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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.

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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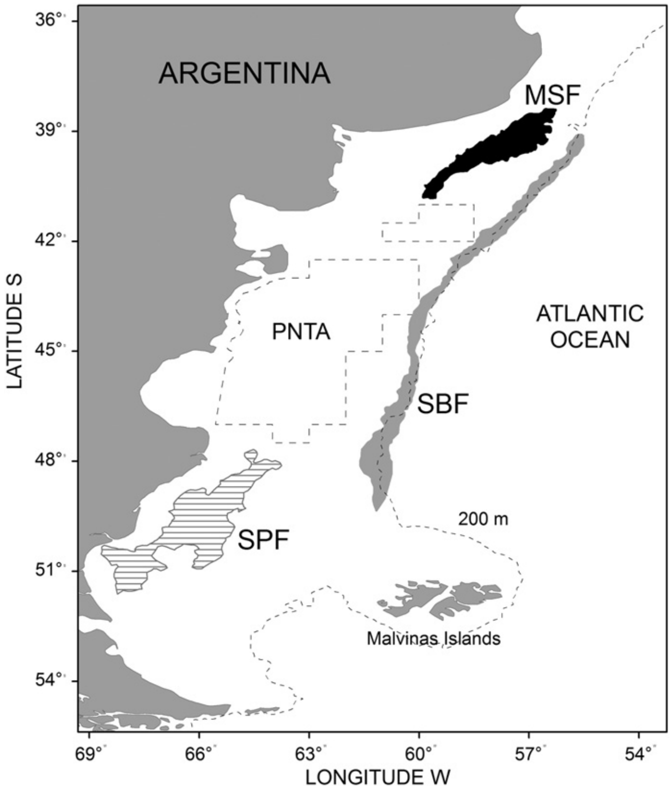

Fig. 1. Study area showing the frontal polygons of the shelf-break front (SBF, gray), the mid-shelf front (MSF, black) and the southern Patagonia front (SPF, horizontal lines); PNTA: Patagonian no-trawling area in 2008.

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*)