked.

This relatively new approach to the management of large marine areas emphasizes the delicate balance present in ecosystems in general and underlines certain key issues necessary for its success. Among them are the following:

A) Long Term Specific Studies.

The recording of accurate and relevant data over a long period of time is crucial to the sorting out of environmental patterns and man-induced changes that may impact LMEs. Daan (1986), stresses the importance of specific and detailed studies over time to understand and possibly postulate future changes in fish stocks in the North Sea. This author reports that although abundant information is available regarding fish catch data from the North Sea, specialized studies, such as prey-predator relationships within this ecosystem are essential to be able to test existing theories regarding these fisheries. Levin (1990) and Ricklefs (1990) go one step further and stress the complexity of identifying not only adequate temporal scales but also spatial scales in which physical and biological processes occur within a given ecosystem. These authors observe that many patterns of marine biological activity parallel patterns in the physical environment and that local processes are always immersed in a set of larger scale processes. Thus, within a management plan the setting of priorities is influenced by the scale under which the plan will work.

B) Interdisciplinary Approach.

It is now recognized that management strategies for LME cannot stem solely from the fish biologists. As Alexander (1990) observes, management of LMEs concerns the natural scientist as much as the economist and the lawyer. As an example he mentions jurisdictional patterns found in LMEs shared by several states such as the North Sea LME. In this case the northeast and east central parts are under Norwegian jurisdiction while the rest is managed by the European Economic Community's Common Fisheries Policy. This author notes, that for most LMEs under two or more states' jurisdictions, cooperative management strategies are difficult to achieve.

C) Unifying Concepts in LMEs.

Bakun (1986) and Sherman (1990) stress the importance of identifying major processes within LMEs in order to identify the predominant variable acting upon the system. Sherman (1990) reports controlling variables affecting fish stocks (from both environmental and human caused changes) in eleven LMEs. An example is the increment in coastal pollution in the Baltic ecosystem that seems to be the cause for changes in coastal productivity.

The concept of a large marine ecosystem is not a simple one. As Alexander (1990), points out ... "are the boundaries between systems clearly defined?"... The LMEs identified by Sherman (1990) are all undergoing outside pressures such as overfishing, pollution or environmental fluctuations. Therefore, the organisms living in such systems are undergoing changes, such as fluctuations in the species composition of a certain area or a decrease in the number of organisms present in a certain population. These changes can be detected and measured. The detection of biomass fluctuations as well as seasonal changes in physical characteristics has helped set boundaries in LMEs. One may ask then, are these boundaries fixed or do they fluctuate with time? Under what parameters can one identify an open ocean LME where the stress on the biomass is impossible to quantify, or is there no such thing? Is a LME merely a management unit? Detailed monitoring of the areas now identified as LME over a substantial time span may help clarify these points in the future.

Perhaps the most important issue that LMEs address is the indisputable fact that integrated management is essential if managerial options are to work for a certain area (in this case LMEs) withstanding the test of time. This realization gives the LME concept enormous importance and completely modifies present ocean management techniques that utilize the one species approach. Multispecies relationships such as prey/predator interactions, coupling of physical and biological characteristics, and the realization of the time and spatial patterns present are issues that need to be considered within successful managerial strategies (Bax and Laevastu, 1990; Levin, 1990).

The Gulf of California, between the Baja California peninsula and the states of Sonora and Sinaloa in western Mexico constitutes as enclosed sea, roughly 240,000 Km^2 with intrinsic characteristics, not present in the adjacent Pacific, and with a large pelagic fish fisheries currently under strong overfishing stress. The purpose of this paper is to present the biological and physical characteristics of this LME and to identify the main sources of stress present in this area.

2) THE GULF OF CALIFORNIA

A. General Characteristics.

The Gulf of California or Sea of Cortez is a narrow semi-enclosed sea roughly 150 by 1600 kilometers in the northwest of Mexico. It is surrounded by arid and mountainous regions having the states of Sonora and Sinaloa to the east and the peninsula of Baja California to the west. These arid lands around it strongly influence climatic patterns in the Gulf. A range of high mountains in the Baja California side, from the Sierra de San Pedro Martir facing the northern portion of the Gulf to the Sierra de San Lazaro at the tip of the Gulf shield the Gulf of California from the moist Pacific breezes making it a large evaporation basin (Figure 1) (Brusca, 1977; Thomson et al., 1979).

Sediment deposits from the Colorado river make the northern portion of the Gulf, north of the Midriff Islands (Angel de la Guarda and Tiburon Islands) shallower than the rest with maximum depths of around 450 meters (Alvarez-Borrego and Lara-Lara, 1989). Here there is a strong tidal component due to resonance with the semi-diurnal tides that enhances water mixing (Bray and Robles, 1989).

A large portion of the land around the head of the Gulf consists of coastal plains formed by sediments from the Colorado river delta. The sediment deposits extent a little past the Midriff Islands reaching, in some areas, 5000 meters in thickness (Brusca, 1977). Deltaic and marine deposits reaching 5700 meters in depth have been identified in the Imperial Valley and northern Gulf of California area. With the creation of Hoover Dam in 1935, in order to provide irrigation for the Imperial Valley, there has been a drastic cut in the flow of the Colorado river into the Gulf. This has reduced the volume of Colorado river waters from over 500 m^3/sec to an entirely subsurface flow that constitutes an unknown percentage of freshwater inflow (Brusca, 1977; Maluf, 1983).

The central and southern parts of the Gulf are characterized by steep cliffs, high ridges and v-shaped basins with sills as deep as 1500 m (Maluf, 1983; Alvarez-Borrego and Lara-Lara, 1989). Workers studying the Gulf of California still disagree as to where the southern boundary lies. In this paper, Cabo Corrientes will be considered the entrance to the Gulf because of the complex physical characteristics associated with the confluence of three currents that separate Gulf from Pacific waters. This point will be discussed later.

The central and southern coasts of the Baja California Peninsula and most of the Gulf islands consist of rocky shores while the mainland coast is formed by gentle sloping sandy beaches with occasional rocky headlands. Both coasts have a variety of habitats as estuaries, mangrove swamps and salt marshes which allow for a high diversity of fauna and flora (Thomson et al., 1979)

The Gulf of California presents unique physical and biological characteristics that are not found in the adjacent Pacific Ocean. It is a highly productive area and counts with two of the most important fisheries in Mexico, the shrimp and the sardine fisheries. Both these fisheries complete their life cycles within the Gulf and couple their biological processes to the pelagic environment of the area (Instituto Nacional de Pesca, 1988; Huato-Soberanis and Lluch-

Belda, 1987).

Management of marine resources in the Gulf of California is minimal and nonexistent in many areas. Although federally protected areas are present in the Gulf of California other interests, such as tourisms and fishing activities, predominate over conservation strategies (Merino, 1987).

B. Origin.

A number of authors place the spreading and northwest drift of the Baja California Peninsula and thus the creation of the Gulf of California during the Tertiary period of the Cenozoic era, around 4.5 million years ago (Pliocene epoch). Among them, Gastil et al. (1983) place the initial spreading axis around the Midriff Islands of the Gulf, east of Isla Angel de la Guarda.

Paleontologic data indicates that the northern Gulf dates as far back as the Miocene and is older than the central and southern portions. It is believed that originally the Gulf consisted of a shallow and narrow southern portion adjacent to a deeper northern basin. North to south spreading processes eventually gave rise to the southern Gulf (Brusca, 1977).

C. Physical Characteristics of the Gulf of California.

Thermohaline Circulation

As mentioned previously, the Gulf of California acts as a large evaporation basin which allows for a high salinity, warm water mass with a vertical thermohaline circulation. In spite of evaporation exceeding precipitation, a net gain of heat from the atmosphere has been shown to occur in this area (Bray and Robles, 1989). These authors report that the net heat gain is large enough to compensate water buoyancy loss due to evaporation rates that reach levels of 1 meter per year in the open Gulf. Thus, the thermohaline circulation in the Gulf of California is opposite that of other semienclosed seas of similar latitude such as the Mediterranean and the Red Sea. In the Gulf there seems to be a thermohaline circulation with a deep water inflow and a shallow outflow. The deep inflow from the nutrient-rich Pacific waters contributes to the high productivity values found in Gulf waters (Alvarez-Borrego and Lara-Lara, 1989).

Wind driven Currents

The movement of water masses in the Gulf is affected by the heat and moisture air sea fluxes (responsible for the thermohaline circulation) as well as by the wind and tides. The wind field over the Gulf has a strong influence over surface currents and distributes surface water properties through upwellings. The wind is channeled by the mountain ranges found both in the mainland side and the Baja California peninsula (Bray and Robles, 1989). However, shelf currents on the mainland side of the Gulf and south of the Midriff Islands seem to be influenced more by very large-scale shelf waves than by wind action. These shelf waves are generated south of the Gulf (Bray and Robles, 1989).

Baumgartner and Christensen (1985), report that two wind-driven current systems, the North Pacific gyre and the equatorial system, influence the sea level climate in the Gulf. In the springtime there is a strong North Pacific gyre that spreads California Current water across the mouth of the Gulf while the weaker equatorial system retrieves to the south. In the fall the North Pacific gyre weakens and a strong equatorial countercurrent reaches the entrance to the Gulf. At this time a strong Costa Rica current extends to the north and also reaches waters at the entrance of the Gulf. These two systems are regulated by the El Nino/Southern Oscillation phenomenon and eventually determine the source of surface and near-surface water available for exchange with the Gulf.

The area where this complex water mixture occurs is between the tip of the Gulf and Cabo Corrientes. Because the waters in this area influence the water composition of the Gulf, the Cabo Corrientes area is, in this paper, considered the southern end of the Gulf of California. Cabo Corrientes is roughly 500 kilometers south of the tip of the Baja California peninsula.

Tides

Tidal energy in the Gulf is significant and provides enhanced water mixing (Bray and Robles, 1989). This is not true of most enclosed seas. However in the Gulf of California, especially in the northern section, the semi-diurnal tide can reach spring ranges of 10 m. Tides are mainly forced by co-oscillation with the Pacific Ocean and resonance of the semi-diurnal component. This remote forcing of the tidal pattern seems to be related to the relatively unrestricted bathymetry found at the mouth of the Gulf. Gravitational forcing (ie. locally generated) has only a small influence (around 3%) on the tidal amplitude in the Gulf. As a result of tidal action, large tidal currents are present in the Gulf specially around the midriff islands providing vigorous water mixing (Alvarez-Borrego and Lara- Lara, 1989; Bray and Robles, 1989).

Salinity and Temperature

Surface salinities in the Gulf vary from 35.0 to 37.0 parts per thousand in the northern Gulf where evaporation can reach values of 1 m/yr (Bray and Robles, 1989; Maluf, 1983). Because of its relatively small size, the Gulf does not influence the climate of the land mass around it. On the contrary, the surface temperatures found in the Gulf are more continental than maritime. The annual surface temperature range is large with a difference of 9 °C at the mouth and of approximately 22 °C at the head (Alvarez-Borrego and Lara-Lara, 1989). During the months of October to March, temperatures in the Gulf are equal to similar latitudes of the neighboring Pacific but during spring and summer months the Gulf exhibits higher surface temperatures. During the summer, the isotherms run parallel to the Gulf with surface water temperatures reaching 29.5 °C on the mainland coast, southeasterly winds dominating and upwellings along the Baja California Coast. During the winter, higher temperatures are found in the Baja California coast, northwesterly winds predominate and upwellings occur around the Guaymas and Yavaros area (Alvarez-Borrego and Lara-Lara, 1989; Hammann et al. 1988, Robinson, 1973) . Bray and Robles (1989) indicate that temperature and salinity are affected by El Nino Southern Oscillations Event (ENSO). However, these authors report that the Temperature/Salinity (T/S) curve is not affected per se but rather the depth of a given T/S relationship varies during an ENSO year. These changes occur in the top 500 m of the water column affecting temperature and nutrient concentrations.

Upwellings

As mentioned before, coastal upwellings occur in both coasts of the Gulf of California. In the winter, strong coastal upwellings are found in the mainland coast and are associated with persistent northwesterly winds of about 10 m/sec (Bray and Robles, 1989; Hammann et al., 1988). During the summer months, southeasterly winds cause weaker upwellings on the Baja California side (Fig. 2). Schrader and Baumgartner (1983) have documented decadal variations of the upwellings on the coast of Guaymas, Sonora (central Gulf). By comparing silicoflagellate population changes in samples taken from slopes in the Guaymas basin, they have been able to estimate the productivity levels of the last 500 years in the central Gulf. These authors suggest that at present, the Gulf of California is going through a period of decreased productivity (relatively speaking) with a slight decrease in upwelling intensity after 1955.

D. Biological Characteristics of the Gulf of California

Productivity

Productivity is defined as the amount of carbon fixed by autotrophs, mainly through photosynthesis, as organic matter is synthesized mainly from inorganic material. The Gulf of California seems to have ideal conditions that lead to high productivity values.

These characteristics include relatively shallow waters rich in nutrients and with low dissolved oxygen values. Strong tidal mixing in the northern Gulf that stir Colorado River sediments that have accumulated for decades also contribute to the high productivity values of the area. The general water circulation in the Gulf also promotes high nutrients in this area as deep nutrient-rich waters flow into the Gulf and are brought to the euphotic zone where photosynthesis occurs (Maluf, 1983; Alvarez-Borrego and Lara-Lara, 1989).

Primary productivity values for the Gulf are around 1 gram of carbon per square meter per day and sometimes >4 grams of carbon per square meter per day. The Guaymas basin produces the highest values (Alvarez-Borrego and Lara-Lara, 1989). Although primary productivity seems to reach its peak values during late spring and the beginning of summer, Alvarez-Borrego and Lara-Lara (1989) report that adequate seasonal or interannual variability values for the Gulf are not possible to compile due to the scarce primary productivity data. However, these authors report that nutrient concentrations increase from the mouth to the interior of the Gulf. The input of nutrients into the Gulf via rivers is minimal and affects only coastal areas. In the Baja California peninsula there is only one very small river at Mulege (around 27 degrees north). On the mainland, most of the rivers have dams that channel their waters into agricultural areas (Merino, 1987).

Biomass in the Gulf of California

A large species diversity can be found in the Gulf of California due to its varied habitats and high productivity levels. Walker (1960) conducted an analysis of the fish present in the Gulf of California and concluded that around 85 to 90 % of the actual fish fauna consisted of 586 species. He also found 92 shallow water species as endemic to the Gulf. A large diversity of crustaceans, molluscs and marine mammals are also present in the Gulf. In general, the neritic species of the Gulf are characterized as having a high diversity, low volume and high economic value while the oceanic species are not as diverse, are present in large volumes and have a low economic value (Arvizu-Martinez, 1987).

The commercial fisheries present in the Gulf of California are extremely important to Mexico. The states of Sonora and Sinaloa alone provide 42 % of the total catch for the country (1,394,175 metric tons) (SEPESCA, 1990). Because of the lack of fresh water on the Baja peninsula, the main ports and processing plants are found on the mainland side, the port of Guaymas being the most important.

Commercial fishing in the Gulf of California started at the beginning of the century when Totoaba (Totoaba macdonaldi), now a protected species, was fished mainly for its stomach which was in high demand in the Chinese market. Eventually, other important fisheries developed in the Gulf and fishing ports, mainly in the mainland side, were established (Arvizu-Martinez, 1987).

This paper will expand on the largest (in volume) fishery in the Gulf, the sardine fishery, and will emphasize the strong coupling between this particular fishery and the physical environment of the Gulf.

The sardine fishery in the Gulf of California accounts for the largest catch in the country (Figures 3, 4). In 1986, 469,000 tons of sardine were caught (approximately 85 % were caught in the Gulf of California) representing more than thirty percent of the national catch (Figure 5) (Robles, 1988; SEPESCA, 1987). Eighty percent of the sardine caught in the Gulf is Monterrey sardine (Sardinops sagax caerulea) with thread herring (Ophistonema spp.) and Japanese sardine (Etrumeus seres) following in importance. Eighty percent of the total sardine catch is directed toward fishmeal production while the rest is canned for human consumption (Robles, 1988; Cisneros Mata, 1988).

Commercial fishing for the Mexican sardine started when the California sardine stock dropped during the thirties. At that time the fishery moved to the area between Ensenada and Isla Cedros on the Pacific side of Baja California. In the fifties, the sardine fleet moved further south to Bahia Magdalena in the state of Baja California Sur. Finally in 1967, with the discovery of large sardine schools in the Gulf of California, fishmeal plants were established in the port of Guaymas in the state of Sonora. Guaymas is now the main sardine port in Mexico (Instituto Nacional de Pesca, 1987).

Sardine fishing in the Gulf of California expanded tremendously in the mid-seventies when new oil revenues made foreign loans accessible to the country. Furthermore, Mexico established its 200 mile Exclusive Economic Zone in 1976 and new legislature promoting fisheries development was enacted. This boost in the fishing industry was aimed at providing an additional source of protein to the rapidly growing population as well as providing foreign exchange through fish exports (World Bank Report, 1989).

Today there are approximately 70 purse seiners operating in the Gulf of California. Most of the boats have holding capacities between 100 and 200 tons and around 70 % of the fleet is owned by the Mexican government. Most of the fishing effort for the sardine occurs in the eastern Gulf around the Guaymas area (Lluch-Belda et al., 1986).

The Monterrey sardines of the Gulf of California stay inside the Gulf during their life cycle. Lluch-Belda et al. (1986) consider the sardine found in the Gulf of California as a group isolated from other sardine sub-populations.

Sokolov (1974) and Hammann et al. (1988) report a strong coupling between the Monterrey sardine biomass and the environmental characteristics of the Gulf. The latter suggest that the general migration pattern of the sardine within the Gulf is coupled to the seasonality of near surface temperature and by Gulf circulation patterns. Adult Monterrey sardines feed in the summer and early fall in the northern Gulf and migrate south along the eastern coast towards their spawning grounds. Spawning takes place during the winter preferentially in areas of strong upwellings such as the Guaymas and Yavaros areas. The adults then return to the northern section of the Gulf. During the spring months, when winds become stronger, jets of cool upwelled water cross the Gulf from east to west carrying with them eggs and larvae. During late spring and summer the circulation pattern changes and southeasterly winds produce upwellings in the western Gulf. It is in this area where nursing grounds for young sardine are found. Eventually the juveniles migrate north along the western coast and join the adult population in the north thus closing the cycle (Hammann et al., 1988; Sokolov, 1974).

The Monterrey sardine population of the Gulf of California has developed a migration pattern that is aided by the natural surroundings. Gravid females concentrate in areas of strong upwellings to enhance the transport of their eggs and larvae to the western shores of the Gulf. Water temperature also influence the reproductive cycle. In the areas around Yavaros and Guaymas the average water temperature in January is around 17.5 °C (Cisneros-Mata et al., 1987). Tibby (1937) reports optimum spawning temperatures for Monterrey sardine found in the California coast to be between 15 and 18 °C.

It has been shown that fluctuations of the Monterrey sardine fisheries in the Gulf are correlated to the El Nino/Southern Oscillation phenomena. Holtschmit (1977) found that there was a strong inverse relationship between December water temperatures and sardine availability during the same season. Lluch-Belda et al. (1986) presented a more complete hypothesis. They propose that the southernmost movement of the sardine population during the winter (when the fishing season starts) depends on three main factors: The intensity of the upwelling present along the eastern Gulf shores, the seasonal cooling of Gulf waters and the southern flow of surface waters. Therefore during warmer years, such as during El Nino events, the range of the Gulf sardine is restricted to northern areas (around Tiburon and Angel de la Guarda Islands) and thus the availability to the fishery is reduced. The same authors report that during cold seasons the catch per unit effort (CPUE) is higher for Monterrey sardine. It is important to note that warmer water temperatures result in higher CPUE of Opisthonema spp. the next most important fishery in this area.

Huato-Soberanis and Lluch-Belda (1987) have compared cyclic fluctuations in mean sea-level and sea surface temperatures of northeastern Mexico to Gulf of California sardine fishery data. They report that 5 + years cycles in mean sea surface temperatures and mean sea level associated with the ENSO phenomena are mirrored by cycles in the average length of sardine caught in the Gulf of California. This would indicate an effect of ENSO on sardine stock recruitment.

Data on the rate of Monterrey sardine stock recruitment for the Gulf of California is not known (Hammann et al., 1988). The size of the present stock as well as the relationship of the sardine population with other pelagic species is also unknown (Robles, personal communication). In 1974, Sakolov estimated 200,000 metric tons of adult Monterrey sardine in the Gulf of California. He then concluded that the maximum catch per season should not exceed 25% of the total adult population, ie. 50,000 tons. In 1986, Olvera Limas and Padilla Garcia concluded that, based on amounts of sardine eggs collected, the biomass for adult Monterrey sardine in the Gulf of California was 343,142 metric tons. The World Bank Report of 1989 suggests that the Monterrey sardine fishery in the Gulf is being sustained by the 1-2 year old population in the last seasons. This contrasts the fact that in the early eighties the fishery seemed to be sustained by the 2-5 year old individuals. This report estimates the maximum potential sardine catch at around 220,000 metric tons per season. Today the main parameters known to affect sardine recruitment and thus landings are anomalies related to the ENSO phenomena and fishing effort found in the Gulf of California which has doubled from the mid seventies to the present day (Lluch-Belda et al., 1986; Huato-Soberanis and Lluch-Belda, 1987).

3) RESOURCE MANAGEMENT IN THE GULF OF CALIFORNIA

The management of resources in the Gulf of California is mainly regulated by two governmental institutions: The Ministry of Fisheries (Secretaria de Pesca) and the Ministry of Urban Development and Ecology (SEDUE). Fishing regulation within the Gulf of California is under the jurisdiction of the Ministry of Fisheries (Merino, 1987).

Only in the past five years has the sardine fishery being regulated. In 1967 only three boats were involved in the fishery with a total annual catch of 126 tons (Robles, 1988). In the next years the number of boats increased rapidly but according to Lluch-Belda et al. (1986) until 1969-70 the number of boats involved in sardine fishing within the Gulf of California was not reliable. Through 1977 the sardine boats had small holding capacities and no ice or refrigeration for preservation purposes.

During this time boats fished from October-November through May-June and only along the eastern Gulf, close to the ports of Guaymas, Sonora and Yavaros, Sinaloa. From 1977 to 1983, 30 boats were added to the fleet representing a 75 percent increase in number. However this addition represented a large increase in fishing capacity as these were larger boats with refrigeration systems that could preserve fish and did not need to unload on a daily basis. These larger boats also increased the fishing area and were able to fish in the northern Gulf around Tiburon and Angel de Is Guarda islands. These changes increased the 1979-1980 Monterrey sardine catch by 169 percent from the previous year. Since 1982, the summer months were also added to the fishery and eventually the sardine fishery was carried out throughout the year (Lluch-Belda et al., 1986).

During the development of the sardine fishery in the Gulf of California, numerous biological studies were done to determine biomass available, average size of the catch, distribution of eggs and larvae and fecundity of the adult female population. However not until the mid eighties was data considered in an effort to establish a closed fishing season. Robles (1985) analyzed information collected by the National Institute of Fisheries (within the Ministry of Fisheries) and concluded that the average size of the Monterrey sardine caught had diminished from approximately 172 mm in the 1972-173 season to around 142 mm in the 1985-1986 season (Figure 6). The data also showed that while in 1973, 50% of the catch consisted of individuals over five years old, in the 1983-1984 season 60 % of the catch consisted of 2 year old individuals with no sardines over 5 years old being caught (Figure 7). These conclusions led to the realization that the average size of Monterrey sardine caught was under the reproductive recruitment size and thus the catch consisted mainly of juveniles. As it would be impossible to enforce a close season for Monterrey sardine only in certain areas of the Gulf of California, because of lack of personnel to enforce and supervise the procedure, Robles suggested a closed season for the whole Gulf during the summer months and a strict enforcement of the established minimum size (150 mm). In 1986, the National Institute of Fisheries, a federal research organization, proposed a closed season for all sardine species caught in the Gulf of California from July 26 to October 2. A closed season has since been implemented during the summer months and early fall. However, in the past season (1989-1990), Robles (personal communication) reports that the total sardine catch in the Gulf has been much lower than previous years while the amount of anchovy in the catch has increased. This may indicate fluctuations of pelagic populations in the area possible due, among other factors, to overfishing.

Protection of coastal and marine areas are placed under the jurisdiction of the Ministry of Urban Development and Ecology (SEDUE) with central offices in Mexico City and state offices in each state. However, state offices must count with the approval of the main SEDUE headquarters in Mexico City before carrying out their respective environmental regulations. SEDUE oversees the creation and management of parks as well as regulating the type of activities allowed within protected areas (Merino, 1987; Silva and Desilvestre, 1987).

Merino (1987) divided the Mexican coast and marine areas into 7 regions according to types of resources found in each region as well as to environmental characteristics. He divided the Gulf of

California into two sections. The first one, Region III, comprises the Baja peninsula side and roughly half of the Gulf including two federally protected areas. These are the Islas del Golfo de California National Park (established in 1978) and the Isla Rasa National Park (established in 1964). These areas were set apart for marine environment research purposes and as nesting sites for waterfowl respectively. Two protected areas are also found in Region IV which includes the eastern part of the Gulf and the coastal areas of the states of Sonora, Sinaloa and northern Nayarit. These are the Isla Tiburon Underwater Refuge (established in 1963 as an example of desert shrub/marine environment) and the Isla Isabel National Park (established in 1980 as a Pacific Island ecosystem). No management plan has been written for any of these parks while tourism and recreational fishing increase rapidly in these "protected areas. The fact that protected marine and coastal areas have been created does not assure their protection. Mexico's political, cultural and economic realities often hinder adequate managerial strategies (Merino, 1987; Chavarria, 1988).

4) CONCLUSIONS

The Gulf of California constitutes a LME in the western coast of Mexico. The Gulf can be designated as a LME because of its unique physical characteristics not present in the neighboring Pacific waters and also because of its endemic fauna and strong fisheries present. It is an area of high productivity that comprises a number of diverse habitats such as upwellings, estuaries and sandy and rocky beaches.

Sherman and Alexander (1986) base the designation of LME not only on biological and physical criteria but also on geopolitical, legal and economic considerations. Because it is a semi-enclosed sea within the country of Mexico, the Gulf of California is solely under this country's jurisdiction.

Sherman (1990) identifies the main sources of fish population fluctuations in 11 LME that have been studied by several authors. In six of these (the Oyashio Current ecosystem, the Kuroshio Current ecosystem, the Humboldt Current ecosystem, the California Current ecosystem, the Iberian Coastal ecosystem and the Benguela Current ecosystem) the changes have been attributed to environmental fluctuations. In the Great Barrier Reef ecosystem predation by the crown of thorns starfish is considered as the main stress factor while in the Baltic ecosystem, extensive pollution seems to be the cause of productivity variability. Human predation, ie. recruitment overfishing, has been responsible for fish population fluctuations in the Gulf of Thailand, the Yellow Sea ecosystem and the U.S. Northeast Continental Shelf ecosystem.

The sardine fishery in the Gulf of California is the largest (in volume) in the country. The sardine stock is susceptible to cyclic temperature fluctuations that accentuate their effect during ENSO years. The sardine fishery has also, since the mid seventies, undergone extensive overfishing stress. In the case of this LME the principal source of sardine population change appears to be the overfishing of juveniles that has occurred during the last decade. Data from the last sardine fishing season is not yet available but workers in the area indicate that sardine landings have decreased significantly (Robles, personal communication).

What has been the role of temperature fluctuations in the changes of sardine stocks as compared to overfishing is impossible to know. Preliminary studies in the Gulf of California relating physical and biological parameters have only recently been conducted. These studies report the coupling of the Monterrey sardine migration to environmental factors.

Lax and Laevastu (1990) observe that mortality from fishing is only a fraction of the total fish mortality and stress the importance of the multispecies analyses approach to point out major sources of mortality for each species. These authors emphasize the importance of predator-prey relationships and demonstrate techniques currently available in estimating fish population fluctuations. Although there is extensive literature concerning the biology of the sardine stock in the Gulf of California no integrated studies have been conducted to determine the present state of the stock.

As mentioned previously, unless data is collected over a certain period of time naturally occurring patterns within an ecosystem cannot be determined. Data collection in the Gulf of California is recent and related only to basic physical and biological aspects.

The Gulf of California is a LME where human activity is increasing in the form of recruitment overfishing and expansion of tourism. The lack of appropriate enforcement agencies in the area hinder the conservation of federally protected areas. Effective managerial approaches are needed in the near future to preserve pristine areas within the Gulf and to regulate excessive resource exploitation. The 1982 United Nations Convention of the Law of the Sea (UNCLOS) emphasizes a comprehensive ecosystem approach to ocean management that fits within the LME concept. Furthermore, workers such as Belsky (1990), recognize the fact that it is now customary law that nation-states apply an ecosystem approach both in their domestic and multinational arrangements. Although the legislation dictating such approach may be present in less developed countries such as Mexico, economic and political factors may hinder the enforcement of management regulations.

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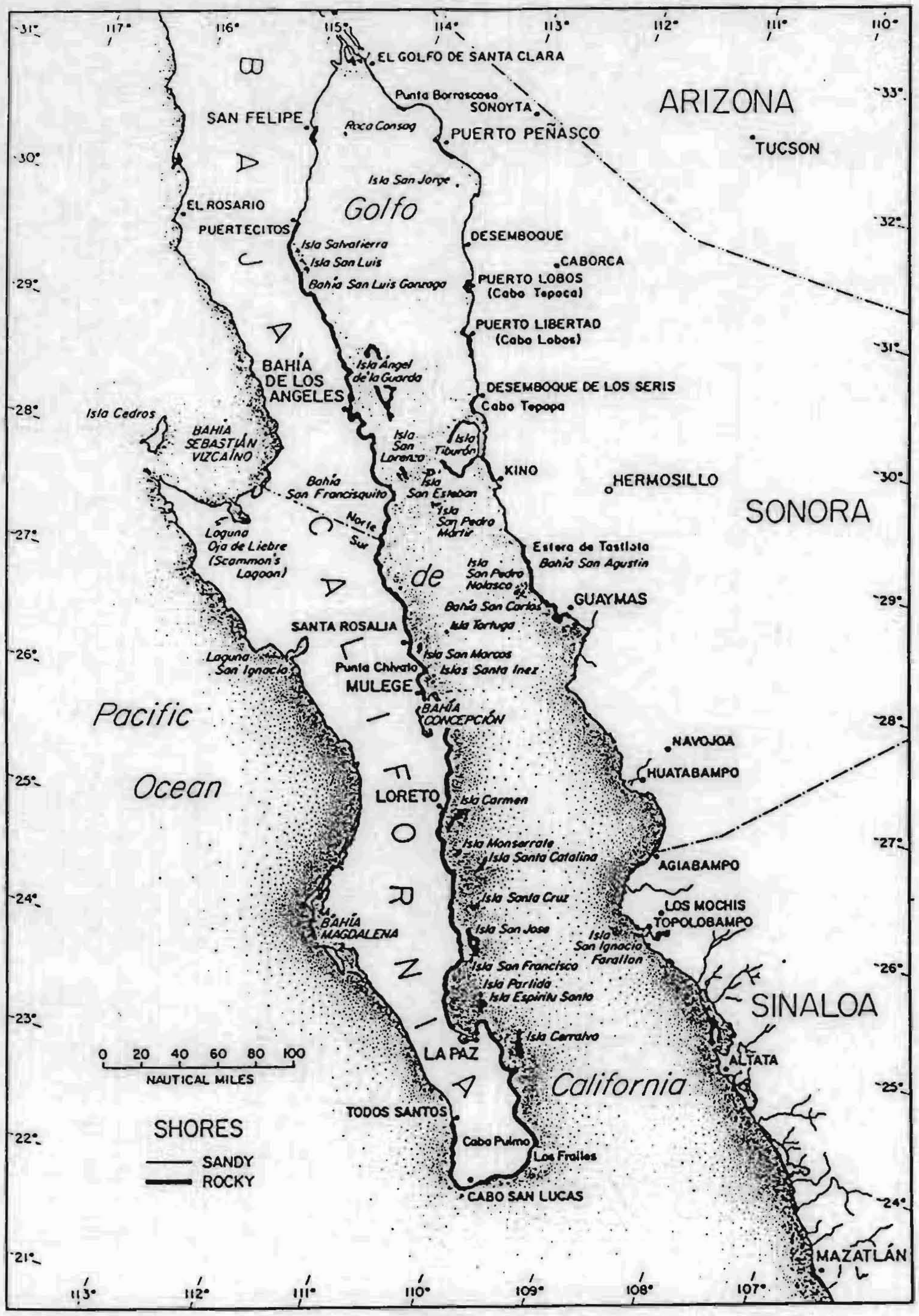


Figure 1. The Gulf of California
(Thomson et al., 1979)

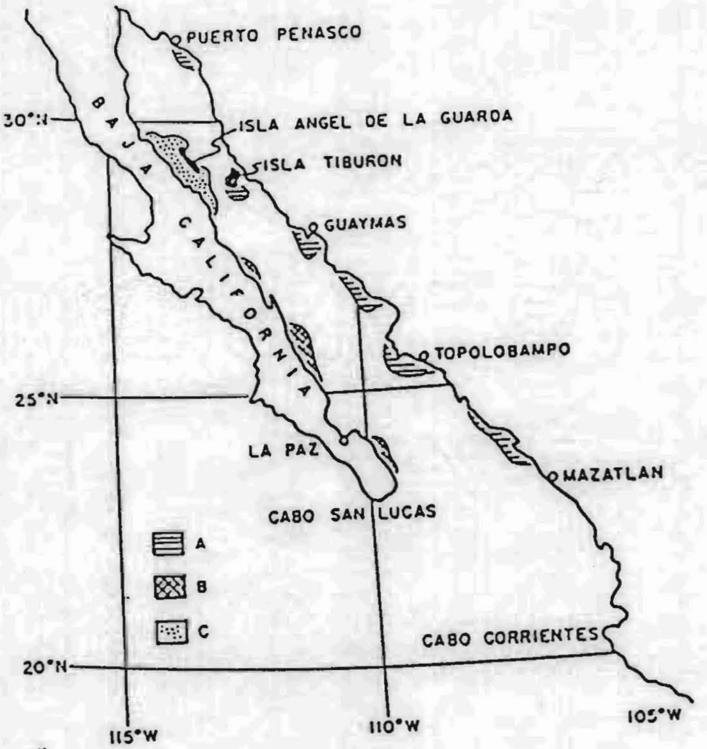


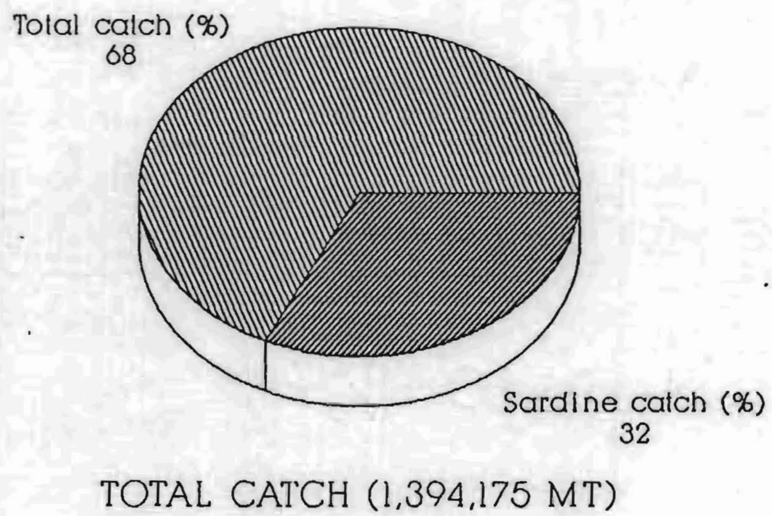
Figure 2. Upwelling Patterns in the Gulf of California

A) With northwesterly winds
B) With southeasterly winds
C) Area with strong tidal mixing

(Bray and Robles, 1989)

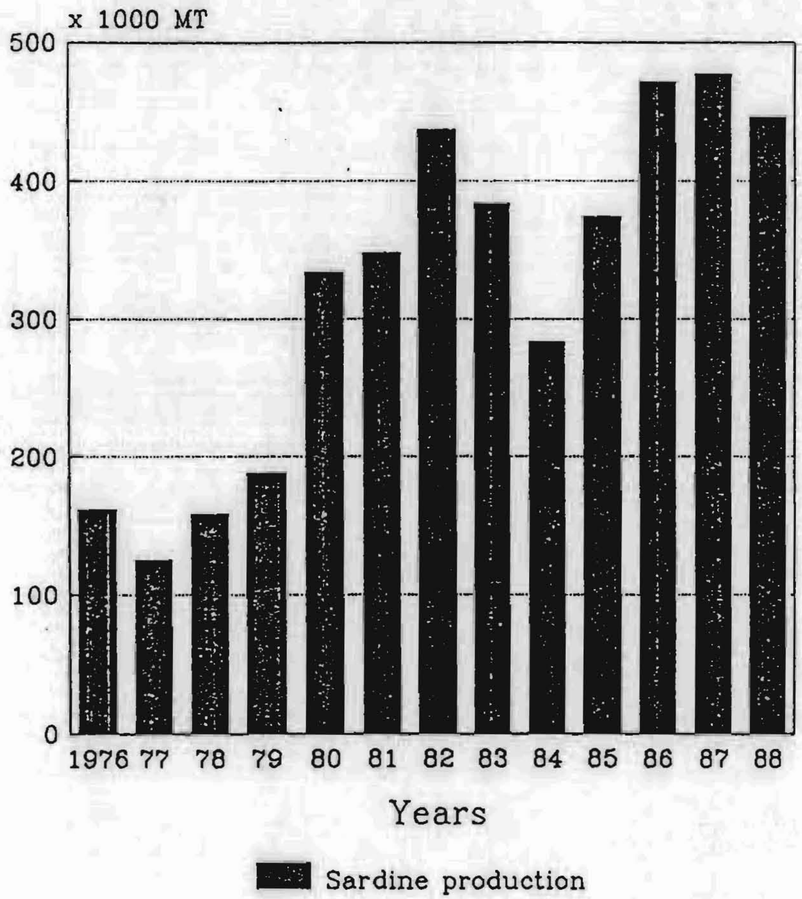
Figure 3. Sardine vs Total Catch

Approx. 85% of sardine is caught in Gulf of California



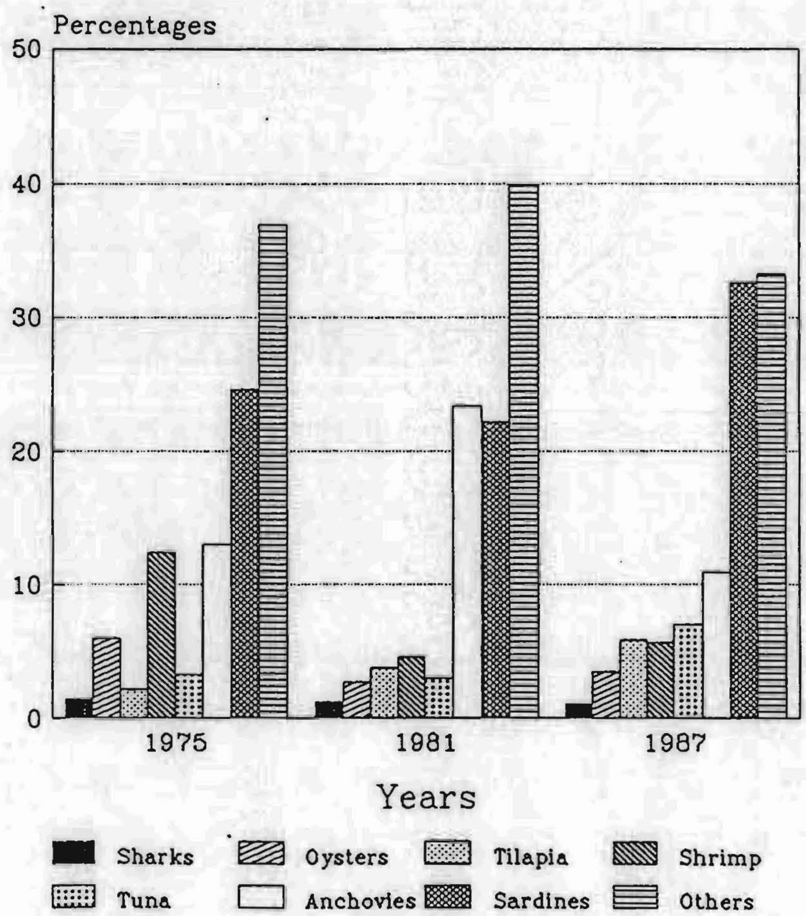
Values for 1987/88 season (SEPESCA 1990)

Figure 4. Sardine Production in Mexico (Metric Tons)



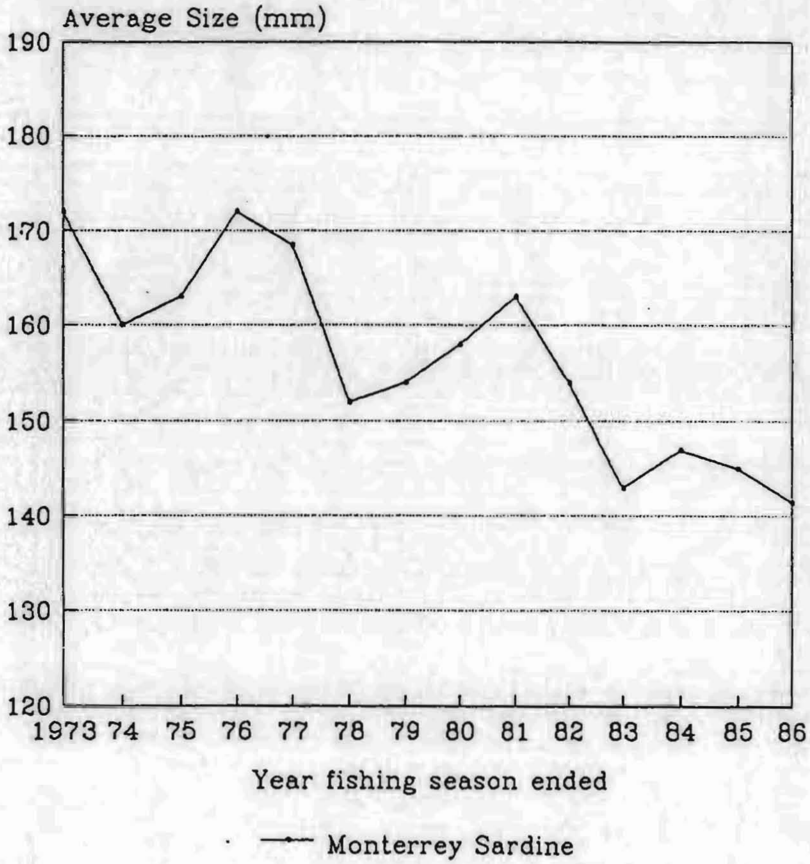
(SEPESCA 1890)

Figure 5. Relative Importance of Species Caught (Selected Years 1975-1987)



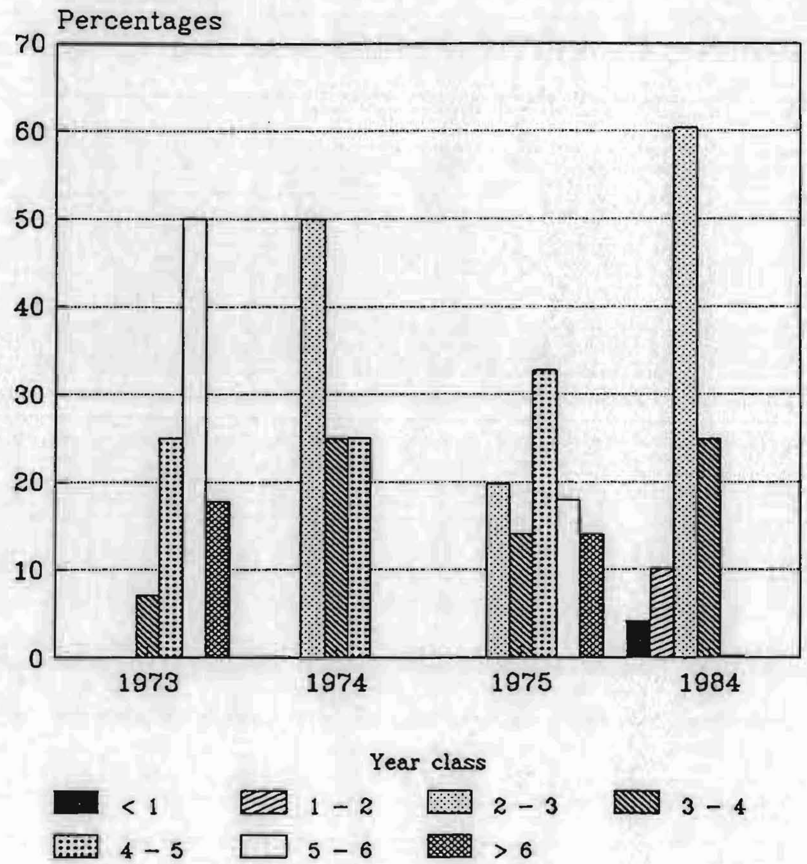
(SEPESCA, 1987)

Figure 6. Average Size of Monterrey Sardine Caught in the Guaymas Area



Data for 1986 represents average size
for months of Oct.Nov.Dic.
(INP, 1986)

Figure 7. Age Frequency of Monterrey Sardine According to Year Classes



(INP, 1986)
Data corresponds to the Guaymas area