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Marine fronts are important fishing areas for demersal species at the Argentine Sea (Southwest Atlantic Ocean)

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ABSTRACT

The high primary and secondary production associated with frontal systems attract a diversity of organisms due to high prey availability; this is why a strong relationship between fronts and pelagic fisheries has been shown worldwide. In the Argentine Sea, demersal resources are the most important, both in economical and in ecological sense; so we hypothesize that fronts are also preferred fishing areas for demersal resources. We evaluated the relationship between spatial distribution of fishing effort and oceanographic fronts, analyzing three of the most important frontal systems located in the Argentine Sea: the shelf-break front, the southern Patagonia front and the mid-shelf front. Individual vessel satellite monitoring system data (VMS; grouped by fleet type: ice-trawlers, freezer-trawlers and jigging fleet) were studied and fishing events were identified. Fishing events per area were used as a proxy of fishing effort and its spatial distribution by fleet type was visualized and analyzed with Geographic Information Systems. Oceanographic fronts were defined using polygons based on satellite chlorophyll amplitude values, and the percentage of fishing events within each polygon was calculated. Results showed a positive association between fronts and fishing activities of the different fleets, which suggests the aggregation of target species in these zones. The coupling of the freezer-trawler and jigging fleets (that operate on lower trophic level species; *Macruronus magellanicus* and *Illex argentinus* respectively) with fronts was higher than the ice-trawler fleet, targeting species of higher trophic level (*Merluccius hubbsi*). Marine fronts represent important fishing areas, even for demersal resources, as the distribution of fishing fleets and fishing effort are positively associated with frontal zones.

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1. Introduction

Fisheries are complex and dynamic systems, representing a source of income and livelihood worldwide (FAO, 2010). Fishing affects not only fish stocks but also marine ecosystems (Grafton et al., 2010), representing one of the possible threats to the integrity and sustainability of marine resources (Ye et al., 2012). However, fishing is not evenly distributed in the ocean. An important issue in fisheries research is to understand the distribution of fishing effort, determining where vessels fish (Hilborn, 1985). Fishing vessels do not fish randomly in the distributional area of the target species (e.g., Ellis and Wang, 2007; Stelzenmüller et al., 2008); instead, they search for areas where fish concentrate (e.g., Paloheimo and Dickie, 1964). Thus, fisheries would benefit from predicting and detecting aggregations of fish in space and time (Klemas, 2013). Since fishing activities are distributed in places where certain conditions favor the occurrence of prey (Andrade, 2003), an adequate fisheries management requires the knowledge of fishing effort distribution (Anticamara et al., 2011).

Several pelagic and benthic fisheries are directly or indirectly related to frontal systems (e.g., Patagonian scallop *Zygochlamys patagonica*: Bogazzi et al., 2005; cod *Gadus morhua*: Brynjarsdóttir and Stefánsson, 2004; swordfish *Xiphias gladius*: Podestá et al., 1993; albacore *Thunnus alalunga*: Zainuddin et al., 2008), which would benefit from the identification of these environmental gradients (Olson, 2002). This is evident in the proliferation of the use of satellite and oceanographic data in fisheries management and by fishermen (e.g., Chassot et al., 2011; Klemas, 2013). Currently, vessels targeting pelagic species also employ sea surface temperature and chlorophyll maps to direct their fishing activities (Etnoyer et al., 2004). Thus, fishermen identify specific conditions suitable for the occurrence of target species, directing operations to predetermined locations (e.g., Andrade, 2003), and thus the effort is unevenly distributed (e.g., Stelzenmüller et al., 2008). Therefore, the oceanographic conditions of an ecosystem would affect fisheries by affecting the abundance and distribution of fish in the fishing areas (Agenbag et al., 2003).

Oceanographic structures, such as fronts, are discontinuities in the marine environment influencing the ecology of marine organisms (Leichter and Witman, 2009). In particular, fronts play an important role in reproduction, feeding and migration of fish and squids (Olson, 2002). Frontal systems are characterized by high primary and secondary

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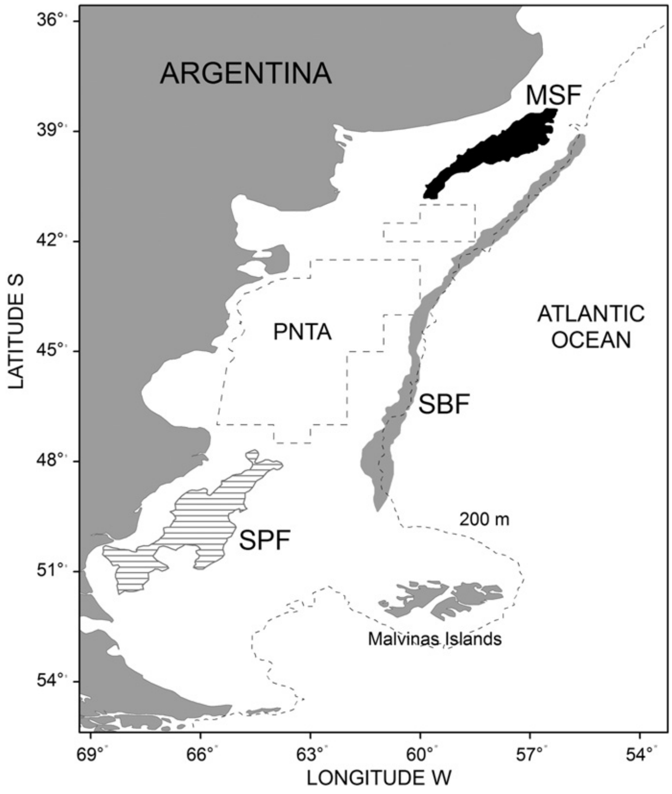

Fig. 1. Study area showing the frontal polygons of the shelf-break front (SBF, gray), the mid-shelf front (MSF, black) and the southern Patagonia front (SPF, horizontal lines); PNTA: Patagonian no-trawling area in 2008.

production (Mann and Lazier, 2006) that is transferred to higher trophic levels within the regional food web. In that sense, fisheries would be related to marine fronts, as their target species would aggregate at or near these oceanographic features.

The association between fronts and pelagic fisheries is better documented than the relationship with demersal fisheries. Pelagic resources, especially large ones (e.g., Atlantic bluefin tuna *Thunnus thynnus*: Druon, 2010; swordfish: Podestá et al., 1993; king mackerel *Scomberomorus cavalla*: Wall et al., 2009; albacore: Zainuddin et al., 2008) seem to be more sensitive to changes in temperature than most demersal organisms and, therefore, it is expected a stronger coupling between the former and marine fronts. Given that in the Argentine Sea the main economical resources are demersal species, it is a suitable scenario for investigating the relationship between oceanographic processes and demersal fisheries.

In this study, we evaluate the relationship between spatial distribution of fishing effort and oceanographic frontal systems in the Argentine Sea. We expect different degrees of association between the distribution of the fishing fleets and fronts, depending on the trophic level of the target species. Thus, it is predicted that fishing fleets targeting organisms of lower trophic level (e.g., the Argentine shortfin squid *Illex argentinus*) would show a stronger relationship with fronts than those fleets operating on resources of higher trophic levels (e.g. Argentine hake *Merluccius hubbsi* and Patagonian grenadier *Macruronus magellanicus*). Although a direct coupling between these fleets and fronts is not expected, we do predict a spatially indirect association, in which fleets would be near the fronts, but their distribution shifted to where currents flow.

2. Material and methods

This study covered the Argentine Sea, including three main frontal systems: shelf-break front (SBF), southern Patagonia front (SPF) and mid-shelf front (MSF; Fig. 1). In order to improve fishery management the Secretariat of Agriculture, Livestock and Fisheries of Argentina implemented a vessel satellite monitoring system (VMS) since the year 2000, to control and monitor fishing vessels operating in this region. The potential of these information sources for ecological studies has been recognized, particularly where comprehensive scientific assessment of patterns and processes involved is complex (e.g., Walker and Bez, 2010; Williams et al., 2010).

To evaluate the relationship between frontal areas and fishing effort, VMS records ($n = 812{,}128$) corresponding to year 2008 were employed. All the fishing fleets were well represented in this data set. Total catches during 2008 were 931,705 t, showing it as a typical year in terms of landings (Martínez Puljak et al., 2010).

Each VMS data has a geographic position (latitude and longitude), date, time, speed and heading of the vessel, registered by a global positioning system (GPS) on board. Each vessel sends information every hour, 24 h a day. Information was divided by fleet type: ice-trawlers (IT), freezer-trawlers (FT) and squid jiggers (J); according to criteria of the Fisheries Management Area of the Argentinean National Undersecretary of Fisheries (Martínez Puljak et al., 2010; Table 1).

VMS does not indicate when a vessel is fishing, thus our estimation of fishing effort (fishing events per area) depends largely on the proper differentiation of fishing vessels activity. Data were filtered to include only those records compatible with fishing activities (hereafter fishing events), using two different criteria, vessel speed and time of the day. For IT and FT fleets, records in which vessel speed ranged between 3.7 and 9.3 km h^{-1} (i.e., 2 to 5 knots, typical towing speeds during fishing activities; Witt and Godley, 2007) were considered fishing events. Given that target species (Argentine hake and Patagonian grenadier) are concentrated near the bottom during daytime, fishing activities are performed during daylight hours, and thus we selected records between 8 a.m. and 8 p.m. For the J fleet, records were selected in which vessel speed ranged from 0 to 3.7 km h^{-1} (0 to 2 knots) and between 10 p.m. and 6 a.m., as this fleet operates during nighttime when its target species (Argentine shortfin squid) perform diel vertical migrations to the upper sea layers (Rodhouse et al., 2013). In this study we had no access to catch data and, although some of the fishing events could be reported with zero catches, this situation is unlikely. At the Argentine continental shelf, fishing fleets operate each year in spatially stable areas and thus, the variability in fishing effort distribution between years is very low (unpublished data). Moreover, there is high correlation between catch distribution and the location of VMS records considered as fishing events (Martínez Puljak et al., 2010).

To identify the fishing and frontal areas, several polygons were constructed. As the fleets analyzed in this study operate all along the Argentine continental shelf (Bertolotti et al., 2001), we constructed a

Table 1
Main features of the three fishing fleets analyzed in the Argentine Sea.

Fleet type	Gear type	Catch cooling	Vessel length	Number of vessels	Target species
Ice-trawlers	Bottom net	Refrigerated	20–71 m	140	Argentine hake (*Merluccius hubbsi*)
Freezer-trawlers	Bottom net	Frozen	56–113 m	6	Patagonian grenadier (*Macruronus magellanicus*), Southern blue whiting (*Micromesistius australis*), Argentine hake
Squid jiggers	Jigging machines	Frozen	32–72 m	90	Argentine shortfin squid (*Illex argentinus*)

polygon (FA, fishing area) delimited by the coastline, the 200 m isobath and the 36° 18′ S and 54° 47′ S latitudes, which included 100% of the fishing events of the three analyzed fleets. This polygon allowed us to calculate the area occupied by fronts relative to the fishing area. As a year-round fishing closure was implemented in the Argentine Sea (Fig. 1), in which trawling activities are banned, this area was not taken into account in the definition of the FA.

To spatially define the frontal systems we used the polygons constructed by Carranza (2009). In these studies, they used monthly satellite chlorophyll data as a proxy for the location of fronts, based on satellite borne radiometric measurements from Sea-viewing Wide Field-of-view-Sensor (SeaWiFS; Feldman and McClain, 2007), available from 1998 to 2006, to produce surface chlorophyll time series. To define the polygons corresponding to the frontal regions, the authors assessed the distribution of amplitude of the annual variations of satellite chlorophyll (aCSAT), instead of using mean satellite chlorophyll values (mCSAT). Satellite chlorophyll has a marked annual cycle associated with variations of solar radiation and stratification, and mean CSAT (mCSAT) shows high values in coastal regions due to the presence of suspended sediment which alter the optical properties of water and overestimate satellite measurements of chlorophyll near shore. Moreover, aCSAT presents a maximum in the middle shelf south of Buenos Aires province (ca. 40° S–59° W), which is not well defined in mCSAT distribution. For these reasons, the frontal areas were defined according to the distribution of aCSAT. At each pixel aCSAT was estimated as the difference between the maximum and minimum monthly averages of the observation period. The shelf-break front (SBF), the southern Patagonia front (SPF) and the mid-shelf front (MSF) were defined in which the amplitude of the annual variations of satellite chlorophyll (aCSAT) was greater than 3.5 mg m^{-3} (Carranza, 2009). Then, the area of each polygon (km^2) and the percentage that each front represents relative to the total fishing area were calculated.

2.1. Spatial distribution of fishing effort

The spatial pattern of distribution of fishing effort by fleet type in the Argentine Sea was visualized and analyzed with Geographic Information Systems (GIS). Data were converted from geographic coordinate system (WGS84) to projected system using the Transverse Mercator projection (UTM, WGS84, 20° S).

To determine areas with different fishing efforts, VMS records identified as fishing events were converted into a continuous raster using the Kernel density estimation function (Spatial Analyst, ArcMap 10). The output cell size was 9.25 km^2 (about 5′; e.g., Martínez Puljak et al., 2010; Sánchez et al., 2010). Six density classes of fishing effort were defined, based on Jenks Natural Breaks Classification method (Jenks, 1967). This method identifies breakpoints between classes using Jenks optimization algorithm, and determines the best location of the values in the different classes by minimizing the sum of intraclass variance. The resulting density plots expressed fishing events per 5′ latitude × 5′ longitude squares (ca. 67.5 km^2 at 38° S).

2.2. Relationship between fishing effort and oceanographic fronts

To estimate the percentage of fishing effort at fronts, and the percentage of the total fishing area represented by each front, the frontal polygons described in Section 2.1 were used.

To evaluate if fishing effort is concentrated in frontal regions, the number of fishing events (by fleet type and month) observed within each front was compared with the number of events expected for the area that each front occupies. A Chi-square goodness of fit test (Zar, 1999) was used to test the null hypothesis of no differences between the observed and the expected fishing events at each frontal system. The percentage of fishing events distributed within frontal polygons in relation to the total records of each fleet in the different months was also calculated. The ice-trawler and freezer-trawler fleets were monthly analyzed. Given that the Argentine shortfin squid fishery extends from February to August (between September and January fishing is forbidden to protect juveniles, Brunetti et al., 2000), the J fleet can be analyzed only during such period (see Table 2).

3. Results

A total of 299,333 fishing events were analyzed from the VMS database. Table 2 shows the number of records by fleet type and month.

Four polygons defined the different studied areas, the fishing area (FA), the shelf-break front (SBF), the southern Patagonia front (SPF) and the mid-shelf front (MSF; Fig. 1). The FA comprised 730,124 km^2, the SBF 34,385 km^2, the SPF 40,871 km^2, and the MSF 22,349 km^2 (4.7%, 5.6% and 3.1% of the total fishing area, respectively).

3.1. Spatial distribution of fishing effort

The ice-trawler fleet operated throughout the year in almost the entire continental shelf (Figs. 2 and 3). During January and February fishing events concentrated in the northern and eastern boundaries of the Patagonian no-trawling area (PNTA), and in the northern part of the shelf-break front (SBF). In March the highest density of fishing effort was distributed in the southeast boundary of the PNTA. From April to June, the highest fishing effort was located north of the shelf, near the shelf-break (Fig. 2). From July to December there were several areas were fishing activity concentrated (Fig. 3), mainly distributed to the north and to the south of the PNTA.

The fishing activity of the freezer-trawler fleet was mainly concentrated between latitudes 50° and 54° S during January, March, April, May, June, November and December (Figs. 4 and 5). During July, August and September there was a concentration of fishing events southwestward of Malvinas Islands that matched the location of the Burdwood-Namuncurá Bank (54° 15′ S–59° W; Fig. 5). In May, June, October, November and December fishing events were clearly distributed over the shelf-break front. The concentration of fishing effort at the edges of the PNTA was more evident from July to November (Fig. 5).

The jigging fleet showed a marked seasonality, with higher concentration of fishing events in the southwest of the continental shelf in March, moving toward the northeast from May to August (Fig. 6). There was a clear overlap between fishing effort and the shelf-break and southern Patagonia frontal systems in April and May. From July, the mid-shelf front became important, with a high overlap of fishing events with the spatial distribution of the front.

3.2. Relationship between fishing effort and oceanographic fronts

Fishing events of the IT fleet were higher in the shelf-break front (SBF) than expected from January to June (Chi^2 tests, $P < 0.001$), and in the mid-shelf front (MSF) from April to June and from September to November (Chi^2 tests, $P < 0.001$). For the FT fleet, fishing events were higher in the SBF throughout the year except in March (Chi^2 tests, 11 months, $P < 0.001$). The number of fishing events of the J fleet was higher than expected in the SBF from April to June (Chi^2 tests, $P < 0.001$), in the SPF from March to June (Chi^2 tests, $P < 0.001$), and in the MSF in July and August (Chi^2 tests, $P < 0.001$). No differences were found between the number of events observed and expected for the IT fleet in March and December at the MSF.

3.2.1. Shelf-break front

The SBF represented 4.7% of the fishing area and concentrated 5.7% of the fishing events of the IT fleet, 10.6% of the fishing events of the FT fleet and 13% of the J fleet (annual means). For IT fleet, during January, February, May and June percentages of fishing effort were higher than 10%, with values in March and April of 6%. For the FT fleet, percentages of fishing effort were above 7% in all months except in March; April, May, June, August and December showed the highest

Table 2
Fishing records by fleet type and month. SBF: shelf-break front, MSF: mid-shelf front, SPF: southern Patagonia front.

	Ice-trawlers			Freezer-trawlers			Squid jiggers			
	Total	SBF	MSF	Total	SBF	SPF	Total	SBF	SPF	MSF
January	14,241	1613	57	5416	369	119				
February	16,775	1707	186	6154	470	338				
March	17,648	971	501	6298	211	207	8718	7	624	6
April	17,687	1117	2737	5609	672	262	10,580	2206	4071	0
May	16,410	1600	1535	5413	1020	238	9683	3340	3064	1
June	14,135	1515	761	4257	729	1	8646	776	635	1
July	15,132	401	258	3594	240	1	7757	0	0	525
August	15,482	603	224	4940	710	6	3249	0	0	2766
September	13,772	352	1025	4978	483	1				
October	18,069	357	2160	5734	405	12				
November	20,857	280	3157	5965	542	24				
December	8654	241	267	3480	737	2				
Total	188,862	10,757	12,868	61,838	6588	1211	48,633	6329	8394	3299

values (12, 19, 17, 14, 21% respectively). The J fleet concentrated their fishing activities in the SBF in April and May, with percentages of fishing effort of 21 and 34% respectively (Fig. 7).

3.2.2. Southern Patagonia front

The SPF represented 5.6% of the total fishing area and concentrated 2% of the fishing events of the FT fleet and 17% of the fishing activities of the J fleet (annual means). No fishing events of the IT fleet were registered at this frontal system. Fishing activity of the FT fleet at the SPF was only recorded from January to May, with values of fishing effort below 5%. The squid jigging fleet concentrated its fishing activities in the SPF from March to June, with high percentages of fishing effort in April and May (38 and 32% respectively; Fig. 7).

3.2.3. Mid-shelf front

The MSF represented 3% of the fishing area and concentrated 3.1% of the fishing activities of the IT fleet and 7% of the fishing events of the J fleet (annual means). When data was monthly analyzed, IT fleet showed values greater than 10% in the MSF during April, October and November. The squid jigging fleet concentrated its fishing activities during August within MSF limits, with values higher than 85% (Fig. 7). No fishing events of the FT fleet were registered at this frontal system.

4. Discussion

We found that fishing effort was unevenly distributed along the Argentine continental shelf showing, in most cases, a positive relationship with fronts. Although these fronts represent a small area of the total fishing area (4.7% shelf-break front, 5.6% southern Patagonia front and 3% mid-shelf front), they concentrated, during certain months, more fishing effort than expected because of the area they occupy. The jigging fleet showed the highest coupling with frontal systems and, though not as strong, a positive relationship was registered between fronts and the ice-trawler and freezer-trawler fleets. The spatial association between fishing events and fronts indirectly indicates a relationship between the target species and the frontal systems of the Argentine Sea.

The spatial patterns of fishing effort would be associated with the abundance patterns of the target species and its fluctuations (Podestá, 1990; Swain and Wade, 2003). In that sense, in the San Matías Gulf (northern Patagonia), fleets obtained highest catches of hake (*M. hubbsi*) near a front, where fishing activities are concentrated (Romero et al., 2013). Thus, in our study, we infer that the catches of target species of the different fleets are higher at frontal systems during those months in which the fishing effort is greater. This positive relationship between fronts and fisheries is consistent with studies in pelagic fisheries in the Pacific Ocean (Zainuddin et al., 2008), the Indian Ocean (Lan et al., 2012), the North Atlantic (Podestá et al., 1993), and the South Atlantic (Andrade, 2003), which reported an association between frontal systems and higher fish catches. The scarce reports on demersal fisheries and fronts show that higher catches of cod (*G. morhua*) were associated with thermal fronts in Iceland, due to food aggregation in those sites (Brynjarsdóttir and Stefánsson, 2004), and catches of hoki (*Macruronus novaezelandiae*) were also associated with a frontal system in New Zealand where food resources concentrated (McClatchie et al., 2005). Thus, fishing activities concentrate at fronts as their target species would aggregate at those productive areas due to food availability and/or for reproductive purposes.

4.1. Shelf-break front

The SBF, an area of high biological relevance (Acha et al., 2004), is associated with high concentrations of satellite chlorophyll (Rivas, 2006; Romero et al., 2006) and high primary production (Lutz et al., 2010), which would attract organisms of different trophic levels. The J fleet, targeting on the Argentine shortfin squid, showed the greatest coupling with the SBF between April and June. This could be due to the close relationship between the life cycle of squid and fronts (Chen et al., 2007). The Argentine shortfin squid makes extensive and seasonal migrations, and large concentrations of pre-reproductive squids locate along the continental slope and outer shelf, mainly south of 44° S in autumn, and north of this latitude in winter (Brunetti et al., 2000). In agreement with our results, the highest squid concentrations are associated with the SBF (Bazzino et al., 2005; Brunetti et al., 1998a) due to increased food availability in that area (Waluda et al., 2001).

The FT fleet, targeting on the Patagonian grenadier and the Argentine hake, mainly operated at the SBF from April to June and from August to December. Two main fishing areas are identified, at the northern part (ca. 39° S–42° S) and at the southern part (ca. 48° S) of the shelf-break. In that sense, the highest fishing effort may be related to the distribution of the Argentine hake and the Patagonian grenadier. It has been pointed out the importance of the shelf-break between 37° S and 41° S as spawning location and nursery area of the northern stock of Argentine hake (Pájaro et al., 2007), probably due to the availability of zooplanktonic preys (Ehrlich, 2000), and retention conditions on this region (Bakun and Parrish, 1991). Spawning and food constitute the two principal biological factors which determinate the abundance of the Argentine hake in autumn in the northern part of the Argentine shelf (Ubal et al., 1987). In relation to the Patagonian grenadier, it shows high densities in two main areas, between 39° S and 41° S and between 43° S and 44° S (Scarlato et al., 2000), in accordance with the fishing effort distribution of the FT fleet reported in this study. Moreover, the area of high commercial catch is located south of 45° S and around the 200 m isobath (Giussi et al., 2004), coinciding with the location of the SBF. The highest concentrations of the Patagonian grenadier are recorded in spring and summer south of 48° S (Giussi et al., 2004), and would take advantage of suitable and abundant preys at the front.

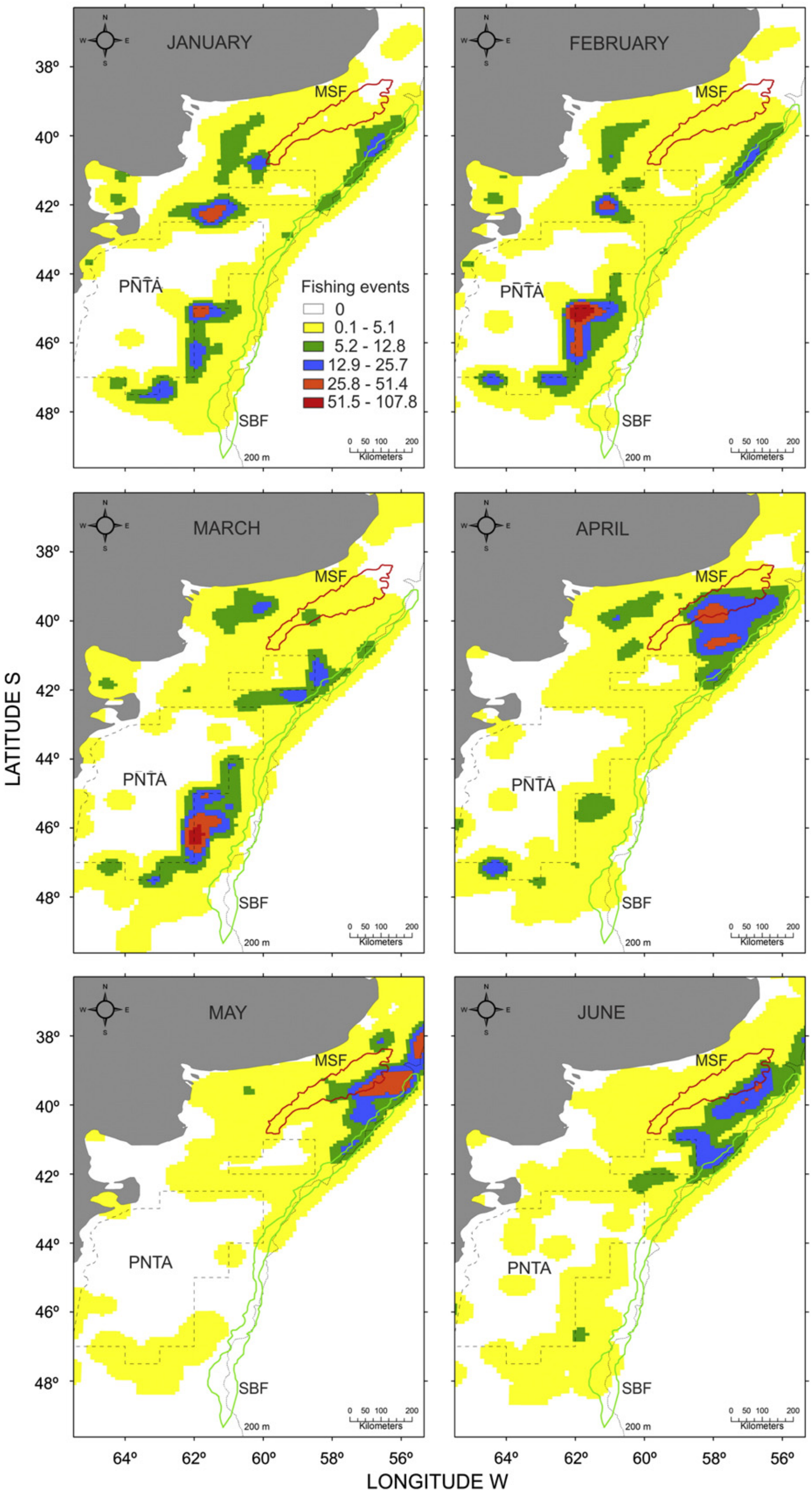

Fig. 2. Fishing effort distribution from January to June of the ice-trawler fleet, targeting on the Argentine hake. Data were obtained from vessels using VMS (Vessel Monitoring System); acquisition frequency every hour. Kernel density plots express fishing events per 5′ latitude × 5′ longitude squares. Abbreviations as in Fig. 1.

The IT fleet, targeting on the Argentine hake, was distributed mainly in the SBF between January and June. The high primary production of the area in those months (Lutz et al., 2010) would lead to high concentration of zooplankton which represent an important food resource for several organisms (e.g., pelagic fish and squid), that in turn are prey of fish of higher trophic levels. The association between the Argentine hake and fronts has been reported in several studies showing the use of the Península Valdés tidal front as a feeding (Ruiz and Fondacaro,

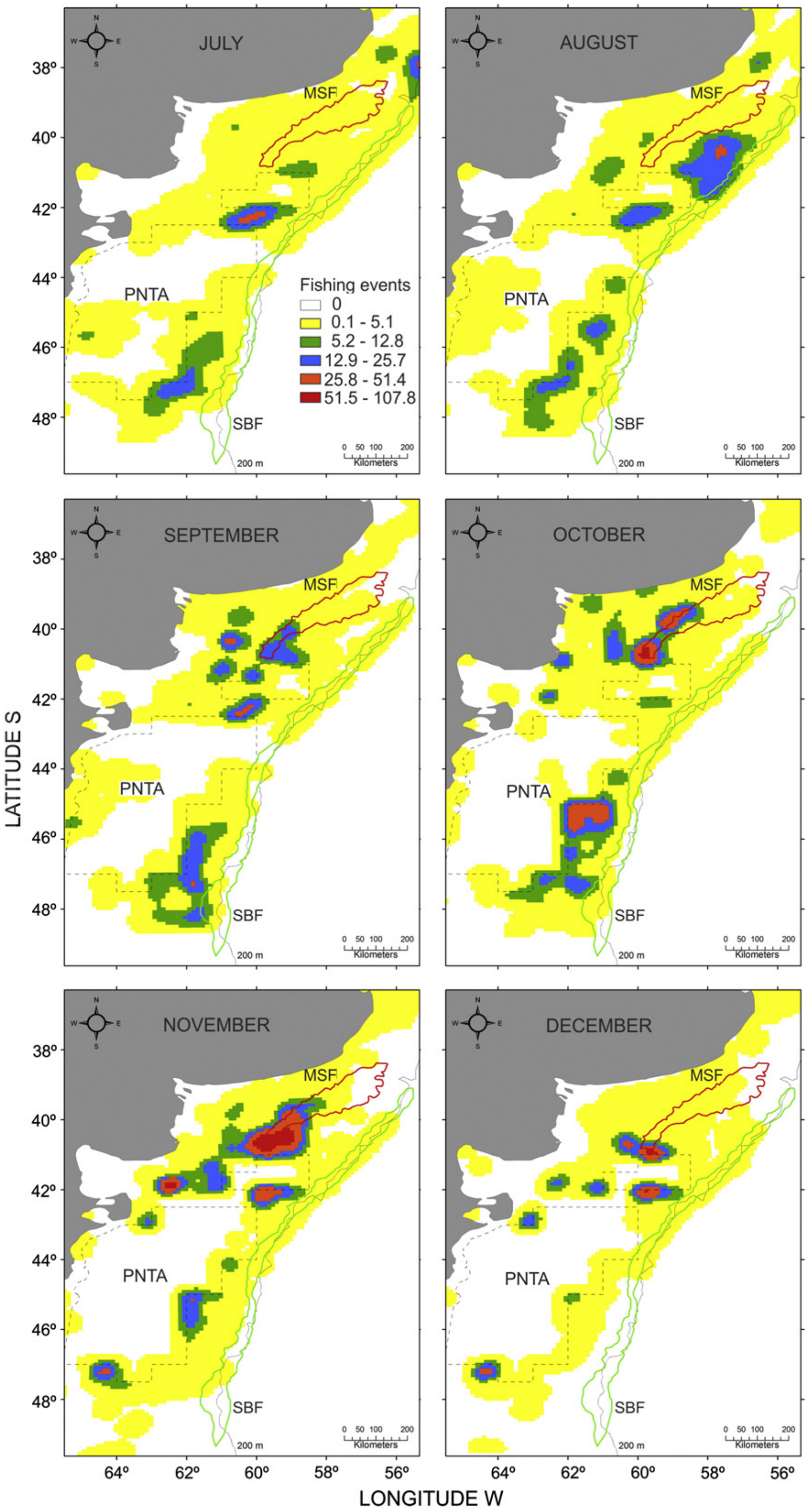

Fig. 3. Fishing effort distribution from July to December of the ice-trawler fleet. Kernel density plots express fishing events per 5′ latitude × 5′ longitude squares. Abbreviations as in Fig. 1.

1997) and spawning area for adults during the warm season (Macchi et al., 2010). Studies on the Patagonian shelf showed a positive association between thermal fronts and hake abundance (Wang et al., 2007), feeding migration patterns (Podestá, 1990) and reproduction (Pájaro et al., 2005). Furthermore, the Argentine hake feeds on preys whose abundance distribution has been linked to frontal systems (e.g., Argentine shortfin squid *I. argentinus*: Brunetti et al., 1998a; Argentine anchovy *Engraulis anchoita*: Hansen et al., 2001).

Thus, given this background, some sections of the shelf-break front represent important fishing grounds, as the fleets analyzed in this

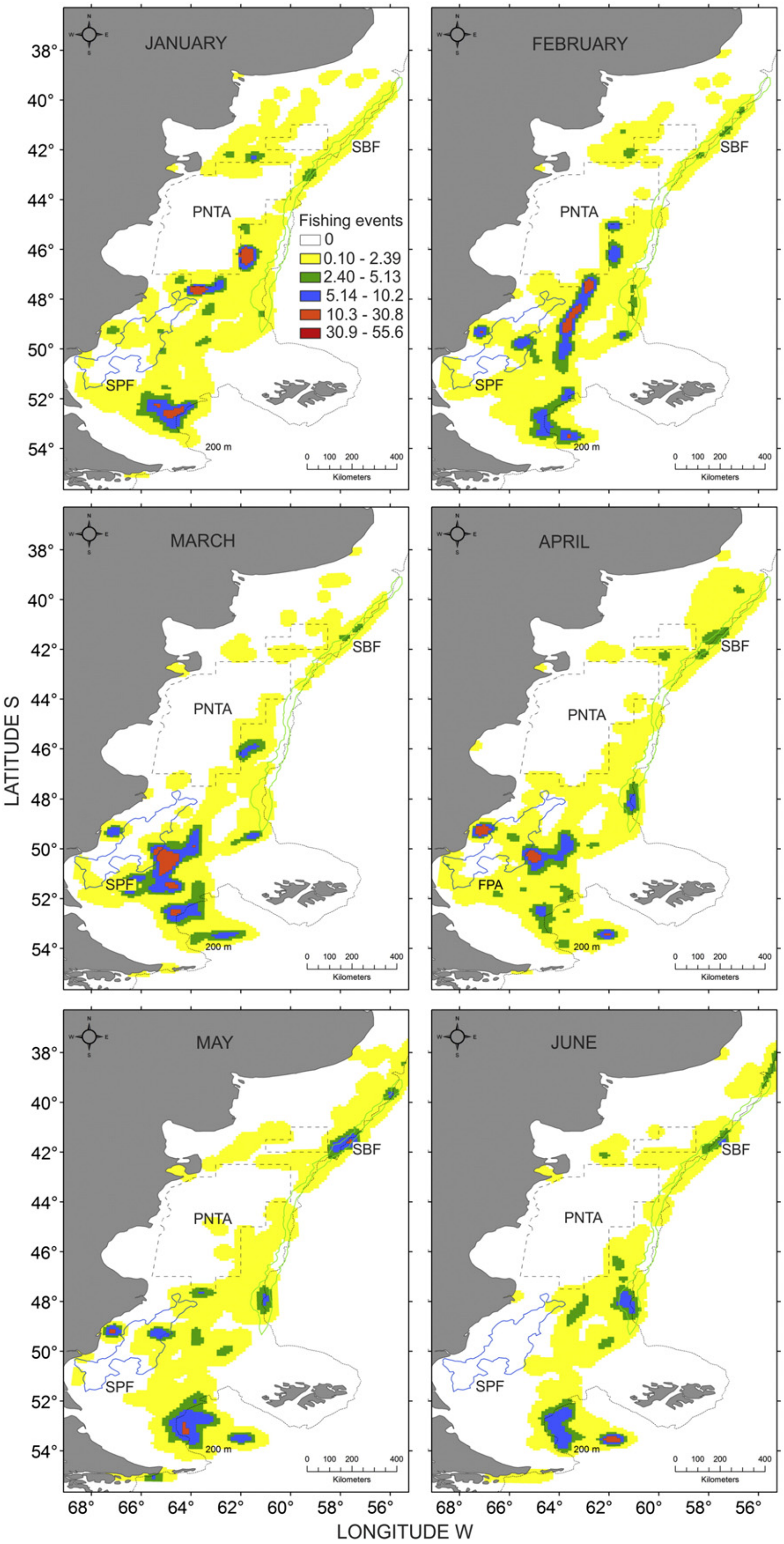

Fig. 4. Fishing effort distribution from January to June of the freezer-trawler fleet, targeting on the Argentine hake and the Patagonian grenadier. Data were obtained from vessels using VMS (Vessel Monitoring System); acquisition frequency every hour. Kernel density plots express fishing events per 5′ latitude × 5′ longitude squares. Abbreviations as in Fig. 1.

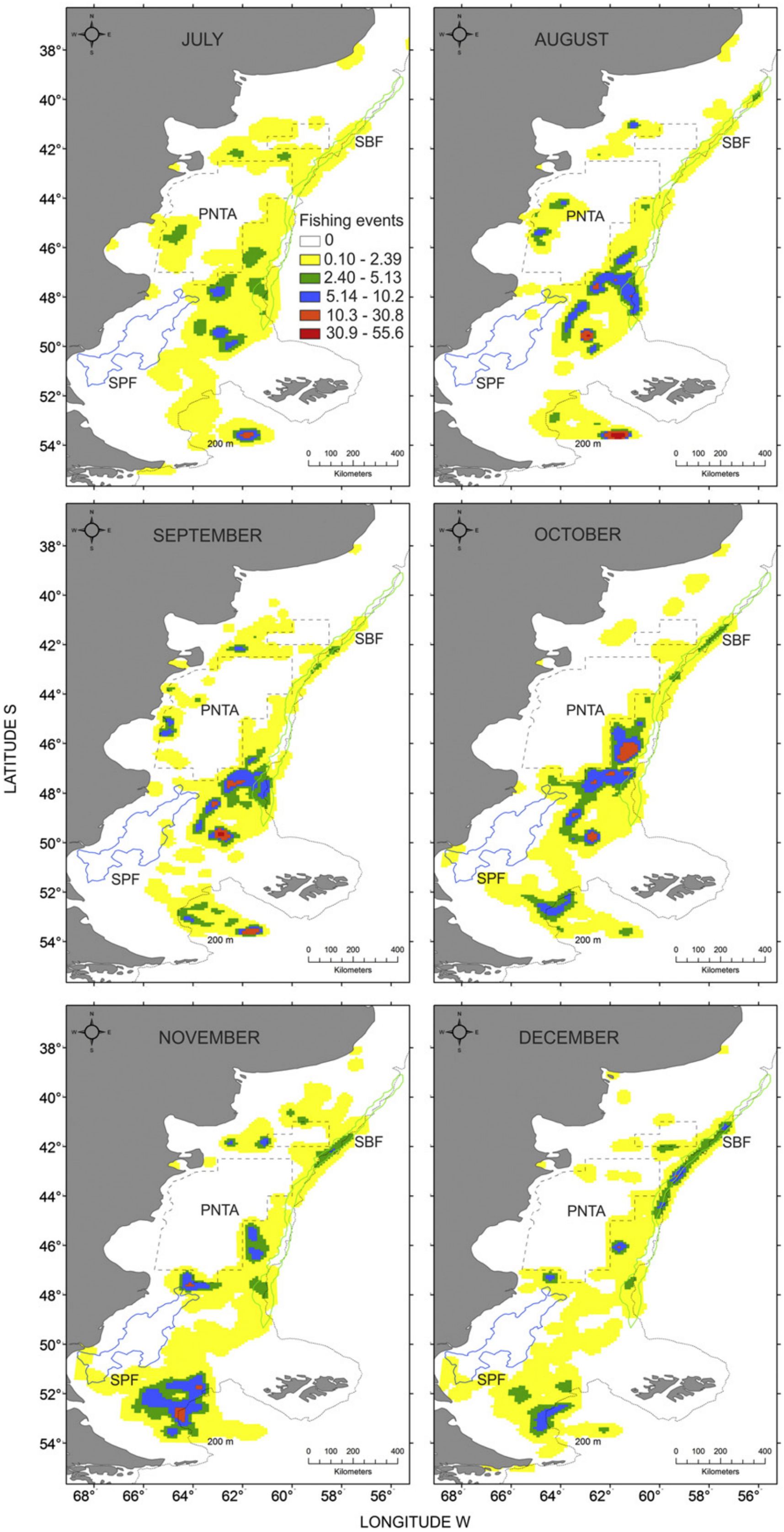

Fig. 5. Fishing effort distribution from July to December of the freezer-trawler fleet, targeting on the Argentine hake and the Patagonian grenadier. Kernel density plots express fishing events per 5′ latitude × 5′ longitude squares. Abbreviations as in Fig. 1.

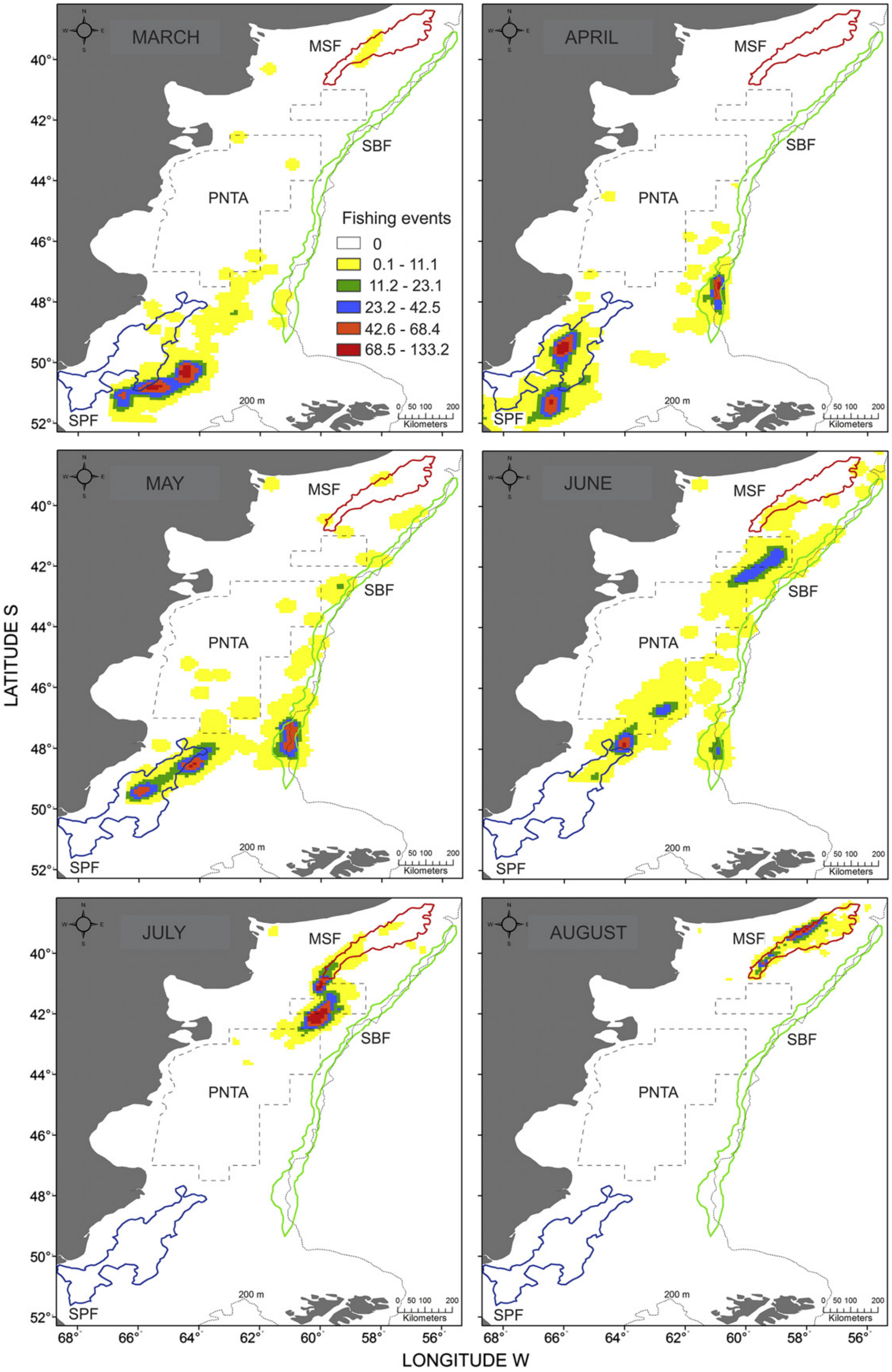

Fig. 6. Fishing effort distribution from March to August of the jigging fleet, targeting on the Argentine short-fin squid. Data were obtained from vessels using VMS (Vessel Monitoring System); acquisition frequency every hour. Kernel density plots express fishing events per 5′ latitude × 5′ longitude squares. Abbreviations as in Fig. 1.

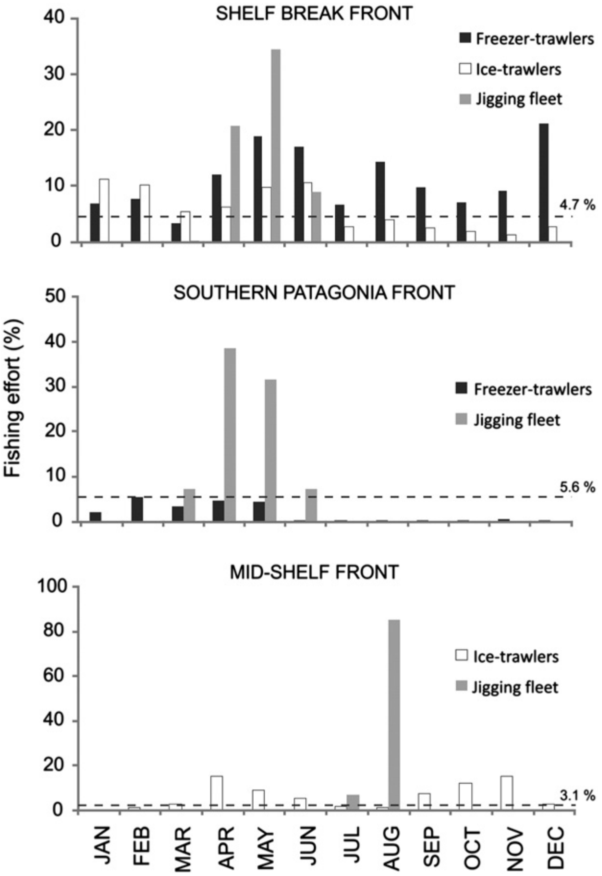

Fig. 7. Percentage contribution of the fishing effort per month of the ice-trawler fleet (gray bars), the freezer-trawler fleet (black bars) and jigging fleet (white bars), distributed inside the shelf-break front, the southern Patagonia front and the mid-shelf front. Dotted lines indicate the percentage each front represents of the total fishing area. Abbreviations as in Fig. 1.

study concentrated their activities in these areas. In terms of the target species, particularly the Argentine hake would exploit the shelf-break frontal system as a foraging area due to prey abundance and, for breeding purposes during the winter season since the northern portion of the frontal system shows high food availability and retention, both suitable conditions for eggs and larvae of the species.

4.2. Southern Patagonia front

The J fleet had a very close relationship with the southern Patagonia front (SPF) in April and May. The amphipod *Themisto gaudichaudii* plays a key role in the food web of the SPF region, being preyed by a variety of organisms (Padovani et al., 2012). The diet of the Argentine shortfin squid in southern Patagonia is mainly based on this amphipod (Ivanovic, 2010), which is highly abundant in the SPF during spring and summer (Padovani et al., 2012). Thus, the jigging fleet concentrates its fishing activity in the SPF as its target species is aggregated in the area, feeding on the abundant food source the amphipod represents. A close relationship was expected between the SPF and the ice-trawler fleet as its target species, the long tail hake, is distributed in the area and feed also on *T. gaudichaudii* (Padovani et al., 2012); however fishing activities of this fleet did not concentrate at this frontal system.

4.3. Mid-shelf front

The J fleet showed a high overlap with the MSF during August, which suggests that the Argentine shortfin squid concentrates in the area. It has been reported that squids complete their migration in August–September, and during spring the largest aggregations of post-spawners are located between 38° S and 40° S between 50 and 100 m depth (Brunetti et al., 2000), coinciding with the position of the MSF. In agreement with our results, the jigging fleet distribution in Argentina reflects the squid distribution (Waluda et al., 2008). In the northern continental shelf (38° S–40° S), concentration of spawning squids was observed during spring–summer (spring spawning stock; Brunetti, 1981), whose catches were recorded between the 50 and 200 isobaths (Brunetti et al., 1998b), matching the MSF position. It has also been shown that the Argentine shortfin squid is distributed in the northern shelf, feeding mainly on amphipods and fish (Ivanovic and Brunetti, 1994), and taking advantage of the high food availability at the front. An association between squids and fronts, due to increased food supply, has also been reported (Bazzino et al., 2005). Thus the relationship between the squid and the MSF would be mainly given by foraging strategies in areas of high prey abundance.

The spatial distribution of the IT fleet also showed an association with the MSF. The IT fleet concentrated its activities in the front from April to June and from September to November, which coincides with the most productive months of the front (Romero et al., 2006). These results are in agreement with studies reporting hake spawning aggregations in northern frontal regions of the continental shelf near the 50 m isobath during April and May (Rodrigues and Macchi, 2010). It has also been shown that the Argentine hake distributes in areas with particular oceanographic conditions, favored by enrichment, food availability and retention, during May, September and November (Bezzi et al., 2004). In the northern continental shelf, the Argentine anchovy is one of the main preys in the diet of hake (Angelescu and Prenski, 1987), whose breeding area (Pájaro et al., 2008) and adult concentration (Marrari et al., 2004) during spring coincide with the MSF. Furthermore, during winter, the Argentine shortfin squid is also an important prey for hake, and high abundance of this cephalopod has been reported between 40° S and 43° S (Bezzi et al., 2004).

As the mid-shelf frontal system concentrates fishing activities of the J and IT fleets, it is concluded that the Argentine short-fin squid and the Argentine hake are aggregated there, as this front seems to represent a foraging area for both species, and also a spawning area for the latter.

4.4. Fronts, trophic levels and fishing effort

Physical processes, such as fronts, affect the distributional pattern of marine organisms at all trophic levels. As organisms increase in size, they occupy higher trophic levels (Cury et al., 2001) and behavior becomes increasingly important (McManus and Woodson, 2012). At fronts, non-motile or weakly swimming organisms, like phytoplankton, passively accumulate (Wolanski and Hamner, 1988; Woodson and McManus, 2007) by convergent flows and by in situ growth due to high nutrient or food availability. Accordingly, there is a strong spatial coupling between fronts and phytoplankton, but the association becomes more complex as we move up in the food web to higher trophic levels (Olson, 2002) where behavior and swimming abilities may determine distributional patterns (McManus and Woodson, 2012). Primary producers show a direct response to fronts due to nutrients and light conditions; but at upper trophic levels, behavioral sensory cues (i.e., temperature, salinity, optical conditions, trace substances) are involved to actively seek out frontal structures (Olson, 2002). The increased phytoplankton abundance at fronts attracts and aggregates organisms like zooplankton and planktivorous fish that in turn attracts piscivorous organisms and top predators (Genin, 2004; Woodson and McManus, 2007). Thus, frontal systems would affect all trophic levels of a marine food web.

Depending of the trophic level of the target species we expected different degrees of association between fronts and fishing effort. As predicted, the jigging fleet targeting on lower trophic level species (*I. argentinus*, trophic level: 3.7; Ciancio et al., 2008) than the other fleets, showed a stronger spatial association with fronts. The freezer-trawler and ice-trawler fleets whose target species are of higher trophic level (TL) than the jigging fleet (*M. hubbsi* TL: 4.8; *M. magellanicus* TL: 3.9; Ciancio et al., 2008) showed an association with frontal systems, although weaker. The Patagonian grenadier (*M. magellanicus*) and the Argentine shortfin squid (*I. argentinus*) are considered small predators feeding on macrozooplankton and micronekton (Angelescu and Prenski, 1987) and of lower trophic level (TL) than the Argentine hake (Ciancio et al., 2008). In that sense, the stronger relationship between the jigging and the freezer-trawler fleets and fronts could be explained by the trophic level of the exploited species. The weaker coupling of the ice-trawler fleet with fronts, compared with the other fleets, would be given by its target species, the Argentine hake considered a large predator of higher trophic level (Angelescu and Prenski, 1987). The Argentine shortfin squid, the Patagonian grenadier and the Argentine hake do not feed at or near the base of the food web, thus the association of these organisms with fronts would be mediated by intermediate links. Their foraging response to prey relates them to physical processes (McManus and Woodson, 2012). Thus, the differential association of the three fishing fleets with fronts would indicate a differential aggregation of their target species to fronts because of their diverse trophic levels.

In conclusion our results suggest that marine fronts represent important fishing areas even for demersal resources, as the distribution of fishing fleets and fishing effort are positively associated with frontal zones. The fishing fleets not always distribute along the frontal areas, however in such cases they seem to distribute in areas nearby fronts. The association between fishing activities and marine fronts suggests the occurrence and aggregation of commercially important species in these productive sites and presumably higher catches.

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References

Acha, E.M., Mianzan, H., Guerrero, R., Favero, M., Bava, J., 2004. Marine fronts at the continental shelves of austral South America. Physical and ecological processes. J. Mar. Syst. 44, 83–105.

Agenbag, J.J., Richardson, A.J., Demarcq, H., Fréon, P., Weeks, S., Shillington, F.A., 2003. Estimating environmental preferences of South African pelagic fish species using catch size- and remote sensing data. Prog. Oceanogr. 59, 275–300.

Andrade, H.A., 2003. The relationship between the skipjack tuna (*Katsuwonus pelamis*) fishery and seasonal temperature variability in the south-western Atlantic. Fish. Oceanogr. 12, 10–18.

Angelescu, V., Prenski, L.B., 1987. Ecología trófica de la merluza común del Mar Argentino (Merlucciidae, *Merluccius hubbsi*). Parte 2. Dinámica de la alimentación analizada sobre la base de las condiciones ambientales, la estructura y las evaluaciones de los efectivos en su área de distribución. INIDEP Contribution n° 561 (205 pp.).

Anticamara, J.A., Watson, R., Gelchu, A., Pauly, D., 2011. Global fishing effort (1950–2010): trends; gaps; and implications. Fish. Res. 107, 131–136.

Bakun, A., Parrish, R.H., 1991. Comparative studies of coastal pelagic fish reproductive habitats: the anchovy (*Engraulis anchoita*) of the southwestern Atlantic. ICES J. Mar. Sci. 48, 343–361.

Bazzino, G., Quiñones, R.A., Norbis, W., 2005. Environmental associations of shortfin squid *Illex argentinus* (Cephalopoda: Ommastrephidae) in the Northern Patagonian Shelf. Fish. Res. 76, 401–416.

Bertolotti, M.I., Verazay, G.A., Errazti, E., Pagani, A.N., Buono, J.J., 2001. Flota pesquera argentina. Evolución durante el período 1960–1998, con una actualización al 2000. In: Boschi, E.E. (Ed.), El Mar Argentino y sus recursos pesqueros, 3. Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata, Argentina, pp. 9–53 (http://hdl.handle.net/1834/2587).

Bezzi, S.I., Renzi, M., Irusta, G., Santos, B., Tringali, L.S., Ehrlich, M.D., Sánchez, F., García de la Rosa, S., Simonazzi, M., Castrucci, R., 2004. Caracterización biológica y pesquera de la merluza (*Merlucius hubbsi*). In: Sánchez, R., Bezzi, S.I. (Eds.), El Mar Argentino y sus recursos pesqueros. Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata, Argentina, pp. 157–205.

Bogazzi, E., Baldoni, A., Rivas, A., Martos, P., Reta, R., Orensanz, J.M., Lasta, M., Dell'arciprete, P., Werner, F., 2005. Spatial correspondence between areas of concentration of Patagonian scallop (*Zygochlamys patagonica*) and frontal systems in the southwestern Atlantic. Fish. Oceanogr. 14, 1–18.

Brunetti, N.E., 1981. Distribución de tallas y biología reproductiva del calamar (*Illex argentinus*) en el Mar Argentino (campañas del B/I "Shinkai Maru", 1978–1979). In: Angelescu, V. (Ed.), Campañas de Investigación Pesquera realizadas en el Mar Argentino por los B/I "Shinkai Maru" y "Walther Herwig" y el B/P "Marburg". Resultados de la parte argentina. Contribución nº 383. Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), Mar del Plata, pp. 119–127.

Brunetti, N.E., Elena, B., Rossi, G.R., Ivanovic, M.L., Aubone, A., Guerrero, R., Benavides, H., 1998a. Summer distribution, abundance and population structure of *Illex argentinus* on the Argentine shelf in relation to environmental features. Afr. J. Mar. Sci. 20, 175–186.

Brunetti, N.E., Ivanovic, M.L., Elena, B., 1998b. Calamares omastréfidos (Cephalopoda, Ommastrephidae). In: Boschi, E.E. (Ed.), El Mar Argentino y sus Recursos Pesqueros Tomo 2: Los moluscos de interés pesquero. Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata, pp. 37–68.

Brunetti, N.E., Ivanovic, M.L., Aubone, A., Rossi, G.R., 2000. Calamar (*Illex argentinus*). In: Bezzi, S.I., Akselman, R., Boschi, E.E. (Eds.), Síntesis del estado de las pesquerías marítimas argentinas y de la Cuenca del Plata. INIDEP, Mar del Plata, pp. 103–116.

Brynjarsdóttir, J., Stefánsson, G., 2004. Analysis of cod catch data from Icelandic groundfish surveys using generalized linear models. Fish. Res. 70, 195–208.

Carranza, M., 2009. Status Indicators of the Patagonian Marine Environment in Frontal Areas. Facultad de Ciencias Exactas y Naturales. Universidad de Buenos Aires, Buenos Aires 115 (http://hdl.handle.net/1834/3857).

Chassot, E., Bonhommeau, S., Reygondeau, G., Nieto, K., Polovina, J.J., Huret, M., Dulvy, N.K., Demarcq, H., 2011. Satellite remote sensing for an ecosystem approach to fisheries management. ICES J. Mar. Sci. 68, 651–666.

Chen, C.S., Chiu, T.S., Haung, W.B., 2007. The spatial and temporal distribution patterns of the Argentine short-finned squid, *Illex argentinus*, abundances in the Southwest Atlantic and the effects of environmental influences. Zool. Stud. 46, 111–122.

Ciancio, J.E., Pascual, M.A., Botto, F., Frere, E., Iribarne, O., 2008. Trophic relationships of exotic anadromous salmonids in the southern Patagonian Shelf as inferred from stable isotopes. Limnol. Oceanogr. 53, 788–798.

Cury, P., Shannon, L., Shin, Y., 2001. The functioning of marine ecosystems. Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem 5, Reykjavik, Iceland, 1–4 October 2001, p. 22.

Druon, J.N., 2010. Habitat mapping of the Atlantic bluefin tuna derived from satellite data: its potential as a tool for the sustainable management of pelagic fisheries. Mar. Policy 34, 293–297.

Ehrlich, M.D., 2000. Distribución y abundancia de huevos, larvas y juveniles de merluza (*Merluccius hubbsi*) en la Zona Común de Pesca Argentino–Uruguaya 1996–1998. Frente Marít. 18, 31–44.

Ellis, N., Wang, Y.-G., 2007. Effects of fish density distribution and effort distribution on catchability. ICES J. Mar. Sci. 64, 178–191.

Etnoyer, P., Canny, D., Mate, B., Morgan, L., 2004. Persistent pelagic habitats in the Baja California to Bering Sea (B2B) ecoregion. Oceanography 17, 90–101.

FAO, 2010. The State of World Fisheries and Aquaculture 2010. State of World Fisheries and Aquaculture. 197 (Rome).

Feldman, G.C., McClain, C.R., 2007. Ocean Color Web. http://oceancolor.gsfc.nasa.gov/forum/oceancolor/topic_show.pl?tid=474 (Access April 2007).

Genin, A., 2004. Bio-physical coupling in the formation of zooplankton and fish aggregations over abrupt topographies. J. Mar. Syst. 50, 3–20.

Giussi, A.R., Hansen, A.J., Wöhler, O.C., 2004. Biología y pesquería de la merluza de cola (*Macruronus magellanicus*). In: Boschi, E.E. (Ed.), El Mar Argentino y sus recursos pesqueros. Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata, Argentina, pp. 321–346.

Grafton, R.Q., Hilborn, R., Squires, D., 2010. Marine conservation and fisheries management: at the crossroads. In: Grafton, R.Q., Hilborn, R., Squires, D., Tait, M., Williams, M. (Eds.), Handbook of Marine Fisheries Conservation and Management. Oxford University Press, London, pp. 3–19.

Hansen, J.E., Martos, P., Madirolas, A., 2001. Relationship between spatial distribution of the Patagonian stock of Argentine anchovy, *Engraulis anchoita*, and sea temperatures during late spring to early summer. Fish. Oceanogr. 10, 193–206.

Hilborn, R., 1985. Fleet dynamics and individual variation: why some people catch more fish than others. Can. J. Fish. Aquat. Sci. 42, 2–13.

Ivanovic, M.L., 2010. Alimentación del calamar *Illex argentinus* en la región patagónica durante el verano de los años 2006, 2007 y 2008. Rev. Invest. Desarro. Pesq. 20, 65–73 (http://hdl.handle.net/1834/4224).

Ivanovic, M.L., Brunetti, N.E., 1994. Food and feeding of *Illex argentinus*. Antarct. Sci. 6, 185–193.

Jenks, G.F., 1967. The data model concept in statistical mapping. Int. Yearb. Cartogr. 7, 186–190.

Klemas, V., 2013. Fisheries applications of remote sensing: an overview. Fish. Res. 148, 124–136.

Lan, K.-W., Kawamura, H., Lee, M.-A., Lu, H.-J., Shimada, T., Hosoda, K., Sakaida, F., 2012. Relationship between albacore (*Thunnus alalunga*) fishing grounds in the Indian Ocean and the thermal environment revealed by cloud-free microwave sea surface temperature. Fish. Res. 113, 1–7.

Leichter, J.J., Witman, J.D., 2009. Basin-scale oceanographic influences on marine macroecological patterns. In: Witman, J.D., Kaustuv, R. (Eds.), Marine Macroecology. University of Chicago Press, London, pp. 205–226.

Lutz, V.A., Segura, V., Dogliotti, A.I., Gagliardini, D.A., Bianchi, A.A., Balestrini, C.F., 2010. Primary production in the Argentine Sea during spring estimated by field and satellite models. J. Plankton Res. 32, 181–195.

Macchi, G.J., Martos, P., Reta, R., Dato, C., 2010. Offshore spawning of the Argentine hake (*Merluccius hubbsi*) patagonian stock. Panam. J. Aquat. Sci. 5, 22–35.

Mann, K.H., Lazier, J.R.N., 2006. Dynamics of Marine Ecosystems. Biological–Physical Interactions in the Oceans, third ed. Blackwell Publishing Ltd., Cambridge, USA.

Marrari, M., Viñas, M.D., Martos, P., Hernández, D., 2004. Spatial patterns of mesozooplankton distribution in the Southwestern Atlantic Ocean (34°–41°S) during austral spring: relationship with the hydrographic conditions. ICES J. Mar. Sci. 61, 667–679.

Martínez Puljak, G., Sánchez, R., Navarro, G., 2010. Pesquerías en Argentina, In: Santos, M.H. (Ed.), Plan de acción nacional para reducir la interacción de aves con pesquerías en la República Argentina, 1ra. ed. Consejo Federal Pesquero, Buenos Aires, pp. 26–57.

McClatchie, S., Pinkerton, M., Livingston, M.E., 2005. Relating the distribution of a semi-demersal fish, *Macruronus novaezelandiae*, to their pelagic food supply. Deep Sea Res. I 52, 1489–1501.

McManus, M.A., Woodson, C.B., 2012. Plankton distribution and ocean dispersal. J. Exp. Biol. 215, 1008–1016.

Olson, D.B., 2002. Biophysical dynamics of ocean fronts. In: Robinson, A.R., McCarthy, J.J., Rothschild, B.J. (Eds.), The Sea. Biological–Physical Interactions in the Sea. John Wiley & Sons, Inc., New York, USA, pp. 187–218.

Padovani, L.N., Viñas, M.D., Sánchez, F., Mianzan, H., 2012. Amphipod-supported food web: *Themisto gaudichaudii*, a key food resource for fishes in the southern Patagonian Shelf. J. Sea Res. 67, 85–90.

Pájaro, M., Macchi, G.J., Martos, P., 2005. Reproductive pattern of the Patagonian stock of Argentine hake (*Merluccius hubbsi*). Fish. Res. 72, 97–108.

Pájaro, M., Macchi, G.J., Ibañez, P., 2007. Análisis de la condición reproductiva del efectivo norte de merluza (*Merluccius hubbsi*) en invierno de 2006. INIDEP Informe Técnico 24, pp. 1–12.

Pajaro, M., Martos, P., Leonarduzzi, E., Macchi, G.G., Diaz, M., Brown, D., 2008. Estrategia de puesta de la anchoíta (*Engraulis anchoita*) en el Mar Argentino y Zona Común de Pesca Argentino-Uruguaya. INIDEP Informe Técnico Oficial 11 (14 pp.).

Paloheimo, J.E., Dickie, L.M., 1964. Abundance and fishing success. Rapp. P.-v. Réun. Cons. Int. Explor. Mer 155, 152–163.

Podestá, G.P., 1990. Migratory pattern of Argentine hake *Merluccius hubbsi* and oceanic processes in the southwestern Atlantic Ocean. Fish. Bull. 88, 167–177.

Podestá, G.P., Browder, J.A., Hoey, J.J., 1993. Exploring the association between swordfish catch and thermal fronts on the U.S. longline grounds in the western North Atlantic. Cont. Shelf Res. 13, 253–277.

Rivas, A.L., 2006. Quantitative estimation of the influence of surface thermal fronts over chlorophyll concentration at the Patagonian shelf. J. Mar. Syst. 63, 183–190.

Rodhouse, P.G.K., Arkhipkin, A.I., Laptikhovsky, V., Nigmatullin, C., Waluda, C.M., 2013. *Illex argentinus*, Argentine shortfin squid. In: Rosa, R., Pierce, G., O'Dor, R. (Eds.), Advances in Squid Biology, Ecology and Fisheries. Part II—Oegopsid squids. Nova Science Publishers, New York, pp. 109–148.

Rodrigues, K.A., Macchi, G.G., 2010. Spawning and reproductive potential of the Northern stock of Argentine hake (*Merluccius hubbsi*). Fish. Res. 106, 560–566.

Romero, S.I., Piola, A.R., Charo, M., Eiras Garcia, C.A., 2006. Chlorophyll a variability off Patagonia based on SeaWiFS data. J. Geophys. Res. 111, C05021. http://dx.doi.org/10.1029/2005JC003244.

Romero, M.A., Reinaldo, M.O., Williams, G., Narvarte, M., Gagliardini, D.A., González, R., 2013. Understanding the dynamics of an enclosed trawl demersal fishery in Patagonia (Argentina): a holistic approach combining multiple data sources. Fish. Res. 140, 73–82.

Ruiz, A.E., Fondacaro, R.R., 1997. Diet of hake (*Merluccius hubbsi* Marini) in a spawning and nursery area within Patagonian shelf waters. Fish. Res. 30, 157–160.

Sánchez, R.P., Navarro, G., Martínez Puljak, G., Tosoroni, V., 2010. Operatoria de la flota argentina sobre las pesquerías costeras en el área del Tratado del Río de la Plata y su Frente Marítimo en 2008. Frente Marít. 21, 57–88.

Scarlato, N., Remaggi, C.A., Hansen, J.E., Wöhler, O.C., 2000. Pesca exploratoria de merluza de cola (*Macruronus magellanicus*) en el talud continental y sector adyacente al norte de 48° S. Informe Técnico Interno INIDEP 88, p. 24.

Stelzenmüller, V., Rogers, S.I., Mills, C.M., 2008. Spatio-temporal patterns of fishing pressure on UK marine landscapes, and their implications for spatial planning and management. ICES J. Mar. Sci. 65, 1081–1091.

Swain, D.P., Wade, E.J., 2003. Spatial distribution of catch and effort in a fishery for snow crab (*Chionoecetes opilio*): tests of predictions of the ideal free distribution. Can. J. Fish. Aquat. Sci. 60, 897–909.

Ubal, W., Norbis, W., Bosch, B., Pagano, D., 1987. Principales factores determinantes de la abundancia de merluza (*Merluccius hubbsi*) en otoño en la Zona Común de Pesca argentino-uruguaya. Publicaciones de la Comisión Técnica Mixta del Frente Marítimo, 3, pp. 7–13.

Walker, E., Bez, N., 2010. A pioneer validation of a state-space model of vessel trajectories (VMS) with observers' data. Ecol. Model. 221, 2008–2017.

Wall, C.C., Muller-Karger, F.E., Roffer, M.A., 2009. Linkages between environmental conditions and recreational king mackerel (*Scomberomorus cavalla*) catch off west-central Florida. Fish. Oceanogr. 18, 185–199.

Waluda, C.M., Rodhouse, P.G., Trathan, P.N., Pierce, G.J., 2001. Remotely sensed mesoscale oceanography and the distribution of *Illex argentinus* in the South Atlantic. Fish. Oceanogr. 10, 207–216.

Waluda, C.M., Griffiths, H.J., Rodhouse, P.G., 2008. Remotely sensed spatial dynamics of the *Illex argentinus* fishery, Southwest Atlantic. Fish. Res. 91, 196–202.

Wang, J., Pierce, G.J., Sacau, M., Portela, J., Santos, M.B., Cardoso, X., Bellido, J.M., 2007. Remotely sensed local oceanic thermal features and their influence on the distribution of hake (*Merluccius hubbsi*) at the Patagonian shelf edge in the SW Atlantic. Fish. Res. 83, 133–144.

Williams, G., Sapoznik, M., Ocampo-Reinaldo, M., Solis, M., Narvarte, M., González, R., Esteves, J.L., Gagliardini, D., 2010. Comparison of AVHRR and SeaWiFS imagery with fishing activity and in situ data in San Matías Gulf, Argentina. Int. J. Remote Sens. 31, 4531–4542.

Witt, M.J., Godley, B.J., 2007. A step towards seascape scale conservation: using vessel monitoring systems (VMS) to map fishing activity. PLoS ONE 2, e1111. http://dx.doi.org/10.1371/journal.pone.0001111.

Wolanski, E., Hamner, W.M., 1988. Topographically controlled fronts in the ocean and their biological influence. Science 241, 177–181.

Woodson, C.B., McManus, M.A., 2007. Foraging behavior can influence dispersal of marine organisms. Limnol. Oceanogr. 2701–2709.

Ye, Y., Cochrane, K., Bianchi, G., Willmann, R., Majkowski, J., Tandstad, M., Carocci, F., 2012. Rebuilding global fisheries: the World Summit Goal, costs and benefits. Fish Fish. 14, 174–185.

Zainuddin, M., Saitoh, K., Saitoh, S.I., 2008. Albacore (*Thunnus alalunga*) fishing ground in relation to oceanographic conditions in the western North Pacific Ocean using remotely sensed satellite data. Fish. Oceanogr. 17, 61–73.

Zar, J.H., 1999. Biostatistical Analysis, 4th ed. Prentice Hall, Englewood Cliffs, NJ.