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The Peruvian artisanal fishery: Changes in patterns and distribution over time

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ABSTRACT

Since 1996, the Peruvian Marine Research Institute (IMARPE) has been collecting data on catches by vessel, species, weight (kg), gear type and fishing grounds for all major ports of the artisanal fishery. At present, this fishery has exclusive rights to undertake commercial fishing operations within 5 miles from the Peruvian coast. During this period there have been significant changes in the composition and spatial pattern of the artisanal fishery including a reduction in catch of sardine and mullet, and increases in catches of jumbo squid, scallops and dolphin fish. Of particular note was the effect of the El Niño of 1997–1998, with a major reduction in the catch of anchovy and silversides and increases in shellfish (mussels and scallops), reflecting a shift during this period from a pelagic to a benthic dominated system. While the fishery has undergone relatively large changes in species composition of catches there has been a relatively steady level of catch per trip for target species and a modest decrease in numbers of trips in the fishery. To some extent the observed changes reflect changes in environmental conditions, with a warmer period before 1999 and a cooler, higher upwelling period since then. The environmental changes were accompanied by the rapid increase of jumbo squid, a voracious predator on many commercial fish species since 1999. However, some changes reflect changes in economic conditions, for example higher oil prices and decreased selling price of many species resulting an increased focus on high value fisheries and exports including the use of set lines to produce a higher quality end-product and the holding of shellfish in pens in the sea to increase their size and bring a higher price. The Peruvian artisanal fishery features strong seasonal variation in some species, generally sustained catches over a long time period, but changes in species dominance in the catches, reflecting a long-term regime-shift-like pattern in this highly productive region as well as the generalist nature of the fishery.

1. Introduction

Many fisheries of the world have experienced stock reductions due to overfishing (FAO, 2002) and many species are overexploited (25% overexploited or depleted and over 50% fully exploited; FAO, 2005). After a long period of increasing world catches, fueled in part by investment in fisheries in developing countries by the World Bank, catches have stabilized and even declined (FAO, 2005). However, catch statistics often ignore catch by artisanal fisheries because these fisheries are difficult to sample and because reporting of catches are often incomplete. Too, these fisheries provide much of the fresh fish for local markets, provide employment for large numbers of people and may harvest significant amounts of economically valuable stocks. Little is known about changes in catch and effort in artisanal fisheries and their response to changing economic as well as environmental conditions in the Peruvian Humboldt Current System (Fig. 1).

Artisanal fishing in Peru produces between 200,000 and 400,000 tons of catch per annum (Fig. 2), which is primarily consumed directly through local markets in Peru. Catches from the artisanal fisheries are important not only in terms of volume but also for its socioeconomic effect, being a source of employment and sustenance for a significant number of Peruvians. Its rate of growth has, however, been slower than other sectors of the economy and the artisanal fisheries sector has not received the needed support to achieve sustainable growth. Nonetheless, the number of fishers has increased 34% in the last 10 years to almost 38,000, while the number of vessels has increased 54% to almost 10,000 (Estrella, 2006). Also, important changes in species composition in the catch have been observed, such as the recent predominance of the jumbo squid (*Dosidicus gigas*) and a reduced level of many finish catches (Figs. 2 and 3).

The Peruvian Marine Research Institute IMARPE (Instituto del Mar del Peru) has collected detailed data on Peruvian artisanal fisheries catches since 1996, with information on each fishing trip including catches by species, location of fishing sites (to an accuracy of 1 nautical mile), gear type, port of landing, time of fishing and various details about the fishing vessels (e.g. tonnage,

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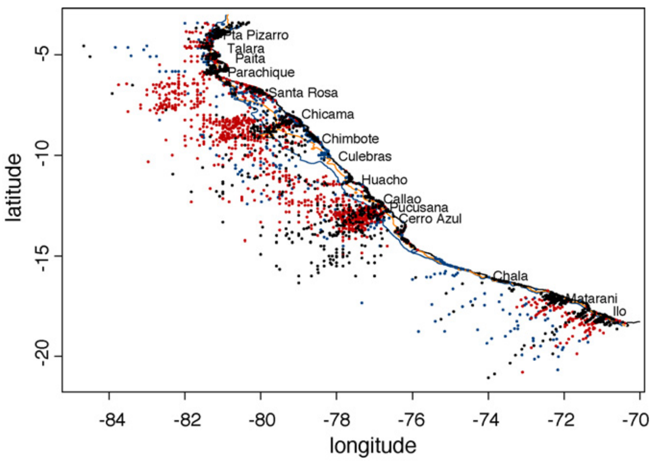


Fig. 1. General range of coverage for the Peruvian artisanal fishery shown by capture locations per trip for the periods summer 1998 (blue), spring 2001 (red), and winter 2004 (black). Major ports are shown, as are the 100-m and 200-m isobaths. The coverage in these three seasons is typical of the artisanal fishery coverage. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

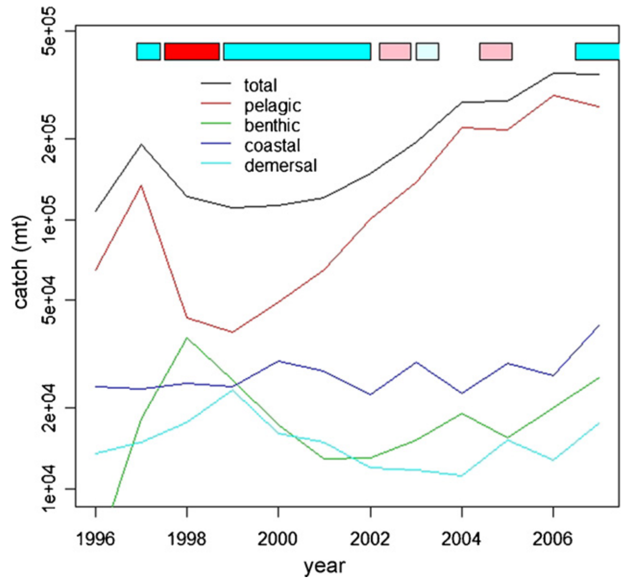


Fig. 2. Graph of the major groups in the artisanal catch from 1996 to 2005 including pelagic and demersal species, coastal species and benthic species. Also shown are the total catch and the time periods of sustained warm and cool temperatures using red for warm periods and cyan for cold periods. The strength of the temperature anomalies at Chicama, Peru during these periods is reflected in the intensity of the cyan (cool periods) and red (warm periods) used to denote the cool and warm epochs respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

hold capacity, length, and horsepower). The Peruvian law defines artisanal fisheries as that being conducted by boats with less than 32.6 m^3 and 30 mt hold capacity (Legislative order No. 012-2001-PE), larger vessels being defined as belonging to the industrial fishery. This unique data set provides insight into the workings and changes of a large artisanal fishery and also can be used as an example of what can be learned with such data if collected by other countries in the future. Overall, Peruvian fishery catch is heavily dominated by the industrial anchovy fishery, a fishery that, under high production conditions (such as since 1998) has maintained a catch of over 10 million metric tons annually (Ñiquen et al., 2004), a truly astounding quantity by world fishery standards. To protect the artisanal fishery the Peruvian government has, since 1992, mandated that the industrial fishery may not fish within 5 nautical miles of the coastline (Executive order N° 017-92-PE; Fig. 1), reserving this region for the artisanal fishery. In special circumstances, such as in El Niño, the anchovy stock is largely confined within 5 nautical miles of the coastline, potentially creating conflict between the artisanal and industrial fisheries that may try to enter the coastal zone of 5 miles reserved for the artisanal fishery, with

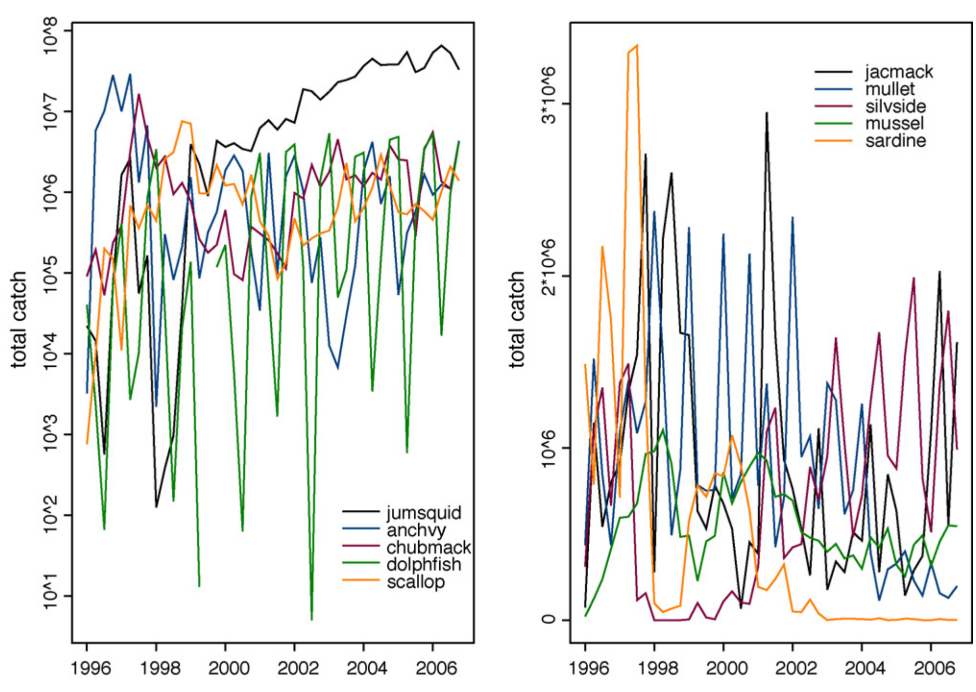


Fig. 3. Overall catch (mt) on a seasonal (3 months per season) basis for the five most important species (left panel; logarithmic scale) and the sixth through tenth most important species by catch biomass (right panel) in the Peruvian artisanal fishery 1996–2006.

Table 1
List of principal species groups caught in the Peruvian Artisanal Fishery including the scientific and common names of each species.

Species group	Group Spanish name	Species in group
Anchovy	Anchoveta	*Engraulis ringens, Anchoa* sp., *Anchoa nasus, Cetengraulis mysticetus*
Bonito	Bonito	*Sarda chiliensis chiliensis*
Chub mackerel	Caballa	*Scomber japonicus*
Crab	Cangrejo	*Cancer* sp., *Platyxanthus* sp., *Platyxanthus cokeri, Euphylax robustus, Euphylax dovii, Cancer setosus, Platyxanthus orbignyi, Portunus asper, Callinectes toxotes, Cancer porteri, Callinectes arcuatus,*
Common dolphin fish	Perico	*Coryphaena hippurus*
Drum	Lorna	*Sciaena deliciosa*
Grunts	Cabinza	*Isacia conceptionis*
Gurnard	Falso volador	*Prionotus* sp., *Prionotus stephanophrys*
Jack mackerel	Jurel	*Decapterus macrosoma, Selar crumenophthalmus, Trachurus picturatus murphyi*
Jumbo squid	Pota	*Dosidicus gigas*
Mullet	Lisa	*Mugil curema, Mugil cephalus*
Mussel	Choro	*Aulacomya ater, Choromytilus chorus*
Rock shell	Caracol	*Stramonita chocolata*
Sardine	Sardina	*Sardinops sagax sagax, Etrumeus teres*
Scallop	C_abanico	*Argopecten purpuratus*
Sculpin	Camotillo	*Normanichthys croockeri, Diplectrum pacificum*
Peruvian rock seabass	Cabrilla	*Paralabrax humeralis, Paralabrax callaensis*
Skipjack	Barrilete	*Katsuwonus pelamis, Auxis rochei, Euthynnus lineatus*
Snake eel	Anguilas	*Ophichthus pacifici, Ophichthus grandimaculatus*
Squid	Calamar	*Loligo gahi, Lolliguncula panamensis, Lolliguncula* spp., *Loliolopsis diomedeae*
Silversides	Pejerrey	*Odontesthes regia regia.*
Weakfish	Cachema	*Isopisthus remifer, Cynoscion analis*
Largehead hairtail	Pez cinta	*Trichiurus lepturus*
Hake	Merluza	*Merluccius gayi peruanus*
Deepbody thread herring	Machete de hebra	*Opisthonema libertate*

an overlap of fishing grounds. This would likely have an adverse affect on the artisanal fishery, since the anchovy purse seines can also harvest significant amounts of other species (including silversides and other species of food fish) that are the main targets of the artisanal fishery and on which many fishers using smaller fishing vessels depend for their livelihood. The Peruvian coast is a region of exceptionally high and sustained upwelling (Thomas et al., 2001), dominated by the Humboldt Current System and, as such, it might be expected to sustain a larger artisanal fishery than less productive coastal areas in other countries. Also, though the artisanal fishery has exclusive fishing rights to the 5 nautical miles nearest the coast they are not restricted to this area and often capture fish as far offshore as 200 nautical miles (Fig. 1). Catch statistics available before 1996 were less precise and incomplete, were only available on an annual basis, made no distinction between industrial and artisanal fishery and included no further information on performance of the different sectors of the fishery (Flores et al., 1994, 1996, 1997, 1998).

The Peruvian artisanal fishery is a highly variable fishery, with multi-gear boats having multi-species catches. The major species groups in the fishery are given in Table 1.

All combinations of gear may be found in both large and small artisanal vessels. Table 2 shows the most frequent ranges of storage capacity and trip length (IMARPE artisanal database, unpublished data), although there are exceptions. For example, there are long line boats with 10 mt capacity, that frequently fish dolphin fish or sharks, but, during winter, when these species move farther offshore they fish jumbo squid because they are closer and more abundant. Some gear types, for example gillnet, are highly variable in trip length. When used close to the coast trips they usually last 1 day; however, there are larger gillnets that can have trips as long as 5 days. Divers using compressed air have the same pattern. Normally they dive a single day, but some boats overnight in islands or more remote fishing zones with trips lasting up to 4 or 5 days.

With the future of the protected status of the Peruvian artisanal fishery in doubt, due to possible illegal incursion of the industrial fleet into coastal waters or possible legislation reducing the protected status of the artisanal fishery, this overview of the trends and patterns of the current fishery provides insight into the current health of this fishery and its likely responses to possible changes in the maintenance and extension of the current 5-mile coastal reserved artisanal zone, if eventually they will have to compete with a large industrial fishery in what previously was solely artisanal fishery waters. Also, analysis of changes in seasonal and temporal patterns of species composition in the catches and of the fishing trips informs other questions such as the effects of ENSO events (El Niño and La Niña) and of regime shifts (La Vieja cool regime and El Viejo warm regime) on catch and sustainability of the fishery. Finally, we want to investigate whether current trends in catch and species composition are compatible with a healthy fishery or suggest a declining or failing one.

Table 2
Range of storage capacity and trip duration by gear type.

Gear type and/or rigging	Maximum storage capacity (mt)	Trip duration (days)
Hook line (fish)	≤5	∼1
Hook line (jumbo squid)	5–10	1
Trap (eelers)	15–20	2
Trap (crabber)	1	1
Gillnet (*)	≤5	5
Purse seine (pelagic)	≤5	1
Purse seine (demersal)	≥10	2–5
Long line (coast)	≤5	1–3
Long line (offshore)	≤10	7–20
Compressed air diving	≤5	1
Shrimp trawl	5–8	1
Fish trawl	≥12	1–3

2. Data sources and analysis

The IMARPE database for Peruvian artisanal fishery landings was developed in 1996 in response to governmental legislation that required artisanal landings to be recorded and maintained in government records. For each trip the following data were recorded: day of landing, vessel or boat number, number of fishing areas visited in each trip, gear type used in each fishing area, zone, latitude and longitude in each fishing area, landing port, kilograms of each species caught in each fishing area and the georeferenced location of the individual fishing sets. A separate database contains information about the vessels including tonnage, length, and registration number, year of construction, building material, and horsepower. These data are contained in an ORACLE database and are proprietary to IMARPE, since they contain information of a commercially sensitive nature. For the period prior to 1996 data on captures of individual species are available from IMARPE on an annual basis (Flores et al., 1994, 1996, 1997, 1998).

We somewhat reduced the large amount of data and simplified the large number of species caught, many of which were in related groups, by dividing the species landed into species groups (except for species which were of special interest to be distinguished from other species in the same species group; Table 1). The data used for this paper run from winter 1996 through spring 2006 (i.e. December 2006), a period spanning the El Niño of 1997–1998, the La Niña of 1998–1999 and the generally cooler regime (La Vieja) after 1999, a period when the pelagic zone was dominated by anchovy (Chavez et al., 2003; Ñiquen et al., 2004).

The total catch for the 10 most important (in overall catch) species were plotted against time by season. To examine the catch patterns of these dominant species we divided the total catch into catch per trip and numbers of trips. By focusing on individual species groups we bypassed (or reduced) the problem of developing a standard measure of catch per unit effort, since such a measure is difficult when variable gear types and target species are considered. We modeled the catch per trip of each of the dominant species (excluding anchovy, because that species, although it is a dominant species in the artisanal catch, is caught in numbers two orders of magnitude larger by the Peruvian industrial fishery; Ñiquen et al., 2000) using a generalized additive model (GAM; Hastie and Tibshirani, 1990) of catch per trip by species as a function of latitude and distance from the coast of the region fished for that species (in cases where multiple locations were fished – less than 5% of the trips – we considered only the principal location fished, since we had no way from the database of separating the catch at each location), and the year and month of the trips. To compare this with the pattern of the fishing trips we plotted histograms of the distribution of number of trips for each species as a function of the same covariates (e.g. where and when they fishery including latitude, coast distance (nautical mile), year and month). GAM is a nonparametric regression technique that generalizes multivariate linear regression by relaxing the assumptions of linearity and normality. Any underlying distribution from the exponential family (including binomial, normal, Poisson and Gamma) can be chosen. The linear assumption is replaced by an additive assumption (i.e. the dependent variable is modeled as a sum of nonparametric smooths of the covariates). Graphical output includes the smooth effect of each significant covariate in the model on the dependent variable (with the overall mean subtracted). An asymptotic significance test is used to test the hypothesis of the significance of each of the covariates. With data sets as large as ours (between 80,000 and 300,000 trips having captures of each of the dominant species over the 11 year time period) asymptotic tests are robust. We chose the normal distribution from the exponential family because residuals were normally distributed based on a Q-Q Kolmogorov test for normality. Additionally, we computed the percentages of trips and catch using each gear type for each of the dominant species. Most of the fisheries for the dominant species were either exclusively of one gear type or were dominated by a single type of gear. Thus it was possible to look at catch per trip and numbers of trips as standards within that species. For the few species groups where several dominant gear types were used to catch a species we performed the GAMs separately for each dominant gear type.

To examine the relationship between observed catch patterns and environmental conditions, catch of coastal fish species, benthic species, more oceanic pelagic species and demersal species were plotted over the study period along with indication of periods of El Niño, La Niña, and warm and cold periods, termed El Viejo and La Vieja (Fig. 2; Chavez et al., 2003). These periods were determined from temperature anomalies off Chicama, Peru, a location that correlates well with temperature anomies at most other Peruvian coastal temperature stations (Ayón et al., 2004; Ayón and Swartzman, in press). Finally, long-term annual catch for nine of the ten most important species groups in the artisanal fishery (excluding anchovy) were graphed to provide a long-term perspective on observations made during the 1996–2006 period for which detailed data on fishing patterns were available (for several species these included combined industrial and artisanal fisheries because separate records were not kept for these two fisheries before 1996).

3. Results

Over the last decade there has been a marked change in the composition of the catch since the ENSO events of 1997–1998. Earlier coastal fish predominated, while after they were replaced as dominants by benthic and pelagic species, especially by jumbo squid. Despite these changes the total annual catch in the artisanal fishery before and after the ENSO was similar (Fig. 2). However, there was a general reduction in pelagic and coastal fish catch during ENSO.

The total seasonal catch for the ten most important (by overall catch for the entire time period) species (Fig. 3) suggests high temporal variability in the catch patterns of the Peruvian artisanal fleet. The five most important species are jumbo squid, anchovy, chub mackerel and dolphin fish and scallops (Table 1). The jumbo squid catch has increased drastically between 1999 and 2004 and dolphin fish catches have increased over this time period as well (Fig. 3), while anchovy, sardine and mullet catches have declined in the artisanal fishery catch (sardine drastically).

While overall catch gives a picture of temporal change in species importance in the artisanal fishery insight into the nature and patterns of the fisheries can be gained by examining the relationship of the catch per trip of the important species with location and temporal parameters. This is provided for these species (excluding anchovy) by GAM modeling of species catch per trip (Fig. 4a–i) as a function of distance to the coast, year, month and latitude. GAM smooths for all species were highly significant based on an asymptotic F test ($p < .00001$) except the effect of distance to the coast on mussel catch per trip (still significant but with $p = .01$). Graphs of the distribution of trips for each of the covariates in each of the GAMS are superimposed below the smooth graphs to provide a comparison between the distribution of catch and the distribution of effort (i.e. numbers of trips). Some of the species, such as silversides, mullet, sardine and the shellfish (mussels and scallops) are caught primarily within 5 nautical miles of the coast and are coastal species. Others, such as jumbo squid and common dolphin fish are caught primarily beyond 5 nautical miles and yet others, such as the chub and jack mackerel, are caught equally within and beyond 5 nautical miles of the coast. Of the dominant species only dolphin fish and mullet show a clear seasonal pattern in the distribution of trips (much lower in winter for dolphin fish and lower in winter for mullet; from trip histograms in Fig. 4), although other species display seasonality in overall catch (scallops, silversides, mussel and sardine; Fig. 3) apparently due to seasonal changes in catch per trip (Fig. 4).

Scallop and mussel catches were extremely high during the La Niña period of 1999 (Carmen Yamashiro, IMARPE, personal communication; Fig. 3).

The dominant species differ in their north-south distribution of trips. Some species, such as chub mackerel, sardine, mullet and dolphin fish had a fairly even distribution of trips over latitude. Jumbo squid and scallops had large fisheries both in the north and in the south of Peru, but little in the central zone (Fig. 4). Jack mackerel

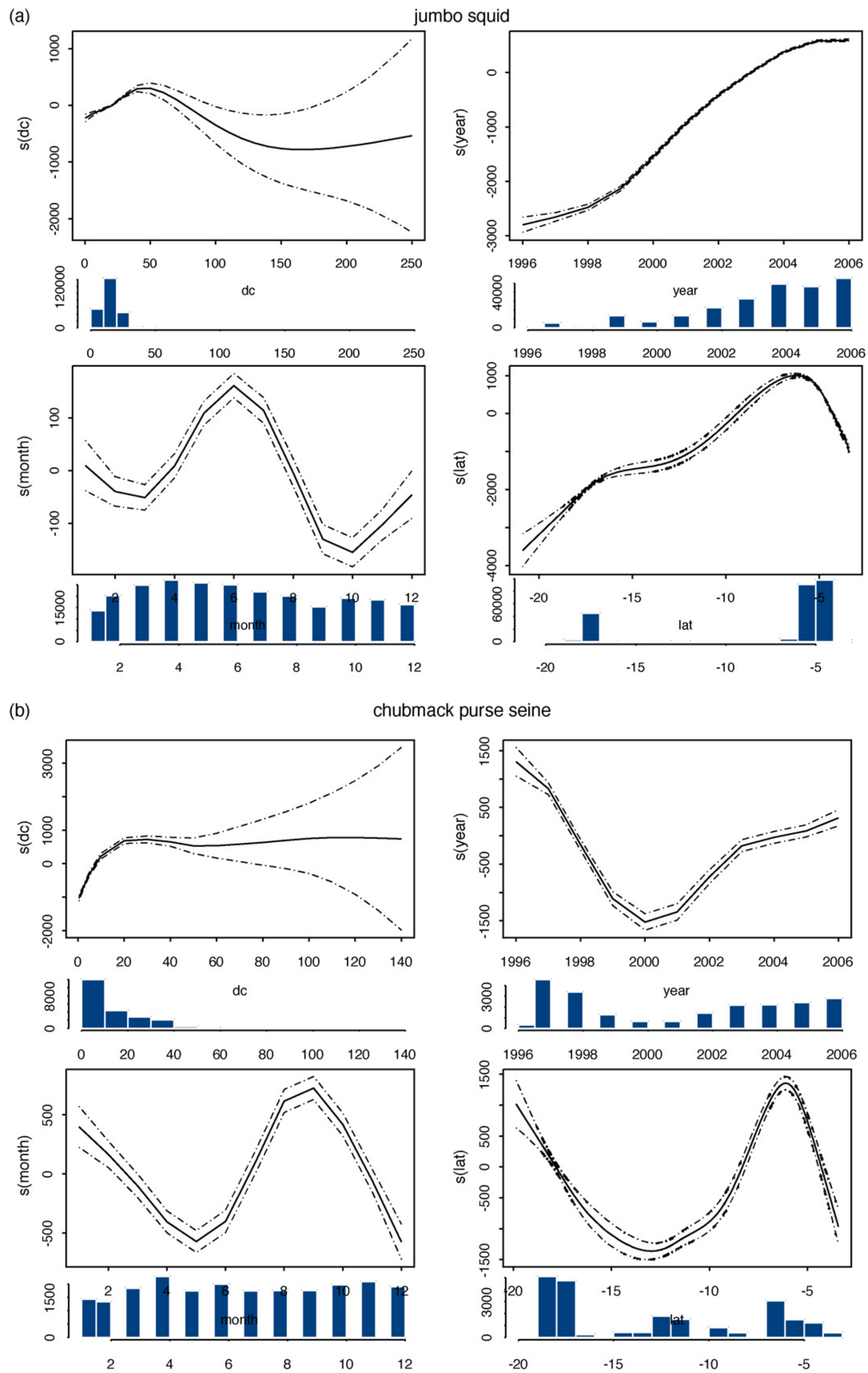
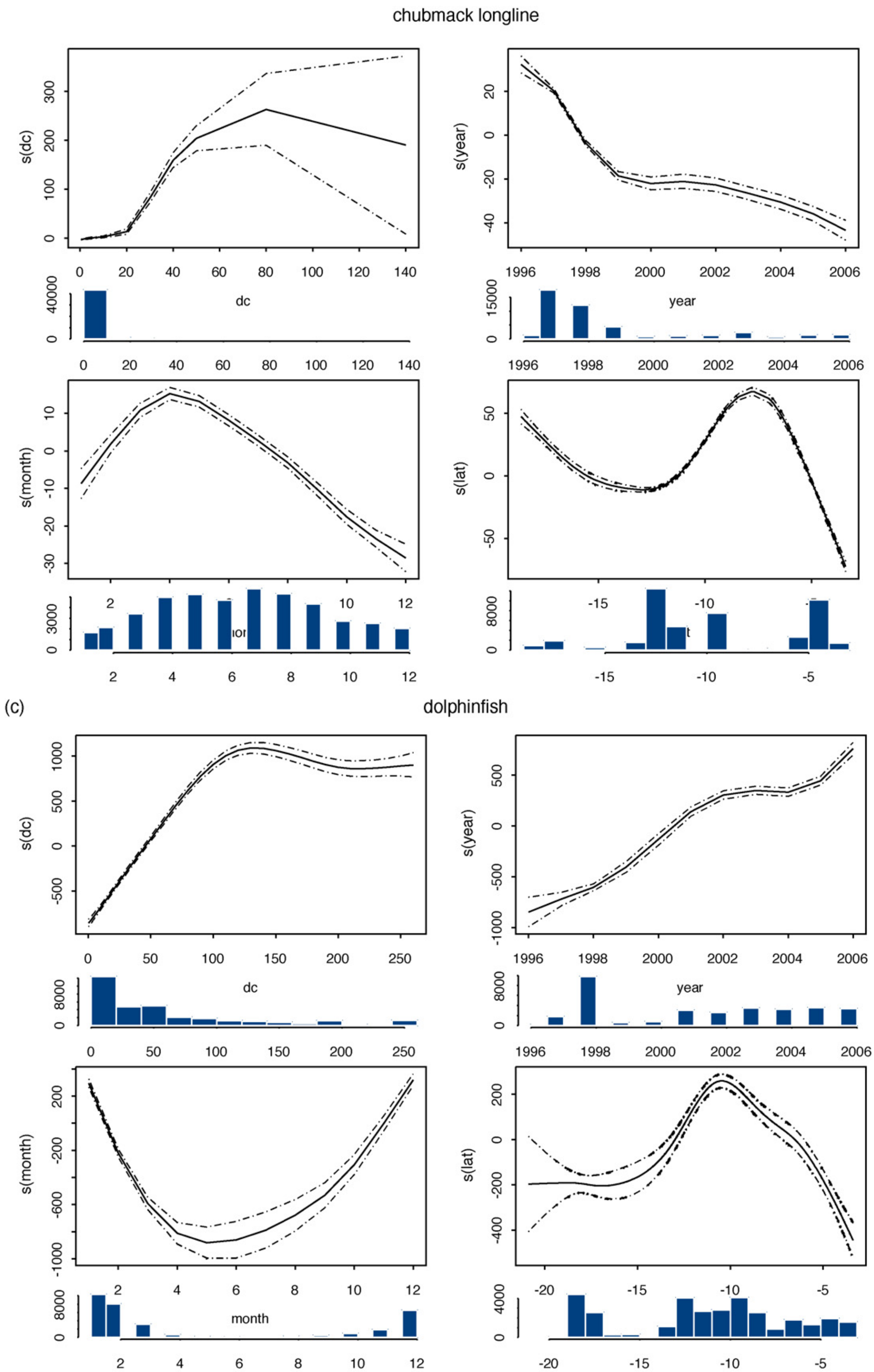


Fig. 4. GAM smooths showing the relationship between the catches per trip (kg) for the dominant species in the Peruvian artisanal fishery 1996–2006 including (a) jumbo squid, (b) chub mackerel, (c) dolphin fish, (d) scallops, (e) jack mackerel, (f) mullet, (g) silversides, (h) mussel and (i) sardine, as a function of distance to the coast (dc; nautical mile), year, month and latitude (lat; °S). The distribution of trips for each of these species are shown by histograms under the *x*-axis for each of the smooths.



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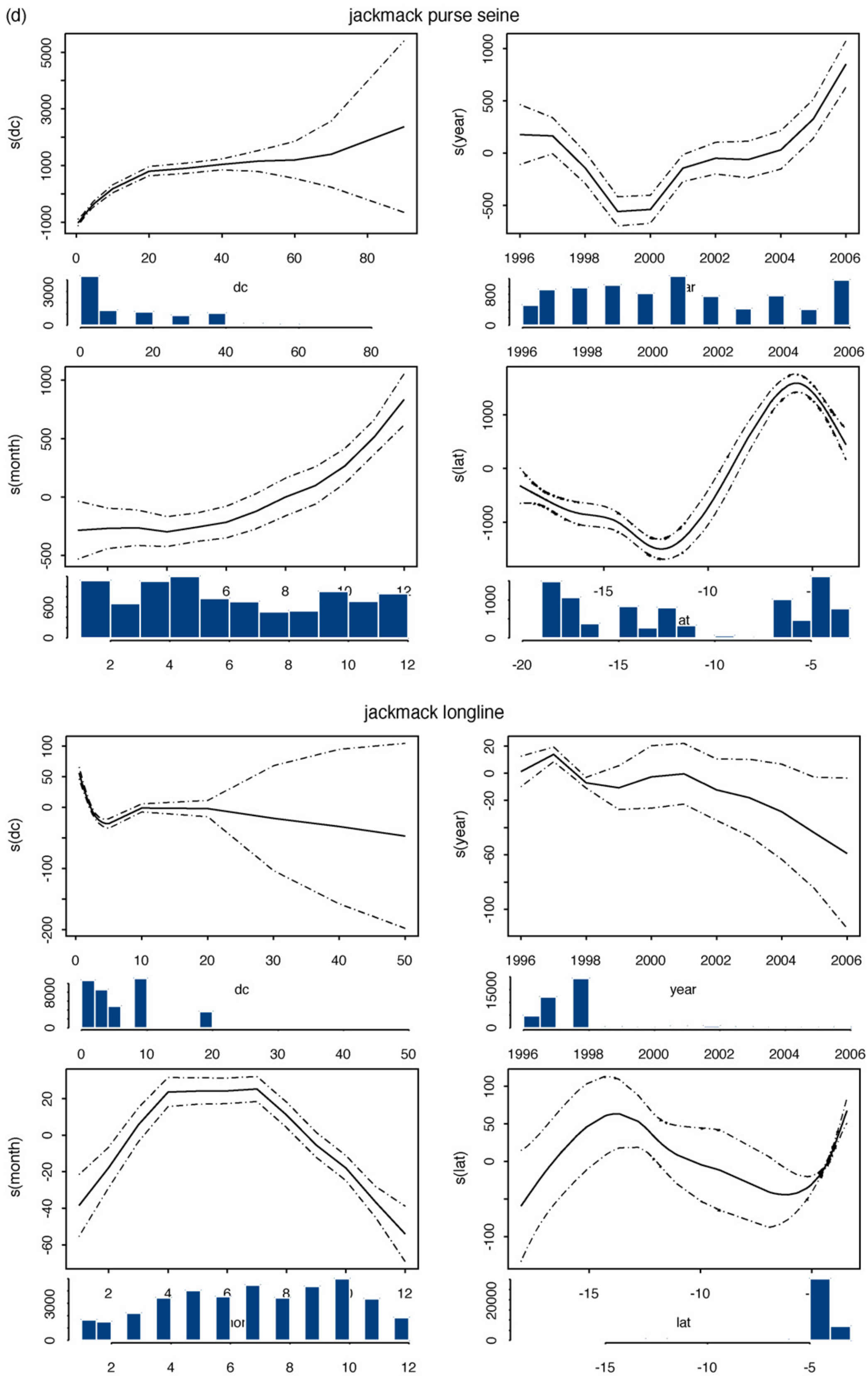

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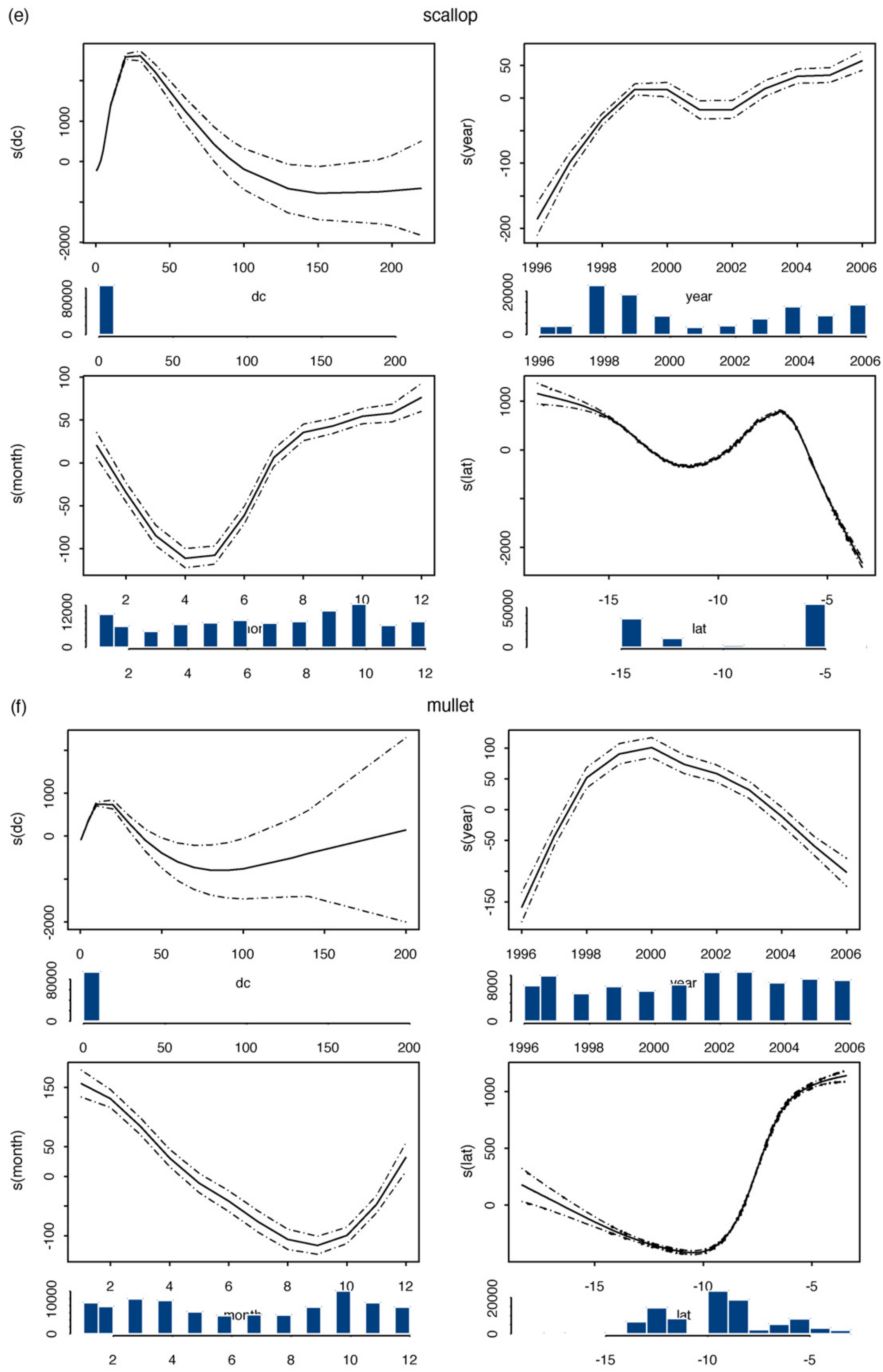

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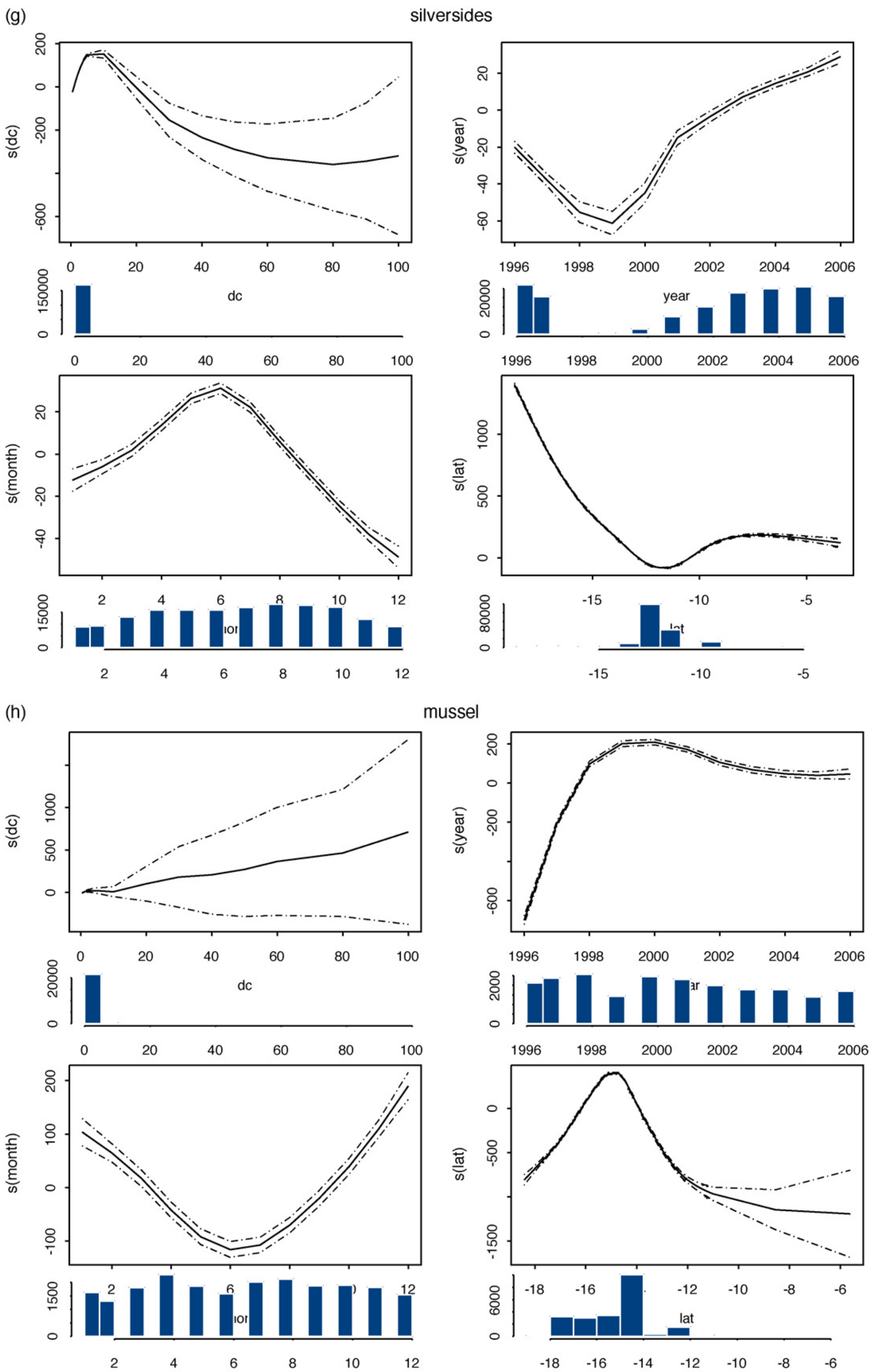

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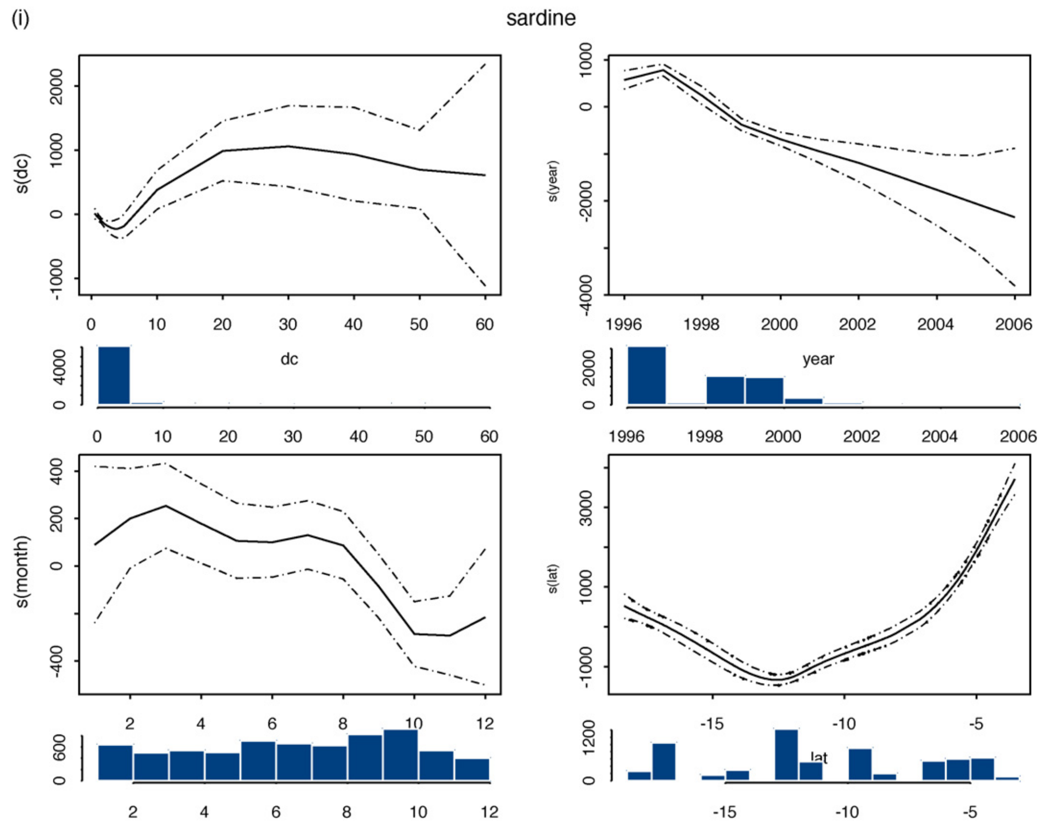

Fig. 4. (*Continued*).

trips (i.e. trips in which jack mackerel were caught) were primarily in the north during this period, while mussel trips were primarily south of 12°S and silversides trips were primarily in the central region around 12°S.

4. Discussion

The pattern of trips for the various species (Fig. 4) reflects a combination of availability of the species as well as the location of population centers, and thereby ports. The disproportionately large number of trips in the central area around 12°S reflects the large population in Lima-Callao (Fig. 1). Similarly, trips in the south and north are near areas of fairly high population. The dearth of trips in some areas simply reflects the natural tendency of the port-based artisanal fishery to fish close to home.

While the Peruvian artisanal fishery is a highly multispecies fishery to give an overview of fishery dynamics we focus on the dominant species. Given the wide range of differences in distribution of locations of catch, trips and gear type within these dominants (Fig. 4) they reflect the dynamics of most of the species taken by the fishery.

4.1. Offshore species

4.1.1. Jumbo squid

Ninety percent of the trips (97% of the catch) were by jigging using lights and 10% by gill nets (3% of the catch). The dominance of jumbo squid in the artisanal fishery catch after 2002 is reflected both in numbers of trips taking jumbo squid and in the catch per trip (Figs. 3 and 4a). Jumbo squid was not taken in significant numbers by the artisanal fishery before 1996 and catch statistics show the increased dominance of jumbo squid off Peru (Fig. 5). Catch per trip increased south to north, justifying the higher number of trips in the north than south. Jumbo squid were mostly fished within 30 nautical miles of the coast, though catch per trip was highest when fished around 50 nautical miles from the coast (Fig. 3a). The current large jumbo squid catch reflects a management concern about the role of jumbo squid as a predator on commercially important fish (particularly juveniles) and as a competitor for feeding as well. However, jumbo squid is an important target species in the northern ports Talara and Paita and the southern port Matarani (Fig. 1) among others. Other squid species also became important in the catch beginning in 2000 (Carmen Yamashiro IMARPE, personal communication).

4.1.2. Dolphin fish

Dolphin fish catches increased between 1996 and 2006 due to a steady increase in catch-per-trip over time. 82% of dolphin fish trips used lines of set hooks, 8% long line and 8% gillnet, although 94% of the catch was by set lines and only 6% by the other gears. Catch-per-trip increased with coast distance up to 150 nautical miles, although numbers of trips decreased with increasing distance from the coast (Fig. 4d) reflecting the increased availability of this oceanic species farther from the coast. The dolphin fish fishery tends to range farther from the coast than other Peruvian artisanal fisheries. Dolphin fish is associated with subtropical superficial waters, which are closer to the coast during warm periods such as summer and El Niño, when they become more available to the artisanal long line fishery, resulting in an increase in trips and catch per trip (Fig. 4d). Dolphin fish captures were low before 1992, and increased significantly after 1998 (Fig. 5) due to a marked increase in the size of the long line fleet targeting dolphin fish (IMARPE, unpublished data) and the willingness of the fishery to move farther offshore to support a new export market for dolphin fish sold as mahi

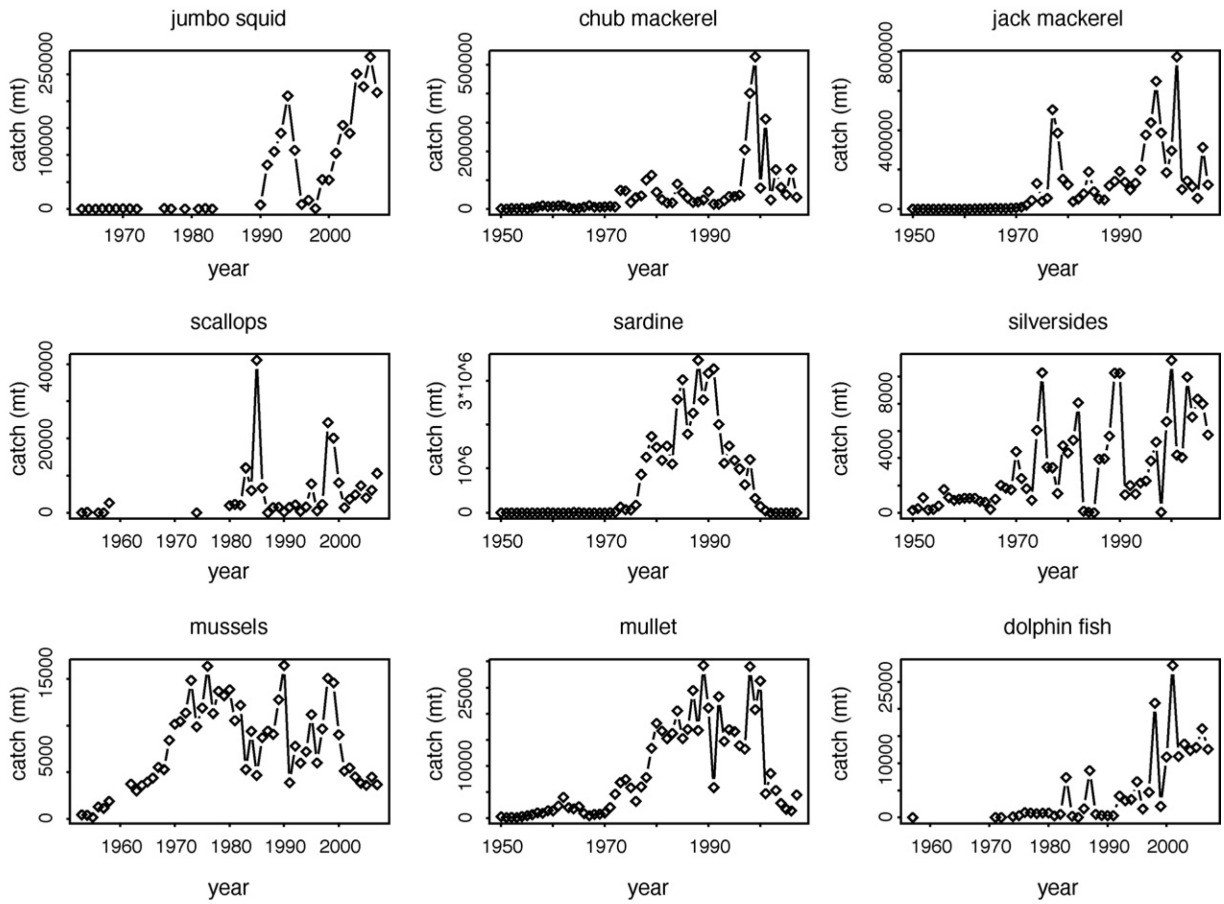

Fig. 5. Annual catch (mt) for dominant species in the Peruvian fishery 1950–2007. These statistics combine landings from both the artisanal and industrial fisheries.

mahi (Quiñones, 2007; Government of Peru production statistics: http://www.produce.gob.pe).

Both dolphin fish and jumbo squid are fished by the artisanal fishery farther offshore than the other dominant species. Yet for both species catch per trip was higher farther offshore than where the bulk of the fishing occurred. There appears to be a conflict between catch efficiency and fuel cost, where the expected higher catch rates offshore are offset by the increased fuel cost to get there.

4.2. *Non-coastal pelagic fish*

4.2.1. *Chub mackerel*

Only about 10% of the overall Peruvian catch of chub mackerel is taken by the artisanal fishery, the majority being taken by an industrial fishery. 61% of the trips by the artisanal fleet use long line, 8% gillnet and 30% purse seine, while catch is dominated by purse seine (96%). Chub mackerel is a historically important target species for both the Peruvian artisanal and industrial fishery (along with sardine, anchovy and jack mackerel). The catch pattern for purse seine (similar to that for gillnet) differs from that for long line captures of chub mackerel (Fig. 4b). Most long line catches are within 10 nautical miles of shore while purse seine trips range farther offshore. Also the long line effort is concentrated more in the central region of Peru than the purse seine. This reflects the opportunistic nature of the long line fishery which may target other species (e.g. dolphin fish) but will take chub mackerel when they are encountered in quantity. Also, the dolphin fish long line fishery is larger in the central region of Peru (Fig. 4d). There has been a marked decline in both catch and trips using long lines for chub mackerel since 1996 (Fig. 4b) but not using purse seines. The rapid expansion of the industrial fishery for chub mackerel to 500,000 mt by 1998 was followed by a marked decline, followed by sustained lower catches, with recovery toward pre-1998 levels in the artisanal fishery (Figs. 3 and 5).

4.2.2. *Jack mackerel*

Peruvian jack mackerel catches are primarily from the industrial fishery (more than 90% recently and historically more than 95%). 76% of the artisanal trips use long lines, 5% gillnet and 18% purse seine with catch distribution by these gear types being 12%, 2% and 85% respectively. There appears to be a strong association between chub and jack mackerel (Miguel Ñiquen, IMARPE, personal communication), and the two species are often encountered in the same region. Trips in the jack mackerel long line fishery have declined over the study period and most trips have been in the north, while the purse seine and gillnet (not shown) catches have been more evenly distributed along the Peruvian coast and have increased in the artisanal fishery since 2000, though not in the industrial fishery (compare Figs. 4e and 5). The long line fishery for jack mackerel, as with chub mackerel, is a bycatch fishery, though jack mackerel is a less expensive product and is only taken near shore as bycatch by the long line fishery.

4.2.3. *Sardine*

Ninety-eight percent of the sardine catch is by purse seine and 2% by gillnet although gillnets comprise 11% of the trips. Sardine almost disappeared from the catch after 2002, and catch per trip was also lower after this time (Figs. 4i and 5) indicating a severe reduction in sardine after this period. This is also seen from acoustic survey data which found no sardine on many surveys after summer 2001 (Gutierrez et al., 2006).

The sardine fishery after 1974 was dominated by an industrial fleet, which caught increasing biomass of sardine up to a peak of 3.5 million mt in 1990, after which the fishery declined rapidly, becoming an entirely artisanal fishery after 1998 (Figs. 4i and 5).

4.2.4. Anchovy

Anchovy was common in the artisanal fishery catch both before and after Niño–Niña but not during the La Niña period because during La Niña anchovy are generally farther from the coast (Gutierrez et al., 2006). The El Niño period had high anchovy catch at first, but not in winter 1997 and in 1998 it was only high in spring (Fig. 3). This appears to be a function of the behavior of anchovy, which crowd close to shore during El Niño periods (Gutierrez et al., 2006). The industrial fishery, which was restricted by severe quotas from catching anchovy during this period, did utilize the 5-nautical mile zone near the coast, although they were technically not allowed to fish there (Ñiquen et al., 2000). The period after 1999 had large anchovy catches in the industrial fishery (Alheit and Ñiquen, 2004), a pattern not reflected in the artisanal fishery anchovy catch, in part due to a general dispersal of anchovy during higher upwelling periods such as occurred more frequently after 1998 (Gutierrez et al., 2006; Swartzman et al., 2008).

4.3. Benthic species

4.3.1. Scallops

Scallops were caught almost exclusively within 5 nautical miles of the coast and catch efficiency was also highest close to the coast (Fig. 4e). 99% of the trips and catch of scallop are by free diving. Catch per trip and numbers of trips increased between 1996 and 1999, probably due to the oxygenation of the benthos by the El Niño of 1997–1998 and resultant increased production in the benthos (Gutierrez et al., in press). Before 1998, scallops were primarily an El Niño fishery, with higher catches occurring after the El Niños of 1983 and 1998 (Fig. 5; Wolff, 1985). However, after 2000, scallops were increasingly 'farmed' by moving small scallops to regions of higher productivity and this has resulted in a sustained scallop fishery even during a cooler epoch (Carmen Yamashiro IMARPE, personal communication). This has supported the continued export of scallops (Quiñones, 2007).

4.3.2. Mussels

Mussels are taken almost exclusively by free diving, using mask, snorkel and grapple hooks. Almost all trips were within 5 nautical miles of the coast (Fig. 4h). Mussels appeared to have a positive response to the El Niño of 1997–1998 and more modest increases were noted after the El Niño of 1983–1984 (Fig. 5). Mussels are generally less preferred than other benthic fish (e.g. octopus, scallops, rock shell) and, as such, their increase in the fishery reflects a reduction in these other target species. Their sessile nature makes them easier to locate, but also easier to overexploit (Carmen Yamashiro, IMARPE, and personal communication). Mussel catches increased from the early 1950s to a fairly steady capture rate between 6 and 16,000 mt through 2000, after which captures have declined due to a combination of somewhat reduced effort and reduced catch per trip (Fig. 4h).

4.4. Coastal fish

4.4.1. Silversides

Silversides are coastal species caught almost exclusively within 5 nautical miles of the coast (Fig. 4g). 93% of silverside trips used gillnets and 6% purse seine, and catch was 69% gillnet and 31% purse seine. The temporal pattern in trips and catch per trip are similar, with reductions during 1998–2000, probably due to the El Niño, which both reduced the silverside habitat, growth and reproduction. Trips occurred throughout the year but catch per trip were highest in winter due to increased availability due to an expansion of their preferred upwelled water habitat (Swartzman et al., 2008). Silverside trips were almost exclusively in the central region (Fig. 4g) due to the wider shelf within this area compared to the narrow shelves both in north and south Peru (Fig. 1). Silversides have been a relatively stable component of the artisanal fishery since 1972, their catch decreasing during warmer periods and increasing during cooler periods (Fig. 5).

4.4.2. Mullet

Mullets are species of the littoral zone, being common near river estuaries and near offshore islands (IMARPE, 2006). 78% of mullet trips used gillnet, 20% purse seine and 2% beach seine, and catch composition is 15% gillnet, 81% purse seine and 3% beach seine. Mullet is a species associated with warmer environmental conditions, in contrast to silversides, although both are coastal fisheries. The spatial pattern of mullet captures is similar between purse seine and gillnet and thus only the total GAM results are shown (Fig. 4f). Mullet was fished almost exclusively within 10 nautical miles of the coast, where catch per trip was highest (Fig. 4f). Mullet trips predominated in the central zone around 8–10°S reflecting the wider shelf in their region and therefore increased preferred habitat (Fig. 1).

The pelagic fish species that dominate the catch, anchovy, chub mackerel, jack mackerel and sardine show a somewhat skewed picture when looking only at the artisanal data because their total catches are or were dominated totally by an industrial fishery. The exclusive fishing rights of the artisanal fishery within 5 nautical miles of the shore skews their catch to be within this region, though catch per trip for all these species is generally higher farther offshore (with the exception of anchovy during El Niño periods). Increased captures in the artisanal fishery for these fisheries may reflect periods when either the stock is low and therefore not targeted by the industrial fishery, or when the industrial fisheries, which have their seasons determined by management (Alheit and Ñiquen, 2004), are not able to fish. Anchovy, for example, was common in the artisanal catch both before and after Niño–Niña but not during the La Niña period. The El Niño period had high anchovy catch at first, but not in winter 1997 and in 1998 it was only high in spring (Fig. 3). This appears to be a function of the behavior of anchovy, which congregate close to shore during El Niño periods (Gutierrez et al., 2006), thereby making anchovy more available to the artisanal fishery, which is not restrained, like the industrial fishery, from fishing in this region.

Separating the total catch by a species into catch per trip and numbers of trips allowed us to examine effort and catch per effort as constituent parts of overall catch. By focusing on single species for analysis we reduce the problem of not having a standard measure of effort (since numbers of trips do not directly reflect effort). Most importantly, however, this fishery is a fishery of opportunity with relatively limited capacity (compared to the larger vessels of the industrial fleet), but with more flexible species targeting. As such catch and effort are as much or even more a reflection of resource availability than of resource abundance. This results in greater variability in captures (both in species composition and catch biomass) than is observed in the industrial fisheries.

This paper presents an overview of the behavior of the Peruvian Artisanal fishery from 1996 to 2006, emphasizing patterns of capture, the relative onshore-offshore and north–south distribution of the fishery, variability of capture and the capture history of the 10 dominant species in the fishery. Our thesis is that the capture pattern was strongly affected by the El Niño of 1997–1998, which resulted in a major shift in species dominance in the fishery.

We provide some explanation for these changes in the changing upwelling conditions before and after the El Niño and resultant changes in the abundance, range and availability of the dominant species. We also informed observations about the artisanal fishery from the 1996–2006 artisanal data through comparison with the (much less detailed) annual capture data for dominant species before 1996.

The fisheries sector plays an important role in the Peruvian economy. However, based on fishing biomass this sector is dominated by the industrial sector, which has more than 90% of the total catch, much of which is sold on the international market. But this context neglects the importance of the artisanal fishery, which provides employment to more people and whose production is oriented toward the Peruvian market. Furthermore, the flexibility of this fishery reflects a market that allows substitution of resources, with a shift from upwelling associated species such as anchovy and silversides, to species that dominate in warmer conditions such as sardine and mullet, and even including El Niño associated benthic species such as mussels and scallops. This flexibility and variety in catch make up suggest a fishery that is in relatively good health.

This work suggests future examination of how changes in species composition of the catch have changed the gear and makeup of the fishery and the behavior of fishers (in terms of distance traveled from port, number of trips and length of trips). For example, how do fishing strategies differ between vessels in different regions and with different target species? We think the fishery responds to changes in abundance and distribution of fish species, regulations (e.g. the 5-mile limit on the industrial anchovy fishery), and economic conditions, such as fish selling price and fuel cost. Better understanding these factors can help to explain the observed catch and trip patterns of the Peruvian artisanal fishery.

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