


CONSERVATION SCIENCE IN MEXICO'S NORTHWEST

ECOSYSTEM STATUS AND TRENDS IN THE GULF OF CALIFORNIA




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EDITORS


SEABIRDS AND PELAGIC FISH ABUNDANCE IN THE MIDRIFF ISLANDS REGION

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Small pelagic fish are food for many marine species. We show that diet and reproduction of seabirds are coupled to oceanographic conditions. This information is used to predict the outcome of fishing efforts several months in advance of the onset of fishing season. The proportions of each fish species in the diet of three seabird species, were found to be closely correlated with those in the commercial catch. Seabirds were found to be much more sensitive than the commercial fleet to fluctuations in the abundance of these fish. In a long term demographic study of Heermann's Gulls, we found their fecundity rates change drastically from ENSO (El Niño) to non-ENSO ("normal") conditions. Simulation analyses under different ENSO frequencies showed a non-linear decline of the population growth rate as the ENSO frequency increases. The population can withstand frequencies as high as one ENSO every 5 years without suffering serious population declines; it will be relatively stable at frequencies of one ENSO every 4 years, but will decrease drastically at higher frequencies.

1. FORAGE FISH AS THE BASE OF THE PELAGIC MARINE FOOD CHAIN

One of the most productive marine areas of Northwest Mexico is the Midriff Island Region, in the Gulf of California (Álvarez-Borrego 1983) (see Figure 1). This area, located in the central Gulf of California, has a high marine productivity due to the strong upwelling induced by the islands and the tides, as well as the more common upwelling promoted by the wind action that is common along many of the coastal areas of the world and, particularly, along the coastal areas of the Gulf of California.

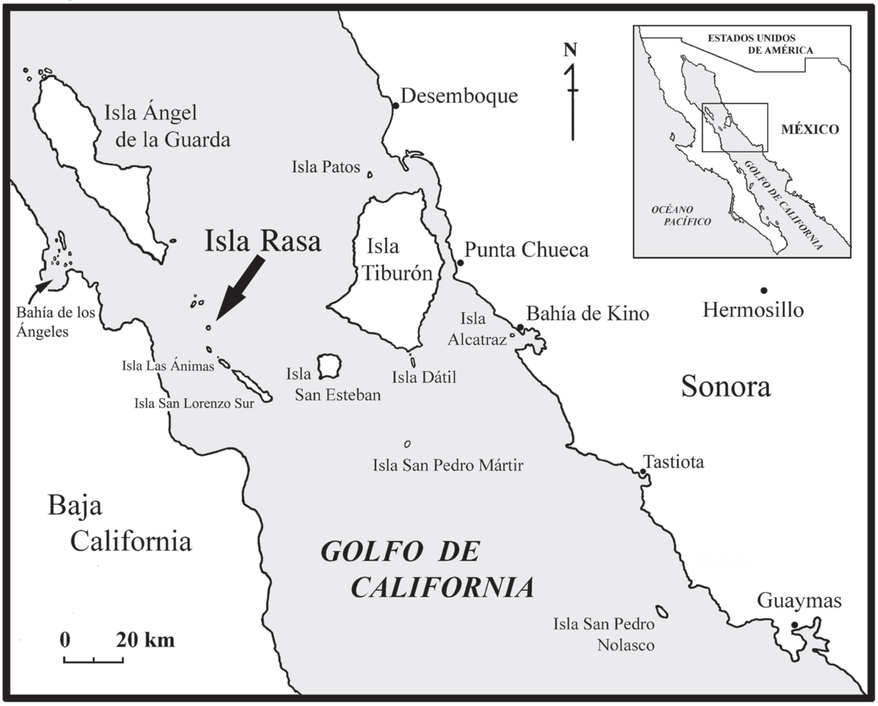

FIGURE 1. Southern section of the Midriff Island Region of the Gulf of California.

The tidal upwelling characteristic of this area adds up to the wind driven upwelling resulting in one of the highest marine productivities in the world. Important to this marine richness is also the extensive presence, at least until a few decades ago, of coastal lagoons and mangrove areas, which constitute superb nurseries for many marine species, be it invertebrates, fish, and also several aquatic bird species. As a consequence, the region's importance for many marine organisms is relevant on a worldwide scale. Seabirds are not the exception when one considers the high percentages of the total nesting populations of at least ten seabird species that occur in the region. Several waterbirds and shorebirds also nest on some of the Gulf of California islands (Anderson *et al.* 1976, Anderson 1983), and the area is also of great importance for the wintering and migration of many other species of these bird groups, such as geese and several duck species.

Offshore islands are some of the most important breeding areas for about 20 seabird species that are known to nest in the area, the most numerous of which are the Least Storm-petrel (*Oceanodroma microsoma*), the Heermann's Gull (*Larus heermanni*) (that nests almost exclusively in the Gulf and is, therefore, considered cuasi-endemic to the area), the Elegant Tern (*Thalasseus elegans*), and the Craveri's Murrelet (*Synthlyboramphus craveri*), all of which have close to 95% of their total populations concentrated in the Gulf during the nesting season; plus the Yellow-footed Gull (*Larus livens*), that is also considered cuasi-endemic to the Gulf (Anderson 1983, Velarde and Anderson 1994).

Conservation problems in the region are not small, including the impact of the large sardine fishing industry that flourished in this area. Historically, at a world-wide level, fisheries have been difficult to manage in a sustainable fashion, and many regional economies have been shaken by the collapse of their fisheries (Radovich 1982, WRI 1994, Botsford *et al.* 1997, Schwartzlose *et al.* 1999). Since the last couple of decades, the majority of the world's fisheries have been in a state of overexploitation, or nearly so, and that includes the small pelagic fisheries such as sardines and anchovies, which constitute close to 25% of total commercial landings (WRI 1994, Botsford *et al.* 1997). The populations of these fishes are characterized by wide population fluctuations, resulting from the effect of fluctuating oceanographic-atmospheric phenomena such as El Niño Southern Oscillation (ENSO). Due to their migratory nature, generally immense biomass, and wide mobility, their populations are hard to monitor, and it has been extremely difficult to obtain robust indicators of their abundance and availability to the commercial fleets (Schwartzlose *et al.* 1999, Sánchez-Velasco *et al.* 2000), thus the management decisions for their fishery have been primarily based on market rather than on biological information.

Small pelagic fishes are the basis of many important coastal marine ecosystems such as the rich California, Humboldt, and Benguela Current systems, and they form the main food source for a variety of larger fish, many of which are also economically important. Small pelagic fish are fundamental food items for marine mammal and seabird species (Anderson and Gress 1984, Burger and Cooper 1984, Furness 1984, MacCall 1984, Furness and Barrett 1991, Furness and Nettleship 1991, Montevecchi and Berruti 1991, Velarde *et al.* 1994, Sánchez-Velasco *et al.* 2000), and many studies have shown the value of seabird diet information as a tool to indirectly monitor the status of the fish species on which they feed, and have shown significant correlations between seabird diet and fisheries parameters (Anderson *et al.* 1980, Anderson and Gress 1984, Burger and Cooper 1984, Furness 1984, MacCall 1984, Berruti and Colclough 1987, Bailey *et al.* 1989, Martin 1989, Barrett 1991, Furness and Barrett 1991, Furness and Nettleship 1991, Montevecchi and Berruti 1991, Velarde *et al.* 1994, Crawford and Dyer 1995, Montevecchi and Myers 1995, Crawford 1998, Sánchez-Velasco *et al.* 2000).

The proportions of each forage fish species in the diet of three seabird species —California Brown Pelican (*Pelecanus occidentalis californicus*), Heermann's Gull and Elegant Tern—nesting in the Gulf of California, have been found to be closely

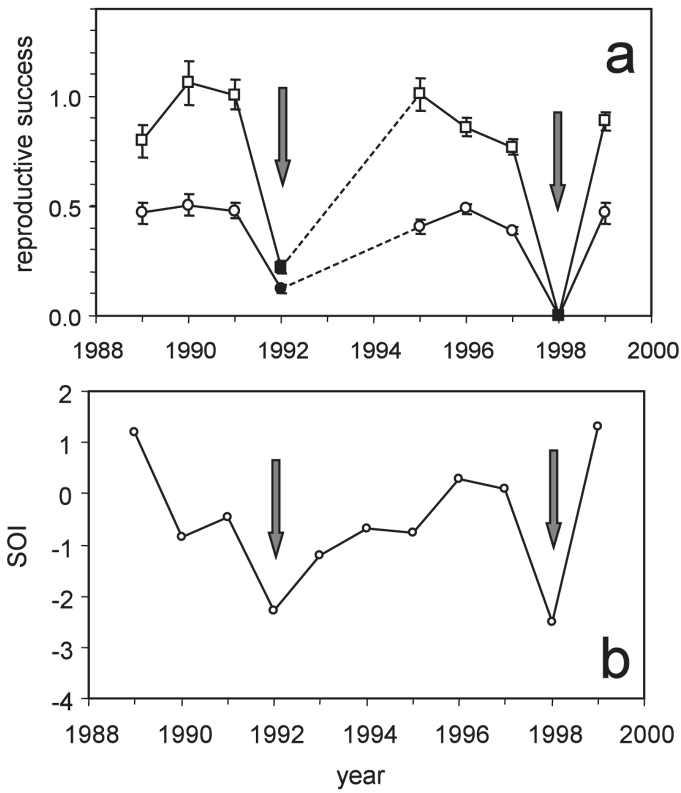

FIGURE 2. Effect of El Niño on seabird breeding success: (a) reproductive success of Heermann´s Gull in the Gulf of California between 1989 and 1999 (excluding 1993 and 1994, in which sampling was interrupted). Squares indicate number of fledglings produced per nest; circles indicate number of fledglings produced per egg laid (means ± 1 SE). (b) Values of the December-May mean Southern Oscillation Index (SOI) between 1989 and 1999. In both figures the arrows indicate years in which the mean December–May SOI reached extreme negative values (less than – 1.5). Taken from Velarde *et al*. 2004.

correlated with those in the commercial catch. However, seabirds have been found to be much more sensitive than the commercial fleet to fluctuations in the abundance of small pelagic fish in the environment (Velarde *et al.* 1994). This renders these seabirds as important indicator predator species of the status of the small pelagic fish populations and communities, a fact that is extremely useful for the decision making at the present at the present time, when effects of global warming are an everyday threat and economic decisions need to be made, taking into account the long term effects of human activity.

2. THE REPRODUCTIVE BIOLOGY OF SEABIRDS AND ITS RELATIONSHIP TO THE ABUNDANCE OF PELAGIC "FORAGE" FISH

In the case of most seabirds, parental age, body condition, and food availability have been found to strongly influence breeding parameters, such as clutch size, number of chicks hatched and fledged, hatching, fledging and reproductive success (Anderson *et al.* 1980, 1982, Sunada *et al.* 1981, Boekelheide and Ainley 1989, Penniman *et al.* 1990, Sydeman *et al.* 1991). In the Gulf of California for example, the main factors driving reproductive success in Heermann's Gull (a vulnerable species according to Mexican federal law) were found to be parental age and body condition (estimated by body mass), and food availability (estimated from Catch Per Unit Effort statistics for Pacific sardine (*Sardinops caeruleus*) + Northern Anchovy (*Engraulis mordax*) by the local fishing fleet) (Vieyra *et al.* 2009). From studies of this species (Velarde 1999, Velarde and Ezcurra 2002, Velarde *et al.* 2004, Vieyra *et al.* 2009) it was clear that breeding parameters showed their lowest values in ENSO years, in which the birds also showed significantly lower individual weights for both males and females. These years also were the ones when local CPUE of sardine + anchovies was lowest (Velarde *et al.* 2004, Vieyra *et al.* 2009) (see Figure 2).

A strong chained relationship was found between the different extrinsic variables such as food availability, which is strongly driven by oceanographic conditions, was found to strongly affect both parental body condition and the survival of eggs into hatchlings and the survival of hatchlings into fledglings, while intrinsic variables, such as parental age (the latter being a biological factor intrinsic to each nesting couple), was found to explain most of the observed between-nest variation in fledgling success, or the proportion of eggs laid by a nesting pair that produced flying young (Vieyra *et al.* 2009).

3. SUMMARY OF THE SMALL PELAGIC FISHERY IN THE GULF OF CALIFORNIA

As summarized in Cisneros *et al.* (1995), in the mid 1900's a small pelagic fishery fleet developed in the Mexican Pacific, along the western coast of the Baja California Peninsula. By the mid 1960's this fishery suffered from the natural fluctuations of oceanographic conditions (ENSO) on these fish populations, in combination with the overfishing that occurred during these years. As a result, the availability of these fish, particularly the Pacific sardine, species on which the fishery was based during the early years of its development, decreased drastically and the existing fleet was moved into the Gulf of California. This industry developed mainly targeting Pacific sardine, initially during the Winter months in the Guaymas basin, and later, when cooling systems were added to the fishing boats, extending to the Midriff Island Region during the Summer months, to initially unimagined levels, growing from a total sardine catch of some 11,000 metric tons in the 1969/70 fishing season, to almost 100,000 in the season 1980/81, almost an order of magnitude in a little over 10 years (Cisneros *et al.* 1995). This period of relatively slower growth was fallowed by another decade of higher growth rate, with a three fold increment in the catches between the latter and the 1988/89 season, reaching a catch of almost 300,000 tons. After that season the catches decreased by almost 100,000 tons and, two years later and in coincidence with the El Niño of 1992, the catches collapsed to around 7,000 metric tons for the next two seasons, a decrease of almost 98% of the record catch of 1989! Following this collapse the catches rapidly recovered, and in 5 years the sardine catches surpassed the 200,000 metric tons, but collapsed again to less than 60,000 in the 1997/98 season, only to recover and collapse once more in the 2001/02 and 2004/05 seasons, respectively, to less than 100,000 tons. Although a clear relationship between the collapses of the catch and the occurrence of the El Niño phenomenon could be observed, a brief analysis of the catch per unit effort (Velarde *et al.* 2004) revealed that, while until 1989 the catches increased in significant correlation with the fishing effort of the fleet, after that year the catch remained independent of the effort, a clear sign of overfishing. Regardless of this, the effort of the fleet was not reduced and between the latter and the 2007/08 season the catch reached another record catch of almost 500,000 metric tons of Pacific sardine, and over that figure in the following season, the highest catch of all its history (see Figure 3).

During the breeding season of 2008 the breeding success of all the seabirds in Isla Rasa was high and feeding frenzies could be observed almost every day right off the island's shores. However, during the 2009 season, the number of nesting Elegant Terns that established in the island were close to 30% of the total normal population, and all abandoned the nesting colony before incubation completion. For the Heermann's Gulls, only about 60% established a nesting territory, and it is not known if a larger fraction of the population arrived to the nesting grounds but was not guarding their territories. Of the gulls that were seen in their territories, only 40% laid at least one egg, but the average clutch size was much smaller than that of "normal" years (1.42 in 2009 and 2.16 average 2000–2008). This is if we consider only the nests where at least one egg was laid. However, if we consider all the nests in the sample, the average clutch size drops to 0.78 eggs per nest. Of the few Heermann's Gulls that laid eggs, even fewer were able to finish incubation, because many abandoned the nest to feed before the mate returned to relieve them, as it is done during

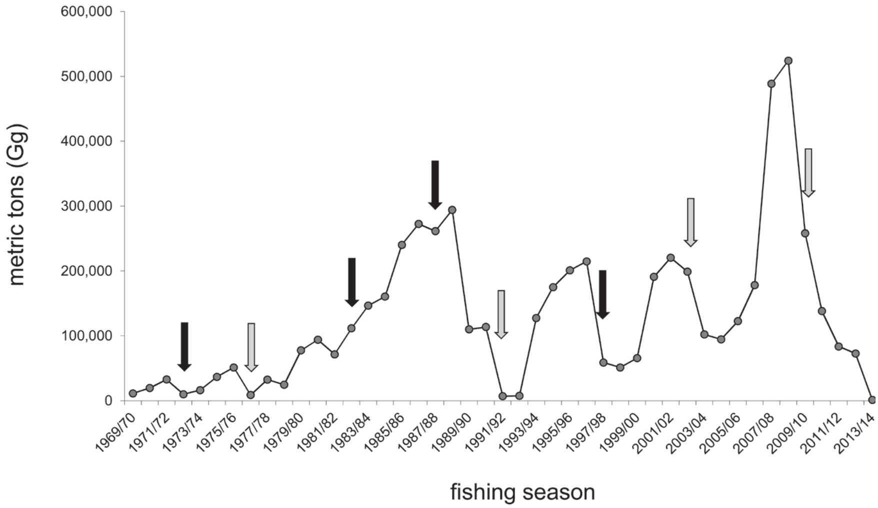

FIGURE 3. Trend of the Pacific Sardine catches by the fleet of the State of Sonora, Mexico in the Gulf of California. Black arrows indicate strong El Niño thermal anomalies, gray arrows show mild El Niño anomalies. Catch information taken from: http://www.inapesca.gob.mx/portal/documentos/publicaciones/Anexo1_InfTec_CaptEsfuerzoFlota_PMGC.pdf

"normal" years. Finally, most of the scant number of hatched chicks died when their parents abandoned them to go to sea in search of the scarce fish that remained in the area, so the breeding success for that breeding season was 0.1 chicks per nest, instead of the average of 1 chick per nest during "normal" years.

4. THE VALUE OF THE INFORMATION ABOUT SEABIRD BIOLOGY TO PREDICT FISHERIES SUCCESS

As mentioned above, small pelagic fish at present constitute 25 to 40% of the fisheries landings in Mexico. Over 70% of these landings, predominantly Pacific sardine (*Sardinops sagax*), are captured in the Gulf of California. Small pelagic fishes are a key component of the Gulf's ecosystem, since they are eaten by seabirds, sea mammals and other fishes. The sardine fishery within the Gulf has been showing signs of overfishing since the early 1990s.

Statistical models show that oceanographic conditions and seabird breeding and feeding data can accurately predict total fishery catch and catch per unit effort (CPUE) of Pacific sardine in the central Gulf of California (Velarde *et al.* 2004). Total catch has been predicted with an accuracy of 54% by a linear model incorporating the Southern Oscillation Index (SOI), the clutch size of Heermann's Gulls, and the proportion of sardine mass in the diet of Elegant Terns. Moreover, CPUE has been predicted with an accuracy of 73% by a model based on the proportion of sardines in the diet of Elegant Terns, the reproductive success of Heermann's Gulls, and the springtime sea surface temperature anomaly in the Gulf region (Velarde *et al.* 2004). Several studies have shown that reproductive ecology of seabirds is coupled to the global and local oceanographic conditions, and that this information can be used to predict the outcome of fishing efforts with several months in advance of the onset of the fishing season (Velarde *et al.* 1994, 2004, in press). Models of this kind are very useful and can provide key information for fisheries administrators and the industry, to make decisions to reduce the effort (and expenses) of the fleet in years when it can be anticipated that CPUE will be low.

5. THE VULNERABILITY OF THE MIDRIFF ISLAND ECOSYSTEM TO LARGE-SCALE OCEANOGRAPHIC ANOMALIES AND THE MANAGEMENT OF ITS NATIVE SPECIES

As it was found in a demographic study based on long term records of the banding, survival and breeding of the Heermann's Gulls nesting in Isla Rasa, their fecundity rates change drastically from ENSO (El Niño) to non-ENSO ("normal") conditions. A matrix-based demographic analysis of their population growth under the two situations predicted close to a 2% annual population growth during normal years, and a rapid decline (-15%) under sustained ENSO conditions. Under non-ENSO conditions fecundities contribute more to population growth rate than survival, but under ENSO conditions survival is the key demographic factor (Vieyra *et al.* 2009). Simulation analyses under different hypothetical frequencies of El Niño anomalies showed a gradual but non-linear decline of the predicted growth rate as the ENSO frequency increases. All other factors being as they presently are, the Heermann's Gull population can withstand frequencies as high as one ENSO event every 5 years without suffering a serious population decline; the population will be relatively stable at frequencies of one ENSO event every 4 years, but will decrease drastically at higher frequencies (see Figure 4). This shows us that the longevity of seabirds seems to be an evolutionarily selected trait in response to the fluctuating environmental conditions that characterize many coastal ecosystems, and the past existence of drastic fluctuations in the availability of pelagic fish.

Heermann's Gulls seem to be well adapted to these fluctuations and are able to resist relatively high frequencies of oceanographic anomalies, without seriously compromising, neither their population growth rate, nor their individual fitness.

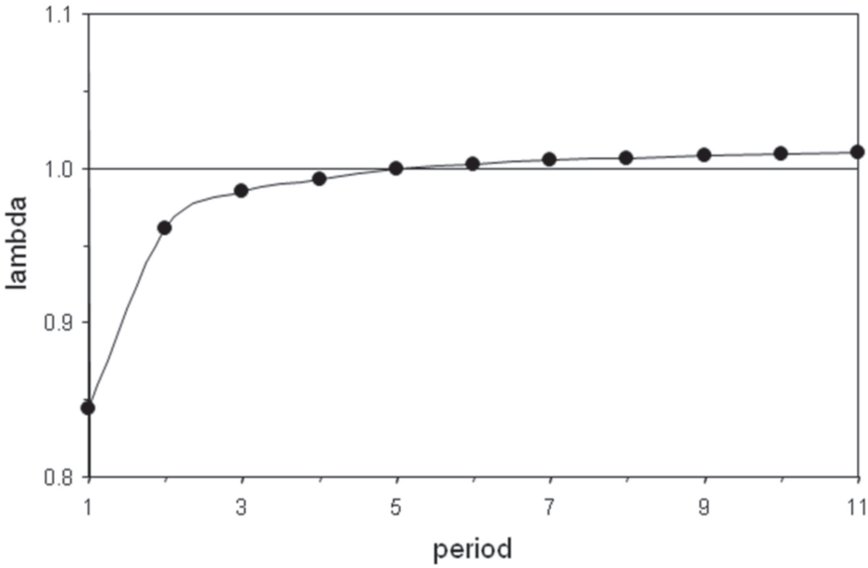

FIGURE 4. Long-term population growth (λ) for Heermann's Gull under different frequencies of occurrence of the ENSO phenomenon (a period of 1 indicates an El Niño event every other year, and so on). Taken from: Vieyra *et al.* 2009.

However, their populations may decline rapidly if warm-phase anomalies increase in frequency in the future as a result of global ocean warming, or if sardine overfishing puts the availability of their food sources at risk. If we believe that other species inhabiting the area have similar adaptations, and consider the effects analyzed here extended to the rest of the ecosystem, the increase of the frequency of the warm phase anomalies may result in severe imbalances through the food chain and drastic consequences to the whole ecosystem, particularly if extractive activities enhance the effects of the natural ones.

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Exploring Mexico's northwest, the Baja California Peninsula, its surrounding oceans, its islands, its rugged mountains, and rich seamounds, one feels diminished by the vastness and the greatness of the landscape while consumed by a sense of curiosity and awe. In a great natural paradox, we see the region's harsh arid nature molded by water through deep time, and we feel that its unique lifeforms have been linked to this desert and sea for thousands of years, as they are now.

These landscapes of fantasy and adventure, this territory of surprising, often bizarre growth-forms and of immense natural beauty, has inspired a wide array of research for over two centuries and continues to inspire the search for a deeper knowledge on the functioning, trends, and conservation status of these ecosystems in both land and ocean.

This book offers a compilation of research efforts aimed at understanding this extraordinary region and preserving its complex richness. It is a synthesis of work done by some exceptional researchers, mostly from Mexico, who indefatigably explore, record, and analyze these deserts and these seas to understand their ecological processes and the role of humans in their ever-changing dynamics.

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