

ARTÍCULO POR INVITACIÓN
ECOSYSTEM-LEVEL EFFECTS OF THE SMALL PELAGICS FISHERY
IN THE GULF OF CALIFORNIA

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ABSTRACT. Documentary scientific evidence supports the notion that the small pelagics fishery in the Gulf of California does not measurably affect the physical habitat or the functional relationships between the species comprising the pelagic ecosystem. Also, there is little information that suggests any negative effects of the small pelagic fishery operations on critically endangered, endemic species, *i.e.*, vaquita and totoaba. Under the current management regime, small pelagics fishery in the Gulf of California has recovered twice from collapses during the last 30 years. Although the small pelagics abundance varies greatly, the long-term productivity of the target species and the structure and function of the pelagic ecosystem are not compromised because the fishery relies on a suitable logistic and administrative platform, which is consistent with international standards for responsible fisheries, precautionary approach and ecosystem-based fisheries management principles.

Keywords: Climate change, collapse, ecological modeling, Pacific sardine, recovery, trophic relationships.

Efectos a nivel ecosistema de la pesquería de pelágicos menores en el Golfo de California

RESUMEN. Existe documentación científica suficiente como para suponer que la pesquería de pelágicos menores en el Golfo de California no afecta significativamente el hábitat ni las relaciones funcionales entre las especies que conforman el ecosistema pelágico del cual depende. Tampoco hay información que indique interferencia entre las operaciones de la pesquería de pelágicos menores y especies amenazadas o en peligro de extinción, específicamente la vaquita y la totoaba. Adicionalmente, bajo el sistema actual de manejo, esta pesquería no sólo ha logrado recuperarse exitosamente en dos ocasiones durante los últimos 30 años sino que también cuenta con la plataforma logística y administrativa necesarias para asegurar un aprovechamiento racional de las especies objetivo y la productividad de la propia actividad en el largo plazo, en congruencia con los estándares internacionales de pesca responsable y enfoque precautorio.

Palabras clave: Cambio climático, colapso, modelación ecológica, recuperación, relaciones tróficas, sardina monterrey.

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APPROACH

The most common way of investigating functional relationships between species is based on their feeding habits. Within an ecosystem, some species interfere with others through competition and predation, while others benefit from feeding in different systems across their migratory routes, compelling other species to follow them as they migrate. This situation results in a complex trophic web in each ecosystem with its own particular dynamic, defined by the less vagrant species with bridges formed to other webs by the most mobile species.

In the Gulf of California, functional relationships have been studied with two complementary approaches. The first involves a description of the feeding habits for the main commercial species (fish resources) and conservation-relevant species (*i.e.*, marine tetrapods). The second approach is a more holistic one, based on the mathematical representation of energy and biomass fluxes among the functional groups in

the ecosystem (herbivores, carnivores, planktophages, etc.), that allows for the examination of effects of fishing at levels of integration above that of the population (Christensen & Walters, 2004). During the last decade, several trophic models of various regions of the gulf have been developed (*e.g.*, Arreguín-Sánchez *et al.*, 2002; Arreguín-Sánchez & Calderón-Aguilera, 2002; Morales-Zárate *et al.*, 2004; Lercari & Arreguín-Sánchez, 2009).

In the gulf's pelagic ecosystem, the dominant functional fish group in terms of biomass consists of the small pelagics, and within this group the Pacific sardine (*Sardinops sagax caeruleus*) is the most abundant species, representing on average 55% of the total catch (Table 1; Figure 1). This species is therefore of great economic and ecological importance. Small pelagics, marine amniotes and some invertebrates such as shrimps have been the focus of the aforementioned approaches during the last 30 years. Bakun *et al.* (2009) regard trophic in-

Table 1. Catch composition (%) of small pelagics in the main landing ports in the Gulf of California; A) Mazatlán Sinaloa; B) Yavaros y Guaymas, Sonora; extracted from Instituto Nacional de la Pesca (2006).

Species/Authority	Common name	A	B
<i>Opisthonema libertate</i> (Berry & Barret)	Pacific thread herring	30	+17.4
<i>Opisthonema bulleri</i> (Regan)	Slender thread herring	30	17.4
<i>Opisthonema medirastre</i> (Berry & Barret)	Middling thread herring	30	17.4
<i>Cetengraulis mysticetus</i> (Günther)	Pacific anchovy	70	20.7
<i>Sardinops sagax caeruleus</i> (Jenyns)	Pacific sardine	-	55.9
<i>Scomber japonicas</i> (Gmelin)	Chub mackerel	-	3.8
<i>Engraulis mordax</i> (Girard)	Californian anchovy	-	0.7
<i>Etrumeus teres</i> (DeKay)	Round herring	-	0.8
<i>Oligoplites</i> spp.	Longjaw leatherjack	-	0.7

teractions, particularly the one where sardines are a source of food for predators, as key elements that should be incorporated into any ecosystem-based management system.

There is a increasing concern regarding the impact that fishing foraging species may have on the structure of marine ecosystems (Bakun *et al.*, 2009), however efforts for integrating available evidence for some ecologically relevant systems are lacking. In the present

study we made a thorough literature survey in order to determine whether there is documentary information suggesting that the small pelagics fishery negatively affects the trophic relationships in the pelagic ecosystem of the Gulf of California, or the critically endangered species and their habitats that are or might be in contact with this fishery. We also examined the role of the small pelagics management system on the fishery behavior and productivity. In the following sections we present a review of tropho-dynamic studies, ecological modeling of small pelagics and environmental impact of this fishery in the Gulf of California, as well as our interpretations of this research in the context of ecosystem functional relationships and fisheries management.

FUNCTIONAL RELATIONSHIPS

Invertebrates and fish

There are more than 40 scientific publications on the feeding habits of several species in different zoological groups that feed upon small pelagics in the region. These references (mostly grey literature) are summarized in (Tripp-Valdéz *et al.*, 2010).

With respect to invertebrates, the jumbo squid (*Dosidicus gigas*) is considered to be the

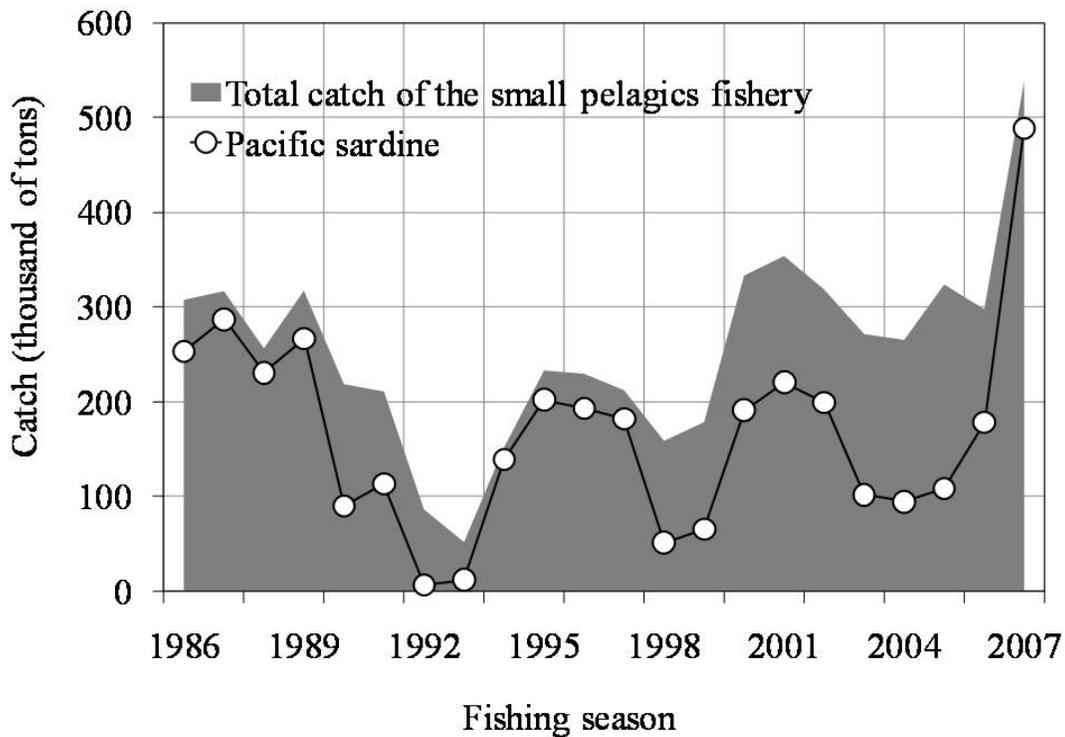


Figure 1. Comparison between the historical total catch of the small pelagics fishery in the Gulf of California and that of the Pacific Sardine in the same region.

most abundant cephalopod in the gulf (>45,000 tons per year since 2000). Its migratory movements, and therefore the interannual variation of its abundance, are thought to be linked to environmental fluctuations, interactions with other fisheries (Instituto Nacional de la Pesca, 2006) and the seasonal displacement of small pelagics inside the gulf. However, these hypotheses have yet to be proved. For instance, descriptions of the jumbo squid's diet indicate that myctophid fish and red crabs are the best represented groups while sardines, although present, do not seem to be such an important (Figure 2) or ecologically relevant component (Rosas-Ruiz *et al.*, 2008). Nevertheless, Bakun *et al.* (2009) suggested that the migratory movement of jumbo squid could influence the mortality and growth rates of sardines, in addition to their reproductive success.

From the available literature, ten species have been identified that feed upon small pelagics. Six of these species include the pacific sardine in less than 3% (Index of Relative Importance) of their diet while just one, the striped marlin (*Tetrapturus audax*) has the sardine representing 24% of its diet. The remaining species feed upon other small pelagics (*O. libertate*, *E. teres*, and *Opisthonema* spp.) in no more than 5% of their diets, except for the sharpnose shark (*Rhizoprionodon longurio*) and the yel-

low snapper (*Lutjanus argentiventris*) for whom small pelagics comprise up to 25% of the diets, however their preys -*Opisthopecterus dovii* and *Harengula thrissina*, respectively, are not target species. Moreover, it is well documented that large pelagics that prey on the sardine show distribution patterns similar to those of teutophagous cetaceans (Salvadeo, 2008a).

There is evidence of a strong seasonal signal in the abundance of striped marlin in the southwest gulf, similar to that observed for ichthyophagous cetaceans such as the common dolphin (*Delphinus* spp.), with a winter/spring maximum (Figure 3) coinciding with the southward movement of the sardine (Lluch-Belda *et al.*, 1986; Cisneros Mata *et al.*, 1995a; Hammann *et al.*, 1998; Ortega-García *et al.*, 2005; Salvadeo, 2008b). It is noticeable that the period in which the stomach contents of the striped marlin were sampled (1988-1989) was anomalously cold, consistent with an increase in sardine abundance and residence time in the southern portion of the gulf (Lluch-Belda *et al.*, 2005). In terms of functional relationships this can be translated into higher, yet casual, food availability for large pelagic predators.

Marine amniotes

Marine amniotes have a larger proportion of small pelagics in their diets, and the avai-

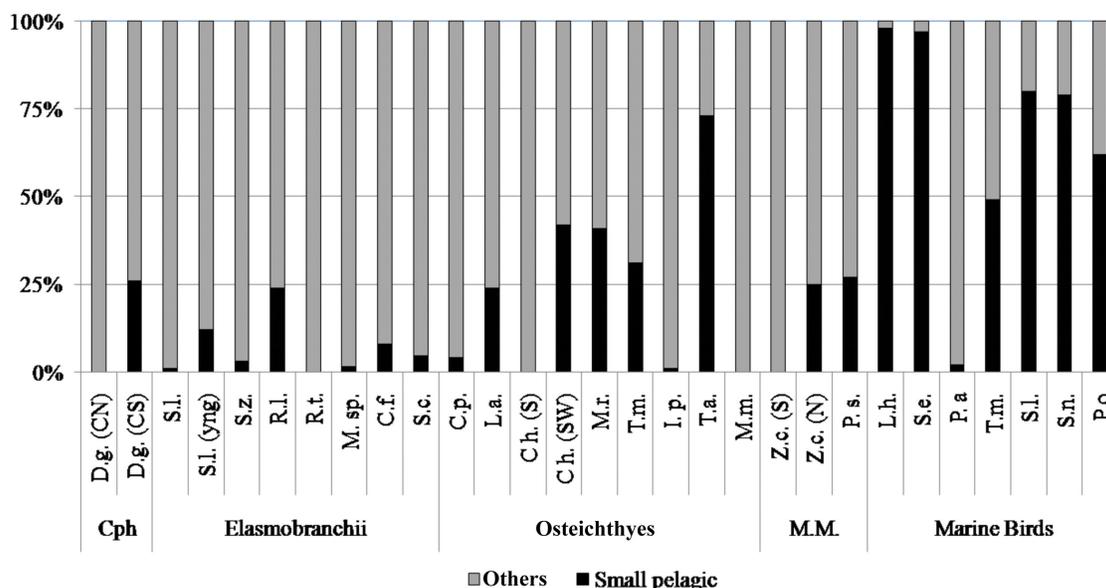


Figure 2. Percentage prevalence of small pelagics (sardine and anchovy = Clupeidae) in the diet of large pelagics in the Gulf of California; Cph (cephalopods), MM (marine mammals), D.g. (*Dosidicus gigas*), S.l. (*Sphyrna lewini*), S.z. (*Sphyrna zygaena*), R.l. (*Rhizoprionodon longurio*), R.t. (*Rhincodon typus*), M.sp. (*Mustelus* sp.), C.f. (*Carcharhinus falciformis*), S.c. (*Squatina californica*), C.p. (*Caulolatilus princeps*), L.a. (*Lutjanus argentiventris*), C.h. (*Corhyphaena hippurus*), M.r. (*Myxoperca rosacea*), T.m. (*Totoaba macdonaldi*), I.p. (*Istiophorus platypterus*), T.a. (*Tetrapturus audax*), M.m. (*Makaira mazara*), Z.c. (*Zalophus californianus*), P.s. (*Phocoena sinus*), L.h. (*Larus heermanni*), S.e. (*Sterna elegans*), P.a. (*Phaethon aethereus*), T.m. (*Thalasseus maximus*), S.l. (*Sula leucogaster*), S.n. (*Sula nebouxii*), and P.o. (*Pelecanus occidentalis*); CN (center-north), CS (center-south), yng (young), S (south), SW (southwest), N (north) from the Gulf.

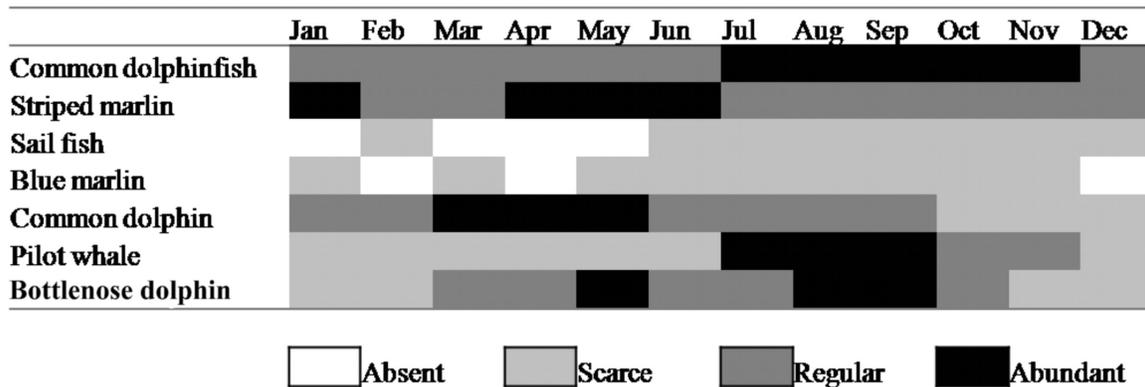


Figure 3. Temporal occurrence of large pelagic species for sport fishing in Cabo San Lucas area: common dolphinfish (*Coryphaena hippurus*), striped marlin (*Tetrapturus audax*), sail fish (*Istiophorus platypterus*) and blue marlin (*Makaira mazara*), extracted and modified from Ortega-Garcia *et al.* (2005); marine mammal occurrence in the southwest Gulf of California: common dolphin (*Delphinus* sp.), pilot whale (*Globicephala macrorhynchus*) and bottlenose dolphin (*Tursiops truncatus*); extracted from Salvadeo (2008a).

ability of these species as a food resource is related to their seasonal movement across the gulf. For two out of the seven marine birds (*Larus heermanni*) and (*Sterna elegans*) that feed upon small pelagics, the northern anchovy (*E. mordax*) corresponds to 70% of their total consumption. However, this species represents less than 1% of the total catch of small pelagics in the central Gulf of California. The pacific sardine comprises the remaining 30%. Furthermore, depending on their relative abundance, there seems to be a shift in the proportion of sardines and anchovies in the birds' diets: when sardines are abundant, the anchovy becomes a less important food item and vice versa (Velarde *et al.*, 1994), resulting in a constant food supply regardless of the ecological regime.

The diets of the blue-footed booby (*Sula nebouxii*) and the brown booby (*Sula leucogaster*) in the central gulf are mainly (57%) composed of Peruvian anchovy, which comprises 20% of the total catch of small pelagics in the region. In one of only two available studies addressing the feeding habits of the brown booby (Suazo-Guillén, 2004), The Pacific sardine represents 41% of the diet. The rest of the dietary components of these and other marine birds such as the brown pelican (*Pelecanus occidentalis*) the royal tern (*Sterna maxima*) and the red-billed tropic bird (*Phaethon aethereus*) consist of small pelagics that are poorly represented or absent in the total catch *Anchoa* spp., *A. exigua*, *A. ischana* and *Lile stolifera*. This suggests that the brown booby has sufficient trophic plasticity to switch between different preys according to their spatial availability, and even though the small pelagics fishery and marine birds do share some target species, there is no evident interference between them

due to the low proportion of these kinds of fish in the catch and in their diets, respectively.

Regarding marine mammals, the sea lion (*Zalophus californianus*) has no dietary preference for small pelagics and feeds upon benthic and mesopleagic species. However, *S. sagax* is the main food item in four of the 13 breeding colonies of sea lions situated around the Midriff Islands, where the size of local sea lion populations (which was declining until 2004; Szteren & Auriolos, 2006) is positively correlated with that of the sardine. For this reason it is imperative to highlight the factors affecting the abundance of small pelagics in the Gulf of California.

The effects of fishing on the population dynamics of small pelagics in the Gulf of California are not fully understood (Wolf, 1992; Cisneros-Mata *et al.*, 1995a). However, there is little doubt about the influence of environmental conditions, particularly the interannual variability (*i.e.*, El Niño/La Niña), on the abundance of these species (Lluch-Belda *et al.*, 1989, 1995; Nevárez-Martínez *et al.*, 2001). To illustrate this relationship, Lluch-Cota *et al.* (1999) forecasted with reasonable accuracy the sharp decline (1992) and later recovery (1996) of the pacific sardine in the Gulf of California using an upwelling index, the sea surface temperature and the reproductive success of the stock (derived from the abundance of eggs and larvae) as the only predictors for the total catch. This may indicate that the observed negative population trend in the four sea lion breeding colonies indirectly responds to environmental fluctuations, in the form of changes in prey availability, more than to dynamics of the fishing effort exerted on small pelagics.

Small pelagics are also important food

items in the diets of common dolphins (*Delphinus delphis*) and (*D. capensis*, Salvadeo, 2008b) and the Bryde's whale (*Balaenoptera edeni*, Urban & Flores, 1996). Similar to what is observed in sea lion breeding colonies, there is a correlation between the presence of these whales and oceanographic interannual variability, mediated by the sardine stock abundance (Salvadeo *et al.*, 2007). Larger cetaceans such as the sperm whale (*Physeter macrocephalus*) and the pilot whale (*Globicephala macrorhynchus*) chiefly consume squid (Jaquet & Gendron, 2002; Salvadeo, 2008b), while the blue whale (*Balaenoptera musculus*) eats zooplankton (Busquets-Vass, 2008). However, species such as the fin whale (*Balaenoptera physalus*) and the bottle-nose dolphin (*Tursiops truncatus*) may benefit from having small pelagics as a dietary component (Gendron, 1993; Jaume, 2004; Salinas, 2005). Fifteen out of 30 cetacean species observed in the Gulf of California are occasional visitors, and of the remaining half only three species, the most abundant ones in the region, feed upon small pelagics in addition to many other groups. None of these predators are included as threatened or endangered on international conservation lists.

Critically endangered species

Regarding the functional relationship between small pelagics and endangered species such as the vaquita (*Phocoena sinus*) there are some available studies that describe feeding habits (for instance, Culik 2004 and www.vaquitamarina.org), although most of them are based on no more than four original articles (Fitch & Brownell, 1968; Silber, 1990; Vidal *et al.*, 1995; Pérez-Cortés Moreno *et al.*, 1996). Only the latter mentions the presence of two small pelagics in the vaquita's diet: the slender anchovy (*A. ischana*) and the gulf anchovy (*A. helleri*) neither of which have been registered by catch or incidental catch in the Gulf of California small pelagics fishery. Moreover, the vaquita is considered to be an opportunistic consumer, preying upon small demersal fish and invertebrates such as the squid.

Another species that is endemic to the Gulf of California, and regarded as critically endangered by the International Union for the Conservation of Nature is the totoaba, (*Totoaba macdonaldi*) which in its adult stage preys upon small pelagics, particularly the pacific sardine (Román-Rodríguez, 1990). The low population numbers of the totoaba are attributable to effects from different factors such as habitat loss, incidental catches of the shrimp fishery, poaching and natural environmental changes (Cisneros-Mata, 1995b; Lercari & Chávez, 2007). Regarding the latter cause, it has been

suggested that certain large-scale climate patterns observed over the Mexican Pacific are positively correlated with regional regimes of sea temperature in the upper Gulf of California. The ecological effects of such changes may be revealed, via trophic web and reproductive success, in the sardine stock abundance and therefore in its availability as prey. The importance of each of these factors on the totoaba's abundance is currently unknown. However, the relative weight of the functional relationship between this species and the sardine is determined by factors that are unrelated to small pelagics fishery.

Ecological modelling

There are several studies addressing the dynamics of trophic flows in the Gulf of California, but only four explicitly including the small pelagics (*i.e.*, *S. sagax*, Arreguín-Sánchez & Calderón-Aguilera, 2002; Arreguín-Sánchez & Martínez-Aguilar, 2004; Rosas-Ruiz *et al.*, 2008; Lercari, 2006). In the first one, the authors recognized environmental variability as a key element for deriving stock biomass estimations for the pacific sardine in the pelagic ecosystem. The second one represents an improvement of the previous model. The authors modified the sardine's vulnerability to predation (*i.e.*, changes in predation rate on sardines) and directly incorporated the sea surface temperature and upwelling index as forcing factors on the sardine's natural mortality. Although such amendments reduced the magnitude of the residuals between the observed and estimated biomass, they did not help to capture the main signals observed in the biomass time series for the sardine. This may be due to the internal structure of the current model, which only allows the incorporation of forcing factors in a linear manner. Del Monte-Luna *et al.* (2007) suggested that changes in sardine abundance over time do not entirely rely on the trophic flow dynamics within the ecosystem, but instead on the non-linear effects of temperature and upwelling on the sardine stock, particularly on its reproductive success (Lluch-Cota *et al.*, 1999).

The third study addresses the role of the giant squid in the pelagics ecosystem in the middle of the Gulf of California. The authors highlight that there is no significant functional relationship between the two species despite the fact that small pelagics are part of the diet of the giant squid. The last of these works explores the effects of fishing (including small pelagics fishery) on different species inhabiting the upper gulf, *i.e.*, vaquita and totoaba. The results indicate that small-scale fishery and shrimp fishery directly interfere with these two species through fishing mortality, and indirectly through

trophic flows. Small pelagics fishery, nonetheless, appeared to be harmless (Lercari, 2006).

Impacts on habitat and selectivity

Two of the less desirable effects of any fishery are alterations in habitat and the direct or incidental mortality of non-target species. Some fishing gears and fishing operations, such as the trawling nets, have the potential to directly affect the immediate benthic habitat and its occupants by traction over the sea floor. Moreover, because of the low selectivity of the equipment, several other species are caught in addition to the commercial sought ones during fishing operations. Such incidental catches may become significant when species have biological traits that render them more vulnerable to external perturbations or when their population numbers are extremely low.

In general, the fishing operations used for small pelagics fishery are virtually harmless to the habitat and to other species because they are performed at the core of the water column, between depths of 30 m and 200 m, using surface or mid-water-column purse seine nets that directly target small pelagics. For example, the Pacific sardine fishery in Washington State (15,000 metric tons in 2002) extracts no more than four non-target species whose total numbers, on average, do not exceed 1000 individuals per year, with most of these being returned alive to the water (Washington Department of Fish and Wildlife, 2002). In Australia, the incidental catch of purse seine nets is negligible. Even when using mid-water trawling nets, the by-catch represents less than 1% of the total catch (Australian Fisheries Management Authority, 2005).

In the Gulf of California, interference with other fisheries and the environmental effects of the small pelagics fishery are minimal. In this region, purse seine nets are deployed at depths between 40 m and 100 m. Additionally the characteristics of fishing gear and boats are regulated by law (NOM-003-PESC-1993) to minimize the extraction of juvenile individuals. According to at-sea direct sampling and interviews with fishermen, discarding and incidental fishing rarely occur. Discards are generally comprised of the same target species and take place when the size of the fish school surpasses the vessel's storage capacity. Besides small pelagics, the purse seine fishing fleet may capture other species such as the jumbo squid and *Oligoplites* spp., which account for no more than 1% of the total catch (Instituto Nacional de La Pesca, 2006).

Another potentially adverse ecological

effect caused by fishing activities is the reduction of a stock's recovery potential when exploited species are driven to very low population levels (depensation or Allee effect) because this may further accelerate the collapse. In gregarious species such as small pelagics, depensation may weaken the aggregation capacity of the organisms, which then would tend to associate with other species to form dense schools (Morales-Bojórquez & Nevárez-Martínez, 2005). In the case of sardines, low probability of egg fertilization is a consequence of depensation (Cisneros-Mata *et al.*, 1995a). Nevertheless, the estimated threshold value for negative effects on the population growth of the species in the Gulf of California is considerably below the historical minimum (1993-1994) of spawning and adult abundance (Morales-Bojórquez & Nevárez-Martínez, 2005). In summary, there is no available evidence that the Pacific sardine had or will display the Allee effect in the near future.

Regarding the relationship between the small pelagics fishery and threatened or critically endangered species, there is no documented evidence of incidental mortality or any other kind of harm. It is possible that the northern limit for the geographic distribution of the Pacific sardine in the East coast of the Gulf (Rodríguez-Sánchez & Ponce-Díaz, 1986) is located near (+100 km) a zone where one vaquita was once sighted, southwest of Punta Peñasco. However, the northern terminus of the geographic distribution for the commercial catch of small pelagics is relatively far from the historical southern limit of the vaquita (Figure 4).

With respect to other vulnerable species, simple matching of distribution maps suggests that the geographic range of *T. macdonaldi* overlaps with that of the commercial fleet that fishes small pelagics. However, the *modus operandi* of the purse seine fishery and the physical characteristics of its fishing gear have little or no effect on the sea floor (Fletcher & Head, 2006), where the entire life cycle of the totoaba takes place (Cisneros-Mata *et al.*, 1995b, 1997). Therefore, this species is out of reach of the purse seine nets. The observed fishing mortality for this species is a result of the shrimp fishery by-catch, gill nets from the small-scale fishery and poaching (Pedrín-Osuna *et al.*, 2001). Other factors unrelated to the small pelagics fishery may play an important role in regulating the totoaba population; such factors include the loss of spawning habitat resulting from a reduction in the discharge volume from the Colorado River and natural climatic oscillations (Lercari & Chávez, 2007).

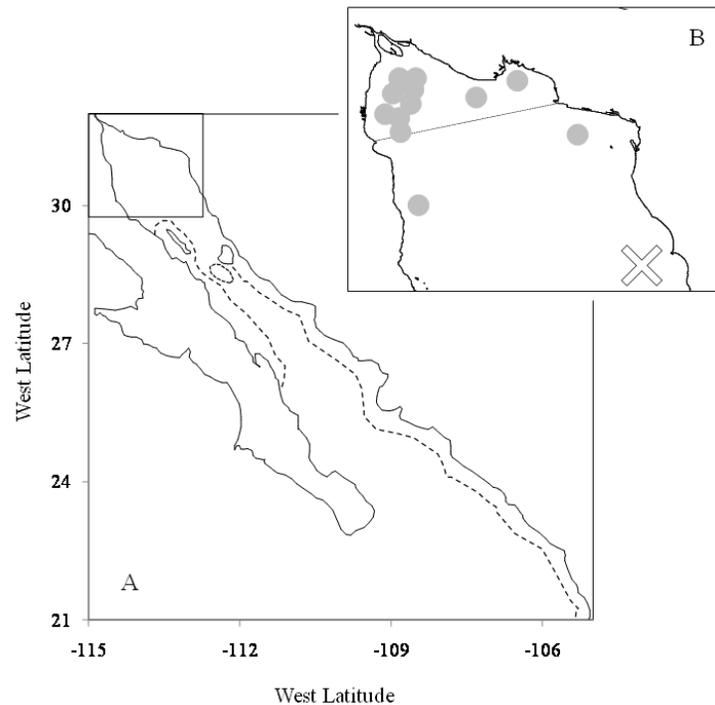


Figure 4. (A) Geographical distribution of the commercial pelagics fishery in the Gulf of California (dotted line). (B) Upper Gulf of California Biosphere Reserve and Colorado River Delta (solid line); sighting distribution of the vaquita (*Phocoena sinus*; solid circles) and observed southern limit of the Pacific sardine in the Gulf of California (white cross). Taken from INP (2006); Map Library from the National Commission of Natural Protected Areas CONANMP, <http://www.conanp.gob.mx>; Culik (2004) www.vaquitamarina.org, and Rodríguez-Sánchez and Ponce-Díaz (1986).

Fish productivity and fishery management

To realize the recovery capacity for a natural population, the population must transit from low to high levels of abundance or re-colonize its original range after a substantial reduction in geographic distribution. These events are fueled by a combination of factors such as the biological traits of the species, the condition of the immediate environment and the implementation of appropriate and adequate management actions. A common feature that characterizes small pelagics around the world is their large abundance fluctuations, sometimes unrelated to fishing dynamics, in time scales ranging from the interannual to multi-decadal that are synchronized with the expansion and contraction of populations along their geographical range (Lluch-Belda *et al.*, 1989; Chávez *et al.*, 2003).

The small pelagics in the Gulf of California are no exception. During the history of the fishery in the region, the total catch has shown drastic reductions. The first and most important drop was registered in the early 1990's, just before catches reached a historical maximum (1988-1989). In no more than four years the catch dropped from 294,000 tons to 7,000 tons (97% reduction), which, under the current

context of fishery management, may be considered a severe collapse. We should clarify that the sardine did not really collapse in the strict sense (population decline to dangerously low levels as a response to uncontrolled, intense, fishing). Instead, schools were restricted to their usual distribution around the Midriff islands and did not expand south to the customary fishing grounds along the eastern coast of the gulf (Lluch-Cota *et al.*, 2007; Bakun *et al.*, 2009).

By the mid 1990's yields had increased to 215,000 tons. Assuming that in this case the total landing of sardines may be used as an index of abundance, then the population would have recovered by 75%. The second reduction occurred a few years later (1998-2000), when the catch dropped to 55,000 tons (a 74% reduction). Between 2000 and 2003, landings built up to 203,000 tons, representing a 94% recovery relative to the previous maximum. Since then, the total catch of small pelagics has shown a positive trend. It must be stressed that after 1990, the fishing effort has been fairly constant (Instituto Nacional de La Pesca, 2006).

Although this situation indicates that the fluctuations in the stock of small pelagics may not be fully explained by the dynamics of the fishing effort, these changes have been attrib-

uted to the effects of fishing and to the competition between small pelagics and other species (Cisneros-Mata *et al.*, 1995a). Alternatively, Lluch-Belda *et al.* (1986, 1989 and references thereafter) linked these fluctuations to environmental stress, manifested as spatial displacements of the adult stock (Rodríguez-Sánchez *et al.*, 2002) and as variations in spawning activity (Morales-Bojórquez & Nevárez-Martínez, 2005). Whatever the cause, the Mexican government along with the fishing industry, NGOs and the academic sector have jointly defined and implemented different management actions aimed at the stock's recovery and maintenance of its long term biological potential, based on quantitative population assessments and frequent fishing surveys that determine the success of recruitment. Furthermore, there is sufficient information available for applying proactive management measures in accordance with international standards for a precautionary approach. Under such management schemes, the populations of small pelagics in the Gulf of California have successfully recovered twice from "collapsing" during the last 20 years. Whether such fluctuations are part of the stock natural variability, fostered by the current management regime, or a combination of both, is not yet fully understood.

After the dramatic decline in 1990, specific management actions included reducing the industrial fishing fleet by half (from 77 to 32 boats), establishing the length at first catch for the principal target species and closing areas (*i.e.*, Loreto Marine Park) to fishing (either totally or partially) during August and September in order to protect the spawning stock. Currently the exploitation of small pelagics in Mexico is regulated by Mexican Official Norm NOM-003-PESC-1993. This norm limits the amount of fishing north of 21° N, including the Gulf of California, and authorizes the substitution of active fishing boats with new and improved ones with better refrigeration systems. In addition, the norm specifies the length at first catch for the Pacific sardine (150 mm), the slender thread herring (160 mm) and the anchovy (100 mm). The effectiveness of such actions can be corroborated with the magnitude of landings during 2010 (surpassing 500,000 tons), the number of active fishing boats (which oscillates between 26 and 32), and the proportion of individuals below the legal length (no more than 30%) that are incidentally caught.

On the other hand, given the large variations in stocks of small pelagics over time, it may be inadequate to define target and limit reference points by fixing catch quotas. Instead, management actions based on harvest rates (catch-biomass ratio), without compro-

missing the stock productivity, may be more appropriate (Caddy & Mahon, 1995; Bakun *et al.*, 2009). For the Pacific sardine, for instance, this ratio (proportional to fishing mortality) must not exceed a threshold value of 0.26 per year, and the proportion of individuals below 150 mm in the total catch should not be greater than it currently is (30%). For the rest of the small pelagic species, there exist reliable estimates for reference points or, at least, the necessary information to derive them from survey data. As for other relevant reference points, the minimum viable (spawning) population size of the Pacific sardine is estimated to be 287 million individuals and the historically observed minimum is ~1000 million (Morales-Bojórquez & Nevárez-Martínez, 2005).

Additionally, every three months, the fishing and academic sectors and federal authorities gather together to analyze developments in the small pelagics fishery on the basis of information generated from constant stock and environmental monitoring and, if necessary, to adopt proper management actions in a consensual manner. Such a scheme has created a cooperative political climate, noticeable not only in the common approval of management actions but also in the financial support given to regional fisheries research from the fishing industry.

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