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Fishing Down Coastal Food Webs in the Gulf of California

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Fishing down coastal food webs in the Gulf of California

ABSTRACT

We used information from interviews with fishers, fisheries statistics, and field surveys to document changes in fisheries and fish assemblages in shallow coastal habitats in the Gulf of California, Mexico. Coastal food webs in the Gulf of California have been "fished down" during the last 30 years—fisheries shifted from large, long-lived species belonging to high trophic levels to small short-lived species from lower trophic levels. In addition, the maximum individual length of the landings has decreased about 45 cm in only 20 years. Although some catches are stagnant or still increasing for some species groups, catch-per-unit-effort declined for most species groups after 1980. These declines were associated to a dramatic increase in fishing effort in the region in the late 1970s–early 1980s, mostly in the number of gillnets. Fishing not only impacted target species, but also caused community-wide changes. These results suggest that coastal fisheries in the Gulf of California are unsustainable and their management needs to be reevaluated with sound regulatory measures to prevent further degradation of coastal food webs, and the concurrent inefficiency of artisanal fishing.

Introduction

Fisheries catches worldwide have gradually shifted from long-lived, high-trophic level species to short-lived, low-trophic level species in what has been called "fishing down marine food webs" (Pauly et al. 1998a; Baum et al. 2003; Myers and Worm 2003; Worm et al. 2003). This pattern is consistent among marine and freshwater ecosystems at both regional and local scales (Pauly et al. 1998a, 1998b, 2001). The consequences of fishing down food webs extend beyond the direct effects on the target species because the removal of large predators can cause changes affecting entire ecosystems (Estes et al. 1998; Jackson et al. 2001). In Mexico, 82% of the fisheries fully exploit or over-exploit their target species (Hernandez and Kempton 2003), but there are no published analyses of fisheries shifts and their ecosystem effects. Here we present evidence of fishing down marine food webs in the Gulf of California, a tropical marine biodiversity hotspot (Roberts et al. 2002), and address the need for rigorous fisheries management in the region.

In spite of its low human population density, the Gulf of California is subjected to intense fishing. Presently, six species of marine fishes (Serranidae and Sciaenidae) are threatened or at risk of extinction in the Gulf of California (Musick et al. 2000). Since no published analyses of the ecosystem impacts of coastal fishing in the Gulf of California exist, we describe changes over time in fish catches and mean trophic level of the coastal fishery in the southern Gulf of California. In addition, we attempted to determine the changes in the structure of coastal fish assemblages associated with documented fishing pressure, and changes in the spatial distribution of the artisanal fleet.

Baja California Sur Fisheries

We studied the coastal artisanal fishery in Baja California Sur. This fishery operates from a large town (La Paz, 154,314 inhabitants) and several small fishing villages ranging from 13 to 177 people (INEGI 2002). The total number of local commercial fishers in the study region is 10,600 (SEMARNAP, 1990–2000), although these shores are also used by hundreds of fishers based on mainland Mexico, from Sonora to as far south as Chiapas. The fishery targets coastal fishes belonging to 25 families (Table 1). The most commonly used fishing gear is a motored fiberglass skiff with hand lines and gillnets.

Fisheries in Baja California Sur showed a general pattern of increasing catch since 1950 but decreasing catch-per-unit-effort (CPUE) after 1980 (Figure 1, Secretaría de Marina 1950–1960; Secretaría de Pesca 1970–1980; Ramirez 1988; SEMARNAP 1990–2000). The only exception of CPUE decrease after 1980 was for a multi-species

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BONY FISHES	SHARKS	RAYS
Serranidae	Alopiidae	Rhinobatidae
Lutjanidae	Carcharhinidae	Mobulidae
Carangidae	Lamnidae	Myliobatidae
Haemulidae	Echinorhinidae	Dasyatididae
Balistidae	Squalidae	
Scaridae	Heterodontidae	
Labridae	Ginglymostomatidae	
Mullidae	Odontaspidae	
Kyphosidae	Scyliorhinidae	
Malacanthidae	Triakidae	
	Sphyrnidae	

Table 1. Major fish families targeted by the artisanal fishery in the southern Gulf of California.

category of medium- and small-sized groupers (Figure 1: "other groupers"). The catches of the goliath grouper (*Epinephelus itajara*) and snappers (except red snapper) also showed declines in catch after 1980. Because CPUE declined over time, the fluctuations and increase of catch in multi-species groups may be due to the shift in target species over time (see Results). These changes were associated with a striking increase in the number of motored fishing boats and gillnets in the region since 1980 (Figure 2) (Secretaría de Marina 1950–1960; Secretaría de Pesca 1970–1980; SEMARNAP 1990–2000). This pattern is similar to that of all Mexican fisheries—in the late 1970s national policies induced a significant migration of unemployed field workers towards coastal states, then landings peaked in 1981, and catches declined afterwards in spite of a huge increase in fishing effort (Hernandez and Kempton 2003).

Methods

Because the catch is pooled into coarse taxonomic groups in the Gulf of California, fisheries statistics do not allow calculation of the mean trophic level (Pauly et al. 2000). Catch

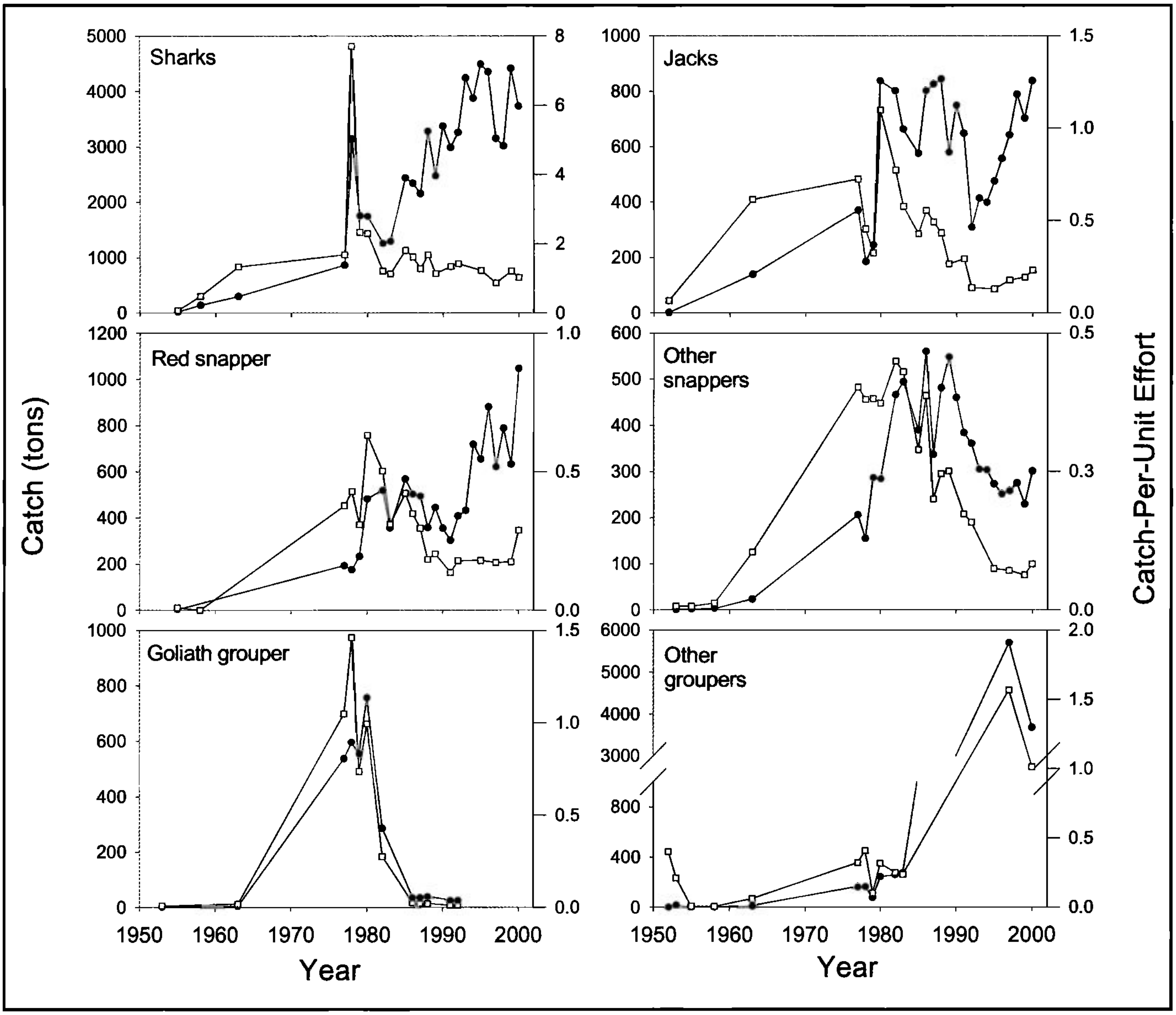
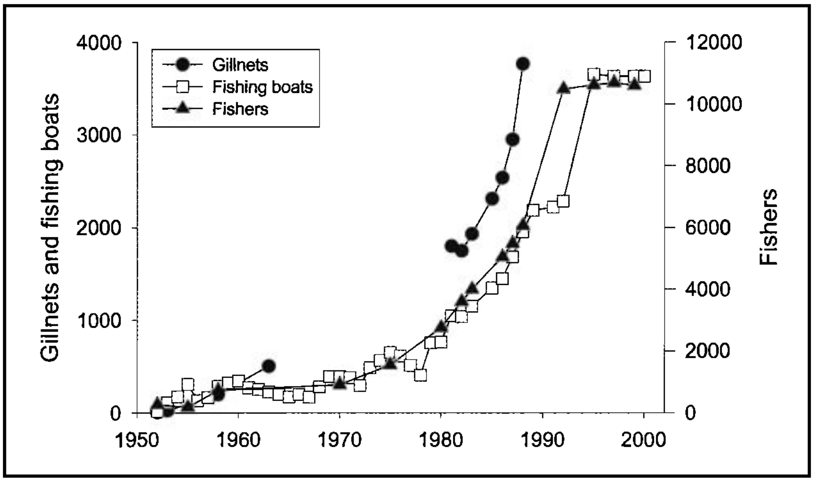


Figure 1. Annual fish catch (solid circles) and catch per unit effort (CPUE; metric tons/boat) (open squares) in the southern Gulf of California.

Sharks include: 37 species from 11 families (Table 1) caught in nearshore and offshore fisheries.
Jacks: green jack (*Caranx caballus*),
Pacific crevalle jack (*C. caninus*),
bigeye crevalle jack (*C. sexfasciatus*),
rainbow runner (*Elagatis bipinnulata*),
Pacific moonfish (*Selene peruviana*), and
gafftopsail pompano (*Trachinotus rhodopus*)
Red snapper: *Lutjanus peru*.
Other snappers include:
yellow snapper (*Lutjanus argentiventris*),
dog snapper (*L. novemfasciatus*),
mullet snapper (*L. aratus*),
spotted snapper (*L. guttatus*),
colorado snapper (*L. colorado*), and
barred pargo (*Hoplopagrus guntheri*).
Goliath grouper: *Epinephelus itajara*.
Other groupers include:
leopard grouper (*Mycteroperca rosacea*),
spotted sandbass (*Paralabrax maculatofasciatus*),
Panama graysby (*Epinephelus panamensis*),
flag cabrilla (*E. labriformis*), and
Pacific creolefish (*Paranthias colonus*).

Figure 2. Temporal changes in the number of fishers, fishing boats, and gillnets in the southern Gulf of California.



data sets for pelagic species such as dolphinfish (*Coryphaena hippurus*) and billfish (Istiophoridae), exclusively reserved for the sport fishery, are misreported (Ramirez 1988). Furthermore, because not all fishers belong to organized fishing cooperatives, their catch is under reported. Here we turned traditional ecological knowledge obtained from interviews with fishers into quantitative information to assess fishing down and spatial effort allocation.

To estimate the relative contribution of fish species to the catch we interviewed 63 fishers belonging to 4 fishing villages located in the southern Gulf, between Cabo Pulmo and San Jose Island (El Pardito, El Sargento, La Ribera, Cabo Pulmo). All fishers on these villages were commercial fishers, and sold their catch in the town of La Paz. We selected the most knowledgeable fishers on the basis of previous interviews. Fishers ranged from 25 to 67 years old, and they provided data only for the time periods when they were active. Interviews with individual fishers were conducted over a period of one year. Fishers were asked about the relative importance of each species in the catch in the 1970s, 1980s, 1990s, and 2000. We used a categorical index of fishing importance from 0 to 5, where 0 means that the species was absent from the catch, and 5 that it was the most important (by weight).

We then estimated the changes over time in the mean trophic level of the catch (Pauly et al. 1998a). Mean trophic level in marine ecosystems ranges from 1 (primary producers) to 5 (top predators, e.g., killer whale, humans, Pauly et al. 2000). We obtained the maximum reported size and trophic level of the species in this study from Fishbase (Froese and Pauly 2002). We estimated mean trophic level ($\overline{TL}_i$) for time period i by multiplying the fishing importance index (I, see above) times the trophic level of the individual species j, then taking a weighted mean (modified from Pauly et al. 1998):

$$\overline{TL}_i = \frac{\sum_j TL_j I_{ij}}{\sum_j I_{ij}}$$

When fishers could not provide information for individual species within a group, we used the average trophic level for the species in that group. We also estimated the mean maximum size of the catch as the summation of the product of the maximum length of each species times its relative contribution to the total catch.

To assess the temporal shifts in the spatial distribution of the artisanal fleet we interviewed fishers from the fishing camp of El Pardito about the location of fishing sites and their use over time. For every fishing site used since 1970 we estimated a number of fishing days per year. We then entered the location and use of every fishing site for every time period into a geographic information system (ESRI Arc View 3.2a). Maps of fishing intensity were obtained interpolating the data on a matrix of 72 points (on a 1:150,000 scale map).

The first effects of fishing are a reduction in the abundance and average size of target species (Dayton et al. 2002). To determine the impacts of the fishery on the size structure of selected target species we used data obtained during visual censuses conducted from 1998 to 2001 in 21 rocky reefs between La Paz and Loreto (Sala et al. 2002). Fish censuses included 140 non-cryptic species. These reefs could be ranked along a gradient in fishing pressure. Fishing pressure was quantified as density of fishing boats (Haro et al. 2001; Sala et al. 2002). Coastal fishing boats carry 3–4 fishers each and carry out daily fishing trips, so we assumed that effort per boat is constant.

Fishing down the food web has effects on the entire coastal fish assemblage beyond the direct effect on the target species. We investigated the changes in the structure (species composition and abundance) of the fish community using a principal component analysis, which shows latitudinal differences in the structure of the assemblages (Sala et al. 2002). To prevent these differences from confounding effects we used only data from the 11 sites in the southern region of study. The first principal component (PC1, which accounts for as much of the variability in the data as possible) explained 86% of the variance, therefore the scores of sampling sites on PC1 were considered good proxies of the structure of fish assemblages. We then performed a nonlinear regression between fishing pressure and the scores of each sampling site on PC1.

Results

There was a marked shift in the composition of the catch in the coastal fishery in the southern Gulf of California (Fig. 3; Chi-square = 95.65, df = 16, $P < 0.001$). Large predatory fishes such as sharks, gulf grouper (*Mycteroperca jordani*), gulf coney (*Epinephelus acanthistius*), goliath grouper, and broomtail grouper (*M. xenarcha*) were among the most important fisheries in the 1970s, but became rare by 2000. Although total shark catches have steadily increased in the southern Gulf of California, these include both coastal and pelagic fisheries (Figure 1). Our results indicate that the nearshore fishery collapsed and was substituted by an offshore fishery. Catch of other species such as leopard groupers (*Mycteroperca rosacea*), snappers, and jacks also decreased, but they are still commonly caught. In contrast, some species that were not appreciated or not targeted in the 1970s, such as parrotfishes (*Scarus* spp.), whitefish (*Caulolatilus princeps*), spotted snapper (*Lutjanus guttatus*), tilefish (*Caulolatilus affinis*), and creolefish (*Paranthias colonus*), have now become common targets. Because the larger species of groupers have become increasingly rare in the catch, most of the growth in grouper fishing has been related to the leopard grouper (Figure 3).

Maximum fish size in the catch decreased 45 cm from 1970 to 2000, and 33 cm in the 1980s alone (Figure 4).

The results of the interviews showed that the depletion of fish stocks near fishing villages forced fishers to move to fishing sites located farther away. In El Pardito, while most of the fishing activities in the 1970s were conducted near the fishing camp (<10 km radius in average), fishing now occurs mostly 50 km from it (Figure 5). We assume that this is representative of other fishing grounds in the Gulf of California. Mean trophic level decreased from 4.2 in the 1970s to 3.8 in 2000, the greatest reduction being in the 1980s. The average size of four abundant species decreased along a gradient in fishing for both carnivorous (leopard grouper, yellow snapper, *Lutjanus argentiventris*; greybar grunt *Haemulon sexfasciatum*) and herbivorous fishes (bluechin parrotfish *Scarus ghobban*) (Figure 6). We found similar patterns for most commercial fishes.

The structure of fish assemblages changed along the gradient in fishing pressure (Figure 7). These results indicate the existence of a threshold (around 7 fishing boats/km) beyond which average fish size is significantly reduced and the structure of the fish assemblage significantly changed.

Discussion and recommendations

The mean trophic level of the catch in Baja California Sur in the 1970s was 4.2, significantly higher than any other fishery in the world at that time (Pauly et al. 1998a). This means that the most important organisms caught were large predators such as sharks and large groupers, while today the most important targets are medium-size benthic-feeding fishes. The decline in mean trophic level of fish landed in only one decade (1980s) was greater than that of the global marine fisheries since 1950, and comparable to the largest regional declines in Canada, northwest and western central Atlantic, and south Pacific (Pauly et al. 1998a, 2001). These estimates are, however, conservative. The first impacts of a fishery are reduction in abundance and size of the target species. Because small individuals tend to have lower trophic levels than large adults (Pauly et al. 1998a, b), the decline in mean trophic level of the catch must have been greater than reported here. These results indicate that the coastal fisheries in the Gulf of California have had comparatively stronger impacts in the short term than most other fisheries in the world. Although there were no rigorous fisheries statistics at the species level for the Gulf of California, the low variance in the data obtained from independent interviews (Figure 3) allows us to believe that the patterns described in this study are consistent.

Sharks were among the most important species in the catch in the 1970s, but now have been replaced by smaller species of bony fishes. The decline in nearshore shark catches may be related to an offshore shark fishery and to the fact that the fished coastal sites may harbor nursery areas. The possible interactions between the coastal artisanal

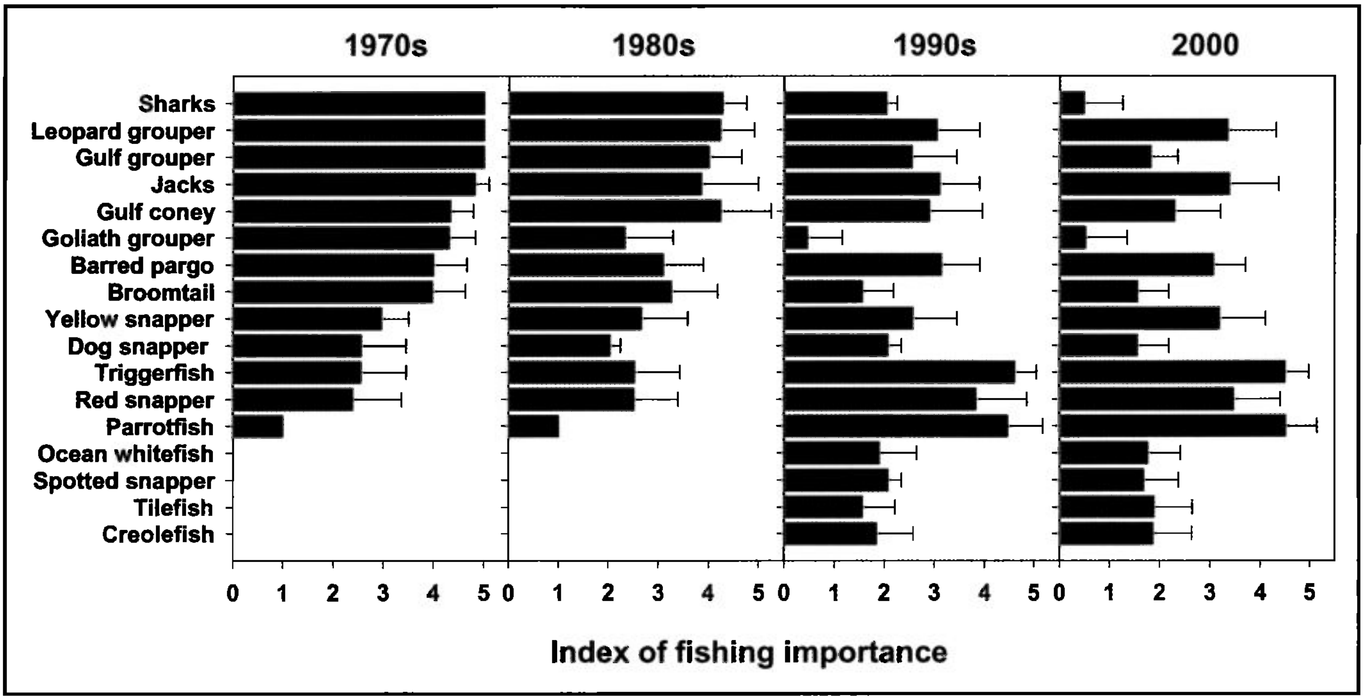


Figure 3. Shifts in fish catches in the southern Gulf of California coastal fishery. Bars represent index of fishing importance (mean ± S.E.) (see text for details). Leopard grouper (*Mycteroperca rosacea*); gulf grouper (*M. jordani*); jacks (*Caranx caballus, C. caninus* and *C. sexfasciatus*); gulf coney (*Epinephelus acanthistius*); goliath grouper (*Epinephelus itajara*); barred pargo (*Hoplopagrus guntheri*); broomtail (*M. xenarcha*); yellow snapper (*Lutjanus argentiventris*); dog snapper (*L. novemfasciatus*); triggerfish (*Balistes polylepis*); red snapper (*L. peru*); parrotfish (*Scarus ghobban, S. compressus,* and *S. perrico*); ocean whitefish (*Caulolatilus princes*); spotted snapper (*L. guttatus*); Pacific tilefish (*Caulolatilus affinis*); creolefish (*Paranthias colonus*).

fishery, and the sport and offshore fisheries targeting pelagic species are not clear and cannot be explored at present because data for the latter is yet unavailable. Nonetheless, the existing data indicate that sharks were abundant in shallow rocky habitats in 1970, where they now have been depleted.

The decrease of the mean trophic level of the catch is also associated with the disappearance of some spawning aggregations of large predatory fishes (such as the goliath grouper) in the southern Gulf of California due to fishing (Sala et al. 2003). The elimination of these aggregations accelerates the decline in mean trophic level at a rate higher than that caused by a fishery targeting non-reproductive individuals. In order to prevent further declines, fisheries management in the Gulf of California needs to incorporate the spatio-temporal patterns of fish spawning.

The removal of large predators from marine ecosystems has cascade effects on food webs (Estes et al. 1998; Jackson et al. 2001). Our results clearly indicate that increasing fishing pressure causes significant changes in the structure of the fish assemblages beyond the direct effects on target species. This supports at local scales Pauly et al.'s (1998) hypothesis that landing data can be used as ecosystem indicators, that is, changes in mean trophic level of the catch reflect changes in the ecosystem. The results of this study suggest that reducing the potential density of

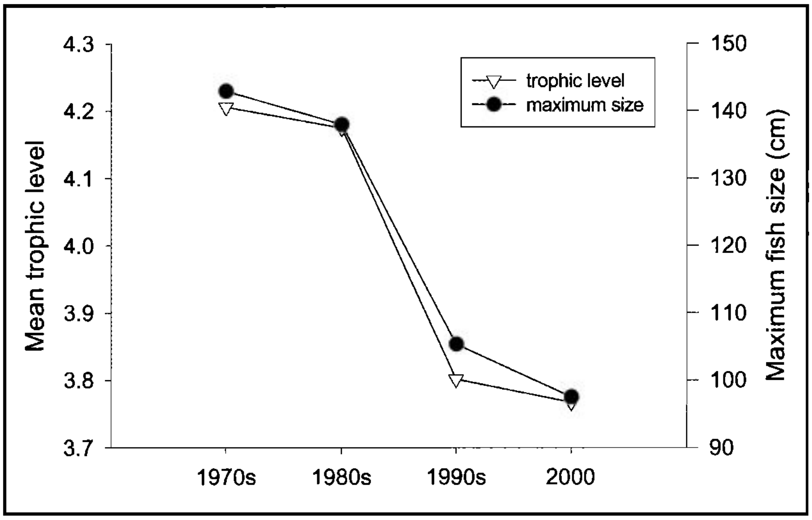


Figure 4. Temporal changes in mean trophic level and maximum fish size of coastal fisheries landings in the southern Gulf of California.

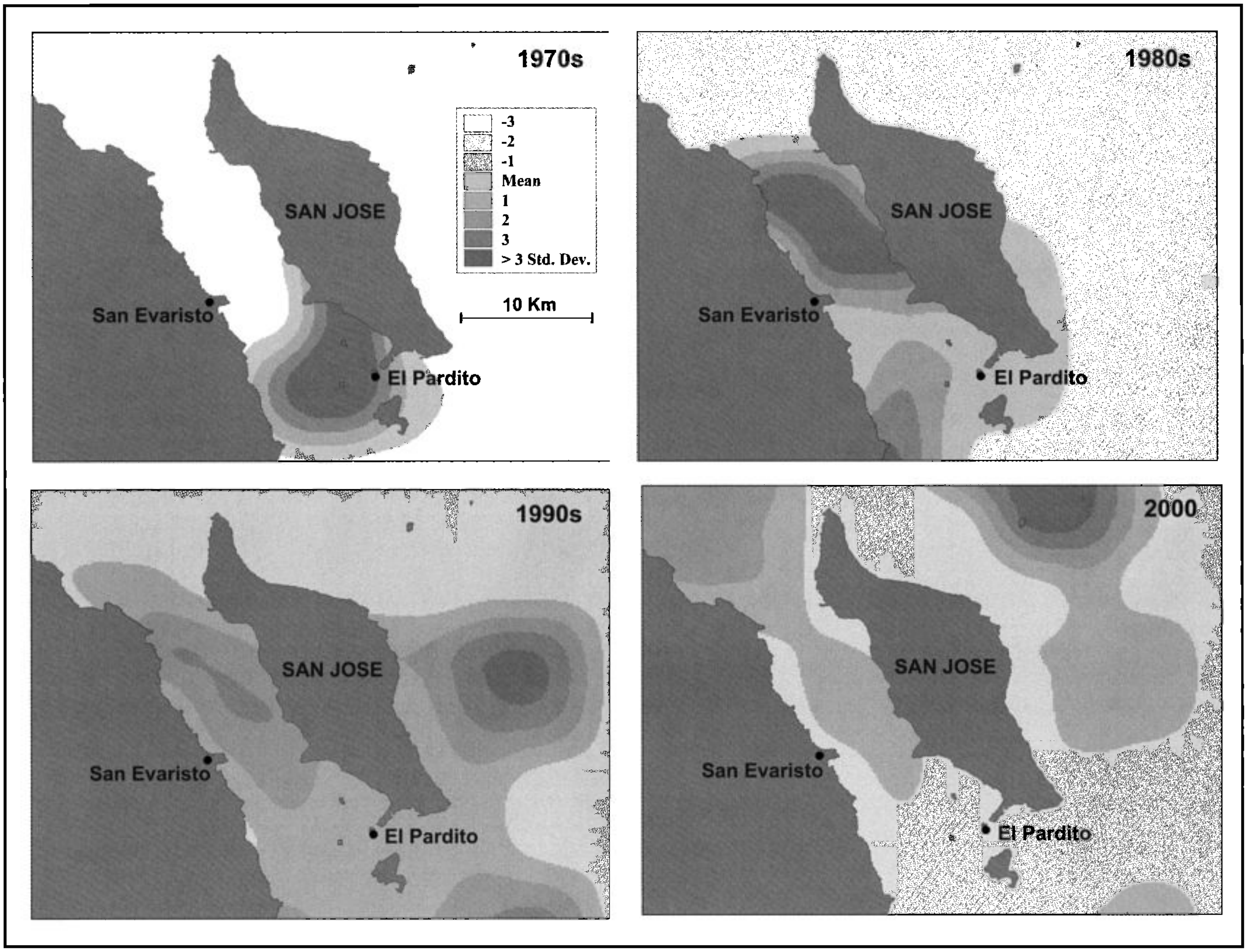


Figure 5. Small scale changes in fishing grounds over time around El Pardito fishing village. Values are deviations from mean fishing use.

boats below 7 boats/km^2 could prevent marked reductions in average fish size and the degradation of fish assemblages. This means that fisheries management should be spatially-explicit and regulate effort as a function of 1) number of boats per fishing camp and 2) the density of boats on fishing grounds at any time.

The overall patterns of species shifts, and decline of CPUE and mean trophic level indicate that coastal fisheries in the southern Gulf of California are unsustainable. Food web collapses might not have occurred yet because the decline in mean trophic level has not been associated with overall declining catches (Pauly et al. 2001), although most species showed stagnant catches. Although coastal fisheries regulations for sharks and finfish in the Gulf of California theoretically limit fishing effort, they do not mention how it is to be reached, beyond restricting fishing zones and gear specifications (DOF 2000). There are no fishing quotas, and enforcement is virtually non-existant. Urgent measures need to be taken to develop and implement sound ecosystem-based fisheries management, while the use of certain types of fishing gear (mainly gillnets) is revised. Protecting those species at risk of local extinction (Musick et al. 2000) and the spawning aggregations of commercial species (Sala et al. 2002, 2003) is also necessary.

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Figure 6. Mean size (± S.E.) of four abundant reef fishes in 21 sites along a gradient in fishing pressure in the southern Gulf of California. N= number of individuals for which size was estimated during visual censuses.

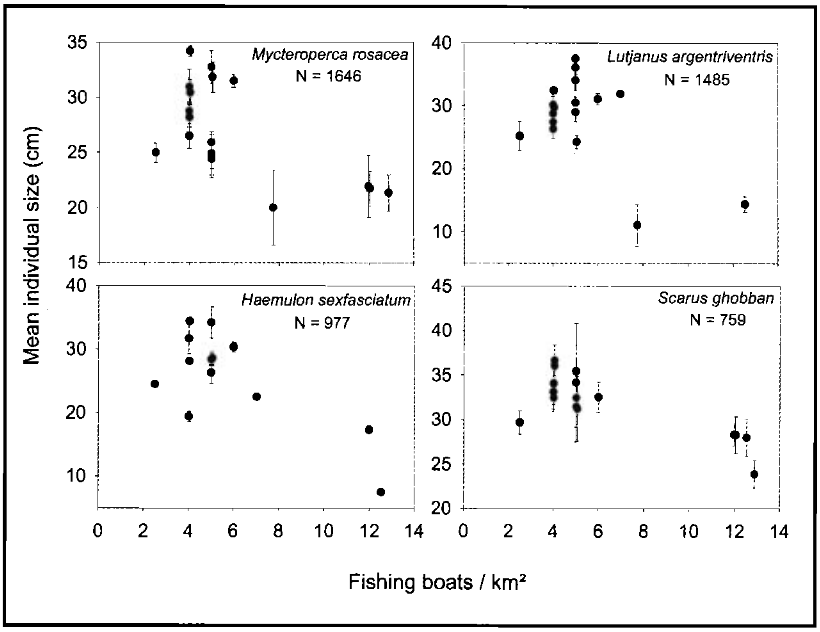
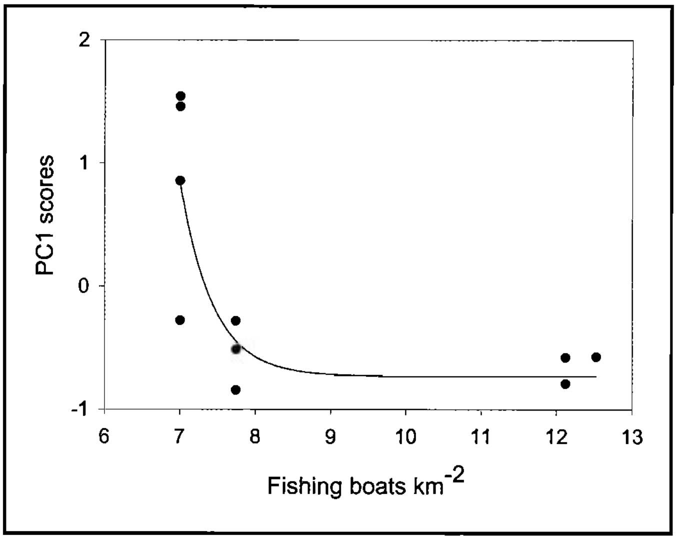


Figure 7. Changes in the structure of fish communities on rocky reefs along a gradient in fishing pressure. Community structure is expressed as the score on the first axis of a principal component analysis, providing a quantitative description of species abundance similarity at different sites. Fishing pressure explains 99% of the variance in the data.



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