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Distribution and intensity of bottom trawl fisheries in the Patagonian Shelf Large Marine Ecosystem and its relationship with marine fronts

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ABSTRACT

Trawling is a major concern worldwide and there is considerable debate about its impact on marine ecosystems. The Patagonian Shelf Large Marine Ecosystem (PSLME) is an important fishing area in the Southwest Atlantic where bottom trawling is the dominant fishing method. We investigated the distribution of bottom trawl fishing within this region, defining the areas of highest trawling intensity (hotspots) and evaluating their relationship with marine fronts. We focused on the three main oceanographic fronts, the shelf-break front, the southern Patagonia front and the mid-shelf front. To estimate fishing effort and trawled areas, we used VMS data from 2006 to 2012. Despite being almost a fully trawlable shelf, we found that the spatial distribution of trawling activity is patchy and trawling hotspots were small, comprising annually <5% of the shelf extension or <7% of the total trawlable area. Contrary to what is believed worldwide, our findings suggest that over the PSLME the magnitude of habitat effects as a result of bottom trawling is relatively small. Regarding the three frontal systems studied, only the shelf-break front showed a positive relationship with trawl fishing activity. Although trawling hotspots did not overlap with marine fronts, the shelf-break front receives more trawling effort than expected. We hypothesize that this pattern is due to aggregation of species near or at the front taking advantage of the opportunities provided by this area.

Key words: Argentine Sea, bottom trawling, fishing effort spatial pattern, interannual variability, trawling hotspots

INTRODUCTION

Human impacts or perturbations (i.e., land- and ocean-based activities) have been influencing environmental changes on marine ecosystems (Halpern *et al.*, 2008), with fishing being one of the major stressors of marine habitats (Hiddink *et al.*, 2006). Particularly, bottom trawling (the dominant fishing gear worldwide; NRC, 2002) mainly targeting demersal fishes, crustaceans and shellfish, also physically alters the seafloor and the biological communities (Kaiser *et al.*, 2002). There is a current debate about the extent and consequences of these effects, with evidence of negative and positive effects. Trawling has been operating on fishing grounds since many years ago, potentially affecting seafloor morphology, sediment characteristics and water turbidity by resuspending sediments (Palanques *et al.*, 2014). Several consequences of bottom trawling have been proposed, such as changes in infaunal benthic communities (Hinz *et al.*, 2009) and epifaunal assemblage structure (Strain *et al.*, 2012), a reduction in the abundance of target and non-target fish by direct removal but also by affecting food availability (Hiddink *et al.*, 2011), and increasing local mortality of hard-bodied and large benthic invertebrates (Kaiser *et al.*, 2006). However, it has been shown that sediment resuspension by trawling would lead to nutrient release and enhance primary production (Jennings *et al.*, 2001), changing benthic communities that may improve feeding conditions (Hiddink *et al.*, 2008), promoting fish growth and increasing fish biomass and fisheries yield (van Denderen *et al.*, 2013). In any case, trawling can be a significant human pressure on the seafloor, thus it is important to know its spatial and temporal pattern, with quantitative estimations of the area actually swept being essential for a full assessment of its potential impact at the ecosystem level.

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As bottom trawling is an important economic activity (Bradshaw *et al.*, 2012) that impacts several organisms of soft bottom continental shelves and slopes (Gray *et al.*, 2006), there is worldwide concern about its effects on marine ecosystems. This concern was highlighted by the environmental NGO community and by scientists, actively supporting the reduction of fishing impact on marine habitats (see Hilborn, 2007). Several countries regulate bottom trawling within their jurisdictions by banning trawl gears or by closing ecologically sensitive areas (FAO, 2014). There are many restrictive measures being discussed and/or imposed worldwide in relation to trawling, in which the requirements for habitat conservation, overfishing control and protection of pristine ecosystems have been strengthened. Such strategies include the reduction of fishing effort, the modification of gear types and, the most extreme one, the establishment of marine protected areas (NRC, 2002). However, the impact of bottom trawling is controversial (Svane *et al.*, 2009) as it is often assumed that the entire area open to fishing is being trawled while some evidence suggests that the actual trawled area is much smaller (e.g., Jennings and Lee, 2012). Estimation of actual swept areas around the world is scarce, thus the precautionary rules highlight the urgent need to assess trawling in the fishing grounds worldwide.

In the Patagonian Shelf Large Marine Ecosystem (PSLME) (Sherman, 2005), the Argentine Economic Exclusive Zone (AEEZ) is an important fishing area (mean annual landings 2006–2013: *c.* 840 000 tonnes; Navarro *et al.*, 2014) where bottom trawling, performed by ice- and freezer trawlers, is the dominant fishing method (FAO, 2014). The Argentine hake (*Merluccius hubbsi*), the Patagonian scallop (*Zygochlamys patagonica*) and the Longtail hake (*Macruronus magellanicus*) are the main targets of the trawl fishing industry (Navarro *et al.*, 2014). Several marine fronts occur at the AEEZ that influence diversity, abundance and assemblage structure of fish and shellfish (Bogazzi *et al.*, 2005; Alemany *et al.*, 2009; Mauna *et al.*, 2011; Lucifora *et al.*, 2012). Marine fronts represent important fishing areas for different fleets (i.e., ice, freezer and jigging vessels) as the fishing efforts of some of the fleets were positively associated with frontal zones, suggesting the aggregation of fish and squids in these productive areas (Alemany *et al.*, 2014). In the present study, we moved a step towards the identification and characterization of bottom trawling activities with emphasis on trawl distribution, fishing effort, swept area and their relationship with fronts. As the distribution of some of the species targeted by fisheries are spatially related to marine fronts (e.g., Alemany *et al.*, 2014), it is expected that areas of highest trawling intensity are somehow related to fronts and, thus, these trawling hotspots represent relatively small areas of similar geographical scale as fronts, that cover an area lesser than 15% of the Patagonian shelf extension (Rivas, 2006). Moreover, given that marine fronts at the AEEZ are spatially and temporally predictable (Romero *et al.*, 2006), a relative inter-annual stability in the location of the more heavily fished areas might be expected. Thus, marine fronts, by influencing organisms' distribution, would be important physical features affecting the dynamics of trawling activities and the location of fishing hotspots.

Given the above background, we evaluate bottom trawl fishery within the AEEZ, and the goals are to (i) study the bottom trawl fishing spatial pattern, (ii) evaluate if the spatial pattern varies across years, and (iii) evaluate if the distribution of bottom trawl fishery is related to marine fronts.

MATERIALS AND METHODS

The study area covered the AEEZ (*c.* 35–55° S, 52–68° W; 1 100 000 km^2), included in the PSLME (Sherman, 2005). To monitor and control fishing vessels operating in the area, the Argentine Secretariat of Agriculture, Livestock and Fisheries enforced a vessel satellite monitoring system (VMS) since the year 2000. This system is an automated method recording the position of fishing vessels at sea. Vessels >10 m overall length (artisanal fisheries are excluded) are required to have a global positioning system (GPS) on board, with the mandatory sending of the geographic position (latitude and longitude), date, time, speed and other information every hour, 24 h a day, and all these records are stored. For the aims of this study, the Argentine Undersecretary of Fisheries and Aquaculture provided us the complete VMS database from 2006 to 2012 to estimate a proxy for fishing effort and trawled areas. Only those fleets operating with bottom trawling nets were selected for the analyses; these were ice-trawlers targeting *Merluccius hubbsi*, freezer-trawlers targeting *M. hubbsi*, freezer-trawlers targeting *Macruronus magellanicus*, *Dissostichus eleginoides* (Patagonian toothfish) and *Micromesistius australis* (blue whiting), and freezer-trawlers targeting *Zygochlamys patagonica*, according to criteria of the Argentine Secretariat of Agriculture, Livestock and Fisheries. The coastal, jigging, long-line and shrimp fishing fleets were excluded from the analyses.

According to Lee *et al.* (2010), inaccuracies in vessel position, speed, duplicate records and records within 3 miles of ports were removed from the database.

As VMS do not indicate different types of activities at sea (i.e., in port, fishing, steaming), and in order to discriminate trawl fishing from non-fishing locations, two behaviour rules based on vessel speed and time of the day were used (e.g., Eastwood *et al.*, 2007; Stelzenmüller *et al.*, 2008). Those records in the VMS database in which vessel speed ranged from 2 to 5 knots (Witt and Godley, 2007) and occurred between 08.00 and 20.00 hours (since trawling activities are performed only during daylight hours), were considered as trawl fishing events. As VMS reports vessel position every hour, 24 h a day, each record fulfilling the criteria mentioned above was considered a trawl fishing hour (TH) and used as a proxy for trawling intensity. While the filtering process in this study is a coarse approach to precisely define trawling, the rules here applied to the VMS database, particularly the speed range, adequately represent vessels undertaking fisheries activities.

Spatial distribution of bottom trawl fishing

To identify areas of highest trawl fishing intensity, the spatial pattern of TH by year was analysed with a Geographic Information System (GIS). The data geographic coordinate system (WGS84) was projected using the Transverse Mercator projection (UTM, WGS84, 20° S). The Kernel density estimation function was used to convert TH into a continuous raster (output cell size 9000 m, squares of 81 km^2). Then, to study the inter-annual variability in the location of the trawling hotspots, four trawl polygons were constructed for each year (Isopleths, Geospatial Modelling Environment, quantiles: 0.25, 0.50, 0.75 and 0.90), and their areas (in km^2) were calculated; trawl polygons concentrated the 25%, 50%, 75% and 90% of the total TH.

Finally, the annual trawled area (ATA, km^2) was estimated by calculating:

$$\text{ATA} = \text{TH} \times S \times w, \quad (1)$$

where TH: trawling hours (h), S: vessel speed and w: average net width.

Typical vessel speed in trawling activities ranges from 3.7 to 9.3 km h^{-1} (2–5 knots; Witt and Godley, 2007). As a precautionary approach, and to avoid underestimation of ATA, the highest value of that range was used in the formula. The average net width of trawlers was 0.03 km, excepting for one trawler that has a net width of 0.08 km (database from the Argentine Undersecretary of Fisheries and Aquaculture). In the case that this trawler appeared in the database, ATA was calculated separately for both net width values and then, to estimate ATA per year, subtotals were summed.

Relationship between bottom trawling areas and marine fronts

In the present study, the focus was on the three main oceanographic fronts at the PSLME, which are the shelf-break front (SBF), the southern Patagonia front (SPF) and the mid-shelf front (MSF).

Chlorophyll concentration in the surface layer of the ocean is commonly used as a relative indicator of oceans primary production, and can be visualized and analysed using satellite images (Romero *et al.*, 2006). Given that marine fronts occurring at the AEEZ are associated with areas of high primary production (i.e., high chlorophyll-*a* concentration; Lutz *et al.*, 2010), and they are well defined by satellite chlorophyll patterns (Rivas, 2006; Romero *et al.*, 2006), satellite ocean colour images were used to estimate proxies of fronts' location and areal coverage. In trying to evaluate the relationship between trawling and fronts, this approach has some limitations as fishing by trawlers takes place on or near the seabed whereas satellite chlorophyll is a surface signal. Moreover, because marine fronts are vertically inclined interfaces between different water masses, the surface expression would not match the location on the bottom. Nonetheless, satellite products still are a powerful tool in terms of the spatiotemporal data coverage. Standard Mapped Images (SMI) of satellite-derived chlorophyll-*a* concentrations provided by the project NASA Ocean Color (National Aeronautics and Space Administration; http://oceancolor.gsfc.nasa.gov), MODIS-Aqua sensor, processing level L3, were analysed. The SMI data were limited to the study area bounded by 35–55°S and 70–52°W (183 by 254 pixels). The monthly composite images with 9 km spatial resolution were processed with GIS, and chlorophyll *a* concentration (CHLOR; in mg m^{-3}) was estimated using the OC3Mv6 algorithm (O'Reilly *et al.*, 2000). As chlorophyll concentration associated with fronts better define these features during austral spring and summer (Romero *et al.*, 2006), images corresponding to September (S), October (O), November (N), December (D), January (J) and February (F), between 2006 and 2012 were selected for the analyses (42 images). Each image was projected using the Transverse Mercator projection (UTM, WGS84, 20° S) and for each cell (size 9000 m) of the continuous raster, CHLOR values were extracted. Then, mean CHLOR and maximum CHLOR per pixel were calculated. During austral spring and summer, values >2 mg m^{-3} represent high chlorophyll concentration (Romero, 2008), and its contours are used to define frontal areas (Carranza, 2009). In this study, the contour line of satellite mean CHLOR of 3 mg m^{-3} (Contour, Geospatial Modelling Environment) based on CHLOR raster dataset defined the frontal polygon characterizing the SBF for the period 2006–2012. As the MSF and the SPF were not clearly defined by mean CHLOR, maximum CHLOR values were instead used, with the CHLOR contour of 12 mg m^{-3} clearly defining the MSF and SPF polygons.

Then, to calculate the percentage that each frontal polygon represents relative to the total trawl fishing area, we used the FA polygon defined by Alemany *et al.* (2014), in which all the trawling events were included.

To evaluate the relationship between bottom trawl fishery and fronts, the number of trawl fishing hours observed within each frontal polygon was compared with the number of trawl fishing hours expected for the area that each front occupies. Then, to test the null hypothesis of no differences between the observed and the expected number of trawl fishing hours at each frontal system a chi-square goodness-of-fit test (Zar, 1999) was used.

Additionally, the spatial relationship between areas of high trawling intensity and areas of high chlorophyll abundance (i.e., marine fronts) was assessed. Trawl polygons concentrating the 25% of trawling hours (hotspots) and frontal polygons were overlapped and their intersection areas calculated. These intersection areas were expressed as a percentage of the 25% trawled polygon to indicate to what extent trawl fishing hotspots overlap with marine fronts.

RESULTS

Spatial distribution of bottom trawl fishing

A total of 1 591 777 trawl fishing hours were analysed from the VMS database for the period 2006–2012 (Table 1). Trawling spatial patterns by year were described by means of four trawl polygons, including the 25%, 50%, 75% and 90% of trawling hours (Fig. 1). Trawling activity of the chosen fleets was mainly distributed between 37° and 47°S, in most cases located at the western side of the shelf-break front (SBF), and associated with the borders of the Patagonian no-trawling area (PNTA). There was also another trawling core area between 51–54°S and 62–64°W. The spatial distribution of trawling activity is patchy. In 2006, three core areas of highest trawling intensity (25% polygon) were identified at 42, 46 and 47°S at the western side of the SBF, and a fourth smaller area located on the SBF following the 200-m isobath (Fig. 1a). In 2007, a similar pattern was observed, with trawling activity concentrating in two core areas westward the SBF (Fig. 1b). In 2008, 2009 and 2010, trawling intensity was similarly distributed, with TH concentrated between 45 and 47°S, and also in other core areas located at 39–40°S and 41–42°S, westward of the SBF and on the front in coincidence with the 200-m isobath (Fig. 1c–e). The distributional pattern of trawling was similar in 2011 and 2012, with the highest concentration of TH at 42°S and between 45 and 47°S, at the western side of the SBF and sometimes overlapping it (Fig. 1f, g). The composite of all data (Fig. 1h) showed trawled areas during the period 2006–2012, with a similar pattern to that observed in each year, with higher trawling intensity concentrating in three main areas: two of them at 42°S, one overlapping the frontal area and following the 200-m

Table 1. Trawl fishing hours from 2006 to 2012 in each of the four studied areas.

		Trawl fishing hours					
Year	FA	SBF (O)	SBF (E)	SPF (O)	SPF (E)	MSF (O)	MSF (E)
2006	263 816	33 373	25 708	412	5249	3644	3764
2007	262 057	23 489	25 537	206	5214	1148	3739
2008	254 356	33 919	24 786	587	5061	1606	3629
2009	152 186	29 338	14 830	272	3028	759	2172
2010	226 826	56 958	22 104	1120	4513	859	3237
2011	248 326	47 914	24 199	592	4941	727	3543
2012	184 210	30 972	17 951	672	3665	450	2628
TOTAL	1 591 777	255 963	155 115	3861	31 671	9193	22 713

FA, total trawl fishing area; SBF, shelf-break front; SPF, Southern Patagonia front; MSF, midshelf front; (O), observed values; (E), expected values.

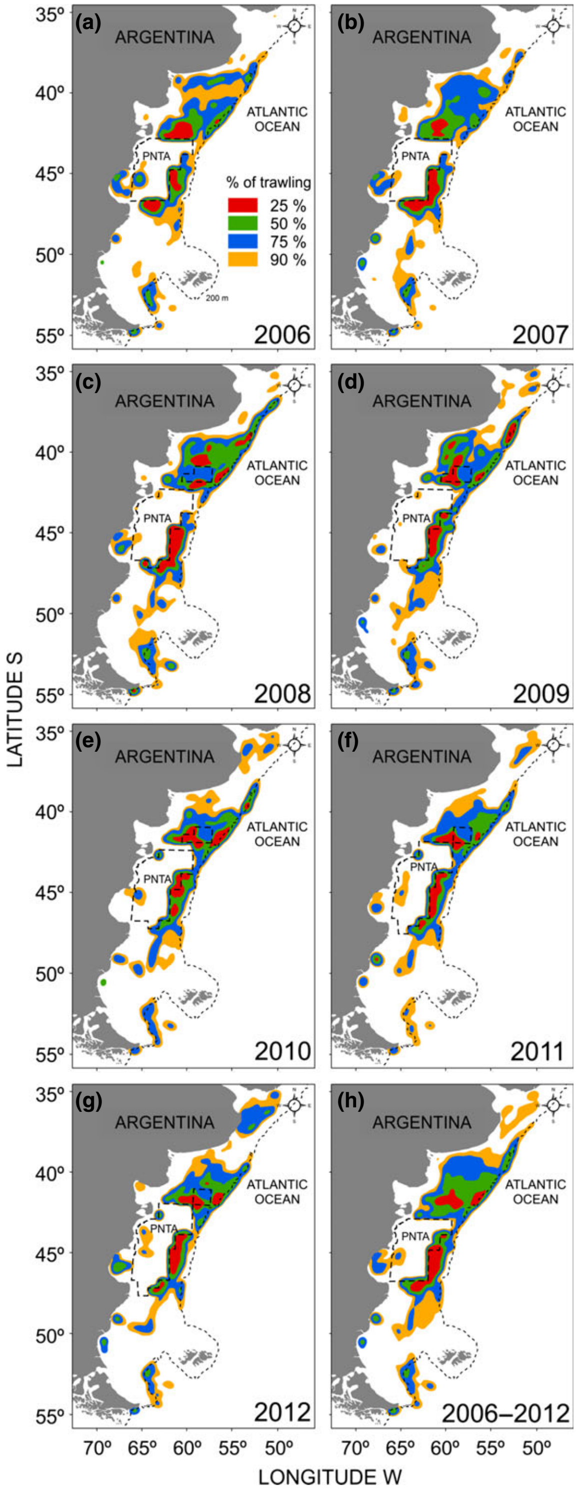


Figure 1. Spatial pattern of trawling by year in the Argentine Economic Exclusive Zone (EEZ) showing the variation in the location of hotspots between years (a–h). In each map, four trawl polygons are shown concentrating 25% (red), 50% (green), 75% (blue) and 90% (yellow) of trawling hours. PNTA, patagonian no-trawling area.

isobaths, and the other at the western side of the front. The third main area was located between 45 and 48°S westward of the SBF.

The trawl polygons that included the 25% of the TH (considered hereafter as hotspots) have a limited extension, representing an area lesser than 5% of the Argentine Exclusive Economic Zone (total AEEZ area *c.* 1 100 000 km^2). The area of the polygons that included the 90% of the trawl fishing hours never exceeded the 42% of the AEEZ. The area occupied by each polygon (25%, 50%, 75& and 90%) during the study period is shown in Fig. 2.

The estimated trawled area per year (Fig. 3) showed that *c.* 7% of the shelf was trawled in 2006, 2007, 2008 and 2011, 6% in 2010, 5% in 2012 and 4% in 2009. Subtracting the area occupied by the PNTA (184 224 km^2, in 2010), the total area in which fishing is allowed becomes 900 000 km^2, and the estimated trawled area per year increased to 8% of this area in 2007, 2008, 2010 and 2011, 9% in 2006, 6% in 2012 and 5% in 2009.

Relationship between bottom trawling areas and marine fronts

To define and compare the different studied areas, four polygons were constructed to evaluate the relationship between trawling distribution and fronts. The total trawl fishing area (FA) comprised 737 915 km^2, the SBF 71 908 km^2, the SPF 14 682 km^2 and the MSF 10 529 km^2 (9.7%, 2% and 1.4% of the FA, respectively; Fig. 4).

The SBF concentrated more trawling than expected for the area it occupied; trawling hours were higher in 2006, 2008, 2009, 2010, 2011 and 2012 (1.3-, 1.4-, 2-, 2.6-, 2- and 1.7-fold higher, respectively; χ^2-tests $P < 0.001$). The SBF represented 9.7% of the fishing area, but it concentrated 13% of the trawling in 2006 and 2008, 19% in 2009 and 2011, 25% in 2010, and 17% in 2012. Only in 2007, trawling at the SBF was 8% lower than expected (χ^2-tests $P < 0.001$). In contrast, trawling was almost negligible at the SPF and at the MSF; during the studied period, trawling was by far lower than expected (χ^2-tests $P < 0.001$) at both frontal systems.

Regarding the spatial overlapping between areas of high trawl intensity and fronts, trawling hotspots partly cover the shelf-break front or were distributed westward of it. In 2006, 2007, 2008 and 2011, the percentage of trawling hotspots (25% polygons) overlapping with the SBF polygon was low (2%, 0%, 9% and 6%, respectively), whereas in 2009, 2010 and 2012, percentages were higher (14%, 25% and 11%, respectively; Fig. 4). No overlapping was detected between

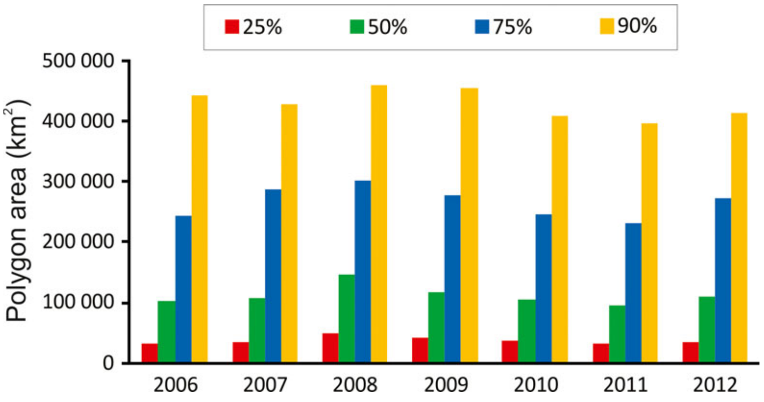
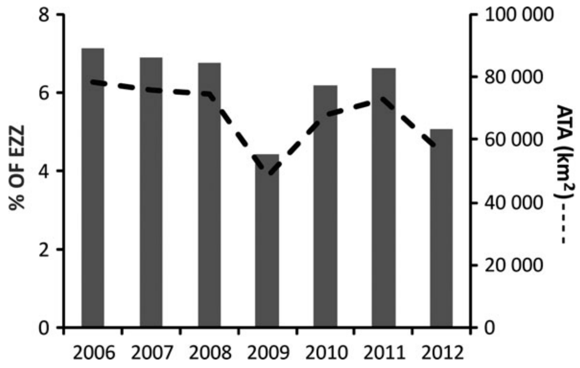


Figure 2. Area (km^2) occupied by each trawl polygon showed in Fig. 1, concentrating the 25%, 50%, 75% and 90% of trawling hours per year.

Figure 3. Main axis: Percentage of the Argentine Economic Exclusive Zone (AEEZ) trawled by year. Secondary axis: estimated trawled area (km^2) per year.



areas of high trawl intensity and the MSF or the SPF during the period 2006–2012.

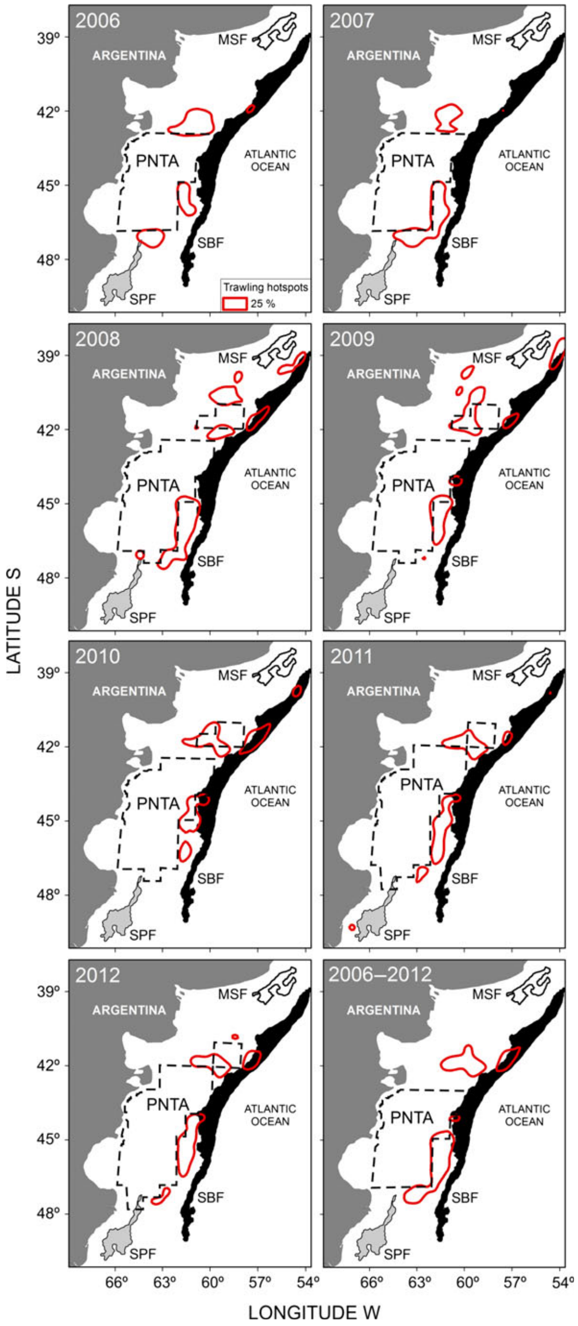
DISCUSSION

We investigated the distribution of bottom trawl fishing during 2006–2012, defining areas of highest trawling intensity (hotspots) and evaluating their spatial pattern and relationship with marine fronts. We found that the spatial distribution of trawling activity in the AEEZ is patchy, with few areas characterized by high trawling effort. However, such hotspots were relatively small, comprising <5% of the total AEEZ extension, and showing little variation in their spatial location between years. In terms of the annual trawled area, it represented <7% in each year. Despite the lack of clear spatial overlapping between trawl fishing hotspots and marine fronts, trawling was positively associated with the shelf-break front, but not with the Southern Patagonia or the mid-shelf front.

Trawling is thought to be a major threat to marine ecosystems and particularly to the seafloor (Palanques *et al.*, 2014). There have been many calls to urgently reduce the amount of trawling around the world under the premise that large areas are being trawled at continental shelves. Hence, many management plans are being carried out to reduce trawling effort around the world (FAO, 2014). At the AEEZ, there is a large closed area (PNTA; in 2010 *c.* 17% of the shelf extension) where trawling activities are banned. In agreement with previous studies (Alemany *et al.*, 2013, 2014), trawling activities were mainly distributed between 37° and 47°S, and in most cases associated with the borders of the PNTA. Despite no-trawling areas diminishing the impact caused by trawl nets, the closure of a large area may reallocate or displace the effort, potentially increasing fishing pressure elsewhere (NRC, 2002). The spatial analysis of trawling distribution at the AEEZ showed that fishing pressure is higher near the boundaries of the PNTA, possibly because fishers would have better catches near closed areas given the net export of fish out of the protection (Kellner *et al.*, 2007). Despite possible protection effects, before the implementation of the PNTA the area was already one of the best fishing grounds of the Argentine continental shelf (Irusta *et al.*, 2001), thus, it would be expected that after implementing the protection, and as occurred in closed areas off the NE USA (Murawski *et al.*, 2005), fishing effort displaced to the PNTA boundaries.

Contrary to what is generally assumed, our data show that although there are particular areas under high fishing intensity, the seafloor being effectively trawled is <7% of the AEEZ. The Argentine continental shelf is a large plain with a smooth slope, lacking any abrupt topography (Parker *et al.*, 1997). The seabed is quite homogeneous, dominated by median-grained sand with patches of small gravel and coarse sand (Parker *et al.*, 1997); consequently, almost the entire continental shelf is suitable for trawling. Nevertheless, the areas of high trawling intensity are small in comparison with the total area able to be trawled,

Figure 4. Spatial distribution of trawling hotspots per year superimposed to polygons representing three different frontal systems at the Argentine Economic Exclusive Zone (EEZ). MSF, mid-shelf front (white fill); SBF, shelf-break front (black fill); and SPF, southern Patagonia front (grey fill); all defined by satellite chlorophyll distribution. PNTA, Patagonian no-trawling area.



and inter-annual spatial variability is low. That is, hotspots are located more or less in the same place year to year. In agreement with our finding of relatively small trawling hotspots, at the North Sea in UK territorial waters, trawling effort is distributed in small, intensively fished core areas and large infrequently fished margins (Jennings and Lee, 2012). It is proposed that areas with high trawling intensity not only remain permanently altered but also that the fauna inhabiting them is readapted to this physical disturbance (NRC, 2002). As trawling hours are concentrated and overlap yearly, the total trawled area is small but trawling effort is much higher in the hotspots than elsewhere.

Although the trawled areas may be small and stable through time, it still remains unknown what the actual ecosystem effects are. As ecosystem sensitivity to trawling fisheries varies regionally (Bolam *et al.*, 2014) it is essential to identify areas in which trawling impacts would be the strongest (Hiddink *et al.*, 2007) to assess the trawling effects. Unfortunately, information on benthic assemblages of the AEEZ is not sufficient to delineate vulnerable areas to trawling. It has been proposed that localized fishing perturbations, although very intensive, may have fewer ecological implications than less intense fishing disturbance in extended areas (Kaiser *et al.*, 2002). In that framework, if as a consequence of the seabed uniformity it is assumed a relative homogeneity of the benthic ecosystem, then it could be hypothesized that trawling would have a minor ecological impact if just small areas are being affected. However, if the benthic habitat and communities are quite heterogeneous at the AEEZ and trawling hotspots coincide with sensitive areas, high trawling intensity may have a significant impact on the marine benthic ecosystem. Thus, to evaluate the effects of trawling in the AEEZ, it would still be necessary to focus research on the trawling hotspots identified in this study.

Marine fronts are relevant areas for fisheries as the high primary production associated with them affects not only pelagic but benthic organisms (Acha *et al.*, 2015). They are regions of high productivity influencing the abundance and distribution of fish in the fishing grounds (Agenbag *et al.*, 2003). Fronts are important fishing areas for some fleets targeting demersal resources in the AEEZ (Alemany *et al.*, 2014), as well as for trawling activities. Trawl fishing distribution was positively related with the SBF, although no association was detected with the southern Patagonia and midshelf fronts. In six of the 7 years studied, the SBF concentrated more trawling activity than expected, suggesting this front as a relevant area for fishing demersal resources. Our results are in accordance with several studies showing the importance of the SBF on demeral (e.g., Podestá, 1990; Lucifora *et al.*, 2012; Alemany *et al.*, 2014) and benthic species (e.g., Bogazzi *et al.*, 2005; Mauna *et al.*, 2008, 2011). The SBF is a large area that follows the continental slope for more than 1500 km (Piola, 2008) and is responsible for the high primary production of the region (Lutz *et al.*, 2010). In turn, this high production attracts organisms of different trophic levels taking advantage of abundant and suitable food at the front. Presumably, trawl fisheries would have better catch opportunities operating at or near the front where several commercial resources distribute.

Despite a positive relationship between trawl fishing and the shelf-break front being found, our analysis showed a spatial decoupling between areas of highest trawling intensity (hotspots) and fronts. In this region, primary production is spatially coupled with fronts (Rivas, 2006) but the distribution of higher trophic level consumers, such as fish, may be decoupled from these features and spatially displaced depending on their trophic level, complex behaviour and swimming ability (see Olson, 2002). Two different but non-exclusive processes would be involved in the decoupling of secondary production and fronts, movement of organisms and/or water masses. Nutrients and detritus are transported among marine habitats by mobile consumers, such as fishes that migrate daily and seasonally across boundaries (Polis *et al.*, 1997). In that sense, there would be an energy flow between frontal areas and adjacent habitats due to organism's movement to forage and/or to defecate. The shelf-break front results from the meeting of two water masses (Malvinas Current and shelf water) and its position shows spatial variability, moving onshore and offshore seasonally (Carreto *et al.*, 1995; Mauna *et al.*, 2008). There is also evidence of water intrusions (nutrient-rich Malvinas Current waters) onto the continental shelf that potentially enhances nutrient enrichment over the region (Piola *et al.*, 2010). The complex circulation pattern of water masses and currents at the Argentine continental shelf would be a possible explanation for the spatial decoupling between fronts and trawling hotspots as the primary production generated at frontal regions would be exported onto the shelf providing food resources for commercially important species. Moreover, the shelf-break front is an inclined interface that reaches the bottom westward of its surface manifestation (e.g., Acha *et al.*, 2004). Consequently, given that trawling activity is done near the bottom, and it distributes westward of the SBF, the actual overlap between this front and the near trawling hotspots would be slightly higher than our results showed.

Finally, the PSLME is a highly productive region in which trawling is the predominant fishing method and, despite an almost fully trawlable shelf, our results show that trawling hotspots are relatively small in size. Thus, these findings suggest that over the shelf the magnitude of habitat effects owing to bottom trawling is relatively small. Although trawling hotspots did not overlap with marine fronts, this study also shows that the shelf-break front receives more trawling effort than expected, given that many species tend to aggregate near or at the front taking advantage of the opportunities provided by this area.

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