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Seabird and marine-mammal attendance and by-catch in semi-industrial trawl fisheries in near-shore waters of northern Argentina

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Abstract. Seabird and marine-mammal attendance and by-catch in mid-water and bottom otter semi-industrial coastal pair-trawl fisheries were assessed for the first time in northern Argentina. Observers were placed onboard trawlers between autumn 2007 and autumn 2008. Fifteen marine top-predator species were associated with the vessels. The most abundant and frequent seabirds (trawl fisheries combined) were the kelp gull, *Larus dominicanus* (~70% of total birds and >96% occurrence), and the Olrog's gull, *L. atlanticus* (~12% and >50%, respectively). Other seabird taxa such as Procellariiforms and Sphenisciforms, among others, were represented in very low numbers. The only mammal species recorded was the South American sea lion, *Otaria flavescens* (1% and 2%, respectively). Analysis of environmental and operational variability affecting the abundance of gulls indicated a significant increase in abundance with fishing depth, time of day, seasonality, wind intensity and wind direction. Incidental mortality of top predators was low and comprised only Magellanic penguins, *Spheniscus magellanicus*, in the mid-water gear. The results of the present study showed that the semi-industrial trawl fisheries operating in coastal waters in northern Argentina may a have a relatively minor impact on marine top-predator populations, at least in terms of incidental capture.

Additional keywords: fishery–top predator interactions, pair-trawl coastal fisheries, marine top predators, South America.

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Introduction

A large number of marine top predators, mainly seabird and marine-mammal species, are attracted to fishing vessels at sea, given that they provide supplementary feeding in the form of discard or fishery waste as well as baits from hooks, fish or squid caught by nets (Northridge 1991; Montevecchi 2002). Although such use of supplementary food could be regarded as a direct positive effect of fisheries on attending species (e.g. boosting population numbers for some species, as documented for several gull species; Furness 2003), the increase of risk of mortality as a result of collisions and entanglements with gear has been regarded as a direct negative effect (Botsford *et al.* 1997; Tasker *et al.* 2000). Increased mortality rates as a result of interactions with fisheries were linked to the global declines in several seabird populations (Lewison and Crowder 2003; Anderson *et al.* 2011), of which albatrosses and petrels have been extensively recognised as the most threatened group (BirdLife International 2012). Not surprisingly, population declines of many marine-mammal and sea-turtle species as a result of fisheries mortality have been increasingly reported in the literature (Hays *et al.* 2003; Lewison *et al.* 2004). Understanding fisheries effect on marine top-predator populations is complex, because many of the key variables required to evaluate causal aspects of the relationships cannot be estimated because of the paucity of fisheries observer data, particularly in coastal fisheries, and uncertainties around environmental and anthropogenic effects on populations (Louzao *et al.* 2011; Lewison *et al.* 2012).

The coastal marine ecosystem of the Northern Argentine Continental Shelf (see Lucas *et al.* 2005) is regularly used by over 60 species of seabirds and shorebirds (Silva Rodríguez *et al.* 2005; Yorio *et al.* 2005; Blanco *et al.* 2006), at least five species of marine mammals (Bastida *et al.* 2007) and three species of sea turtles (González Carman *et al.* 2011), which exploit this area as foraging ground throughout the year. Several of these species are listed as globally threatened by the International Union for Conservation of Nature (BirdLife International 2011) and are thus prioritised by leading organisations (e.g. Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2012; Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC Sea Turtles) 2012). Further, the large diversity of coastal fisheries and logistic difficulties for their monitoring have, not surprisingly, discouraged investigations under an ecosystem approach (but see Jaureguizar *et al.* 2006; Tamini *et al.* 2006; and Menni *et al.* 2010, for other top predators). Most of the available information indicates that in virtually all Patagonian coastal fishing fleets, seabird assemblages attending vessels are dominated by gulls, *Larus* spp., although diving species such as cormorants, *Phalacrocorax* spp., and Magellanic penguins, *Spheniscus magellanicus*, are largely being captured in nets (González-Zevallos and Yorio 2006; González-Zevallos *et al.* 2011; Marinao and Yorio 2011). Further, incidental mortality of South American sea lion, *Otaria flavescens*, and small cetaceans, particularly the franciscana dolphin, *Pontoporia blainvillei*, occurred in virtually all coastal fishing gear (Crespo *et al.* 2007, and references therein). Because of their natural-history traits such as high adult survival rates, delayed maturity, low fecundity and long life expectancy (Perrin *et al.* 2002; Montevecchi 2002), both seabirds and marine mammals tend to be very susceptible to heavy fishing pressure (Furness 2003; Bastida *et al.* 2005). Thus, human activities have been recognised as a serious problem for conservation of marine top-predator species.

Despite the fact that Buenos Aires Province (at northern Argentina) has a long history of coastal fishing (Mateo 2004; Perrotta *et al.* 2007), there is little information available regarding seabird and marine mammals' attraction to trawlers in northern Argentine marine waters. There, over 30 species of both pelagic and demersal fish are being exploited throughout the year by a diverse array of coastal fishing gear (see Perrotta *et al.* 2007); hence, the coastal fishing gear is technically described as a non-selective multi-species fishery, locally known as '*variado costero*' (Federal Fishing Council (Consejo Federal Pesquero) (CFP) 2006). Few stock assessments have been conducted in the area to determine the size and distribution of least traditional resources such as silverside fishes, *Odontesthes* spp. (Hirt Chabbert 1991; Garcia 1994), or the shrimp *Pleoticus muelleri* and prawn *Artemesia longinaris* (Scelzo *et al.* 2002), besides some of these resources (e.g. silversides) may play an important role in the Argentine market and fishing statistics (Boschi 2004; Ministerio de Agricultura Ganadería y Pesca (MAGYP) 2012). Coastal fleet catches silverside fishes from early austral summer (i.e. January) to late autumn (i.e. August–September) (Ercoli et *al*. 1986; Cousseau and Perrotta 2004), whereas crustaceans are being captured in early autumn (i.e. early April) and early winter (i.e. early June) (Scelzo *et al.* 2002; Boschi 2004). During the rest of the year, vessels targeting these species continue fishing on other species (aimed with different gear), such as the chub mackerel, *Scomber japonicus* (Perrotta 2004). The fleets targeting silverside fishes and both crustacean species are classified as semi-industrial pair-trawl fisheries and have being operating in the study area since 1950 (de Ciechomski 1972; Perrotta 2004). Nowadays, the fleet comprises a minimum of few tens of coastal ice-trawl vessels operating chiefly in waters off south-eastern Buenos Aires Province. The current study was designed with the objectives of (1) examining the abundance and composition of seabird and marine-mammal assemblages attending semi-industrial pair-trawl vessels, (2) assessing the effect of factors influencing seabird and marine-mammal attendance to vessels, and (3) estimating the level of interactions with fishing gear and the associated mortality.

Materials and methods

Study area and characterisation of coastal trawl fisheries

Data were collected aboard semi-industrial pair trawlers operating in near-shore waters off the Mar del Plata Harbor (hereinafter MdPH) (38°03′S, 57°32′W), in south-eastern Buenos Aires Province, Argentina. This harbour is the most important coastal port in Argentina, given the total number of fishing vessels based there (*c*. 190 vessels) and its significant contribution to the national coastal fishery catch (*c*. 80%) (Lasta *et al.* 2001). Close coastal vessels locally known as '*rada o ría*' constituted the bulk of the local fleet (>60%). These include vessels that range from 9 to 18 m long, 3 to 4 m wide, 30 to 425 HP and 6 to 12 t of capacity. Vessels are operating within 50 m deep, performing daily trips because of lack of refrigeration facility (Errazti and Bertolotti 1998; Lasta *et al.* 2001).

Once hauled, the catch is sorted on deck and preserved within plastic cubes (~0.05 m^3). Total annual catch of silverside and 'prawn–shrimp' landed by the semi-industrial coastal fleet based at MdPH was estimated to be 295 and 912 t, respectively (average estimations for the period 1995–2010; MAGYP 2012). Because there is currently no information available on the number of semi-industrial trawl vessels under study, and considering the aggregated behaviour of boats in a given fishing day, the minimum fishing effort was estimated on the basis of direct counts of fishing vessels operating in the vicinity of the vessel under study (see below).

The observations of attending marine top predators, including chiefly seabirds and marine mammals, were conducted during normal fishing operations of mid-water paired trawl (hereafter referred to as MWPT, with silverside or 'pejerrey' fishes, namely *O. argentinensis* and *O. smitti* as target species) and bottom otter paired trawl (hereafter referred to as BOPT, with 'prawn-shrimp' as target species) nets. Briefly, the MWPT net consists of a cone-shaped body, normally made of four panels (upper, lower and two laterals) ending in a cod end, with lateral wings extending forward from the opening. The horizontal opening width of the MWPT net was between 10 and 12 m. Towed by two vessels, the horizontal opening of the net is ensured and, thus, these nets are rigged to work in mid-water and are used to catch small pelagic fish (Ercoli *et al.* 1986; Nédelec and Prado 1990). The BOPT is a cone-shaped net consisting of a body, normally made of two or four panels, closed by one or two cod ends, with lateral wings extending forward from the opening. The horizontal opening width of the BOPT net was around 12 m. This gear is kept open horizontally by two vessels, whereas the vertical opening is obtained with floats on the upper edge. Hence, the trawl is designed and rigged to have bottom contact during fishing and is being used for targeting bottom and demersal species in a wide range of depths. In both trawl fisheries, the nets are shot in the traditional manner from one boat, after which the second towing warp is picked up by the other craft (Nédelec and Prado 1990; Scelzo *et al.* 2002). Normally, trawl vessels return to port generally when the catch is completed, usually before nautical twilight. No lights were or are being used to attract the fish, because operations of both trawl fisheries were (still are) conducted during daylight.

Marine top-predator observations

Surveys were conducted on board three semi-industrial trawlers (which varied between mid-water or bottom otter paired trawls, depending on the target species and season) from late May to mid-June 2007 and from mid-February to mid-May 2008 (in the case of MWPT) (this represents ~10% of the whole fleet) and in early June 2007 and late April 2008 (in the case of BOPT) (~30% of the whole fleet). Fishing operations were coded as (1) setting, deployment of the net of the vessel, (2) trawling, towing the net with and without discarding periods, and (3) hauling, lifting the net to the vessel. Fishery discards were scaled into two categories, as follows: 0 = no discards; and 1 = presence of discards. Because fishery discards were recorded in <8% of the overall monitored hauls (pooled fisheries), they were excluded from the general linear model analysis. A haul was defined as a complete sequence of trawling, followed by hauling and sorting the catch, and a fishing trip was defined as a day when at least one haul was made.

Counts of ship-attending marine birds and mammals were estimated for each species within a 30-m hemisphere astern of the vessel. The 30-m radius was calibrated periodically throughout the day by using the methods proposed by Heinemann (1981). Counts occurred approximately every 1 h throughout the duration of each fishing day (28 trips/fishing days, 62 censuses for MWPT, and 9 trips/fishing days, 41 censuses for BOPT). Observers were trained in the identification of seabird and marine-mammal species and tasked to conduct observations on interactions between seabirds and marine mammals with fishing gear (A. M., H. P. L. and J. P. S. P.). Observers stood in the stern corner of the vessel, to provide the least-obstructed view of the active fishing area, and also to minimise observer disturbance to fishing operations. For each count, the observer registered the fishing depth (in meters), with the number of trawlers within 3 km of the observer vessel being recorded for each observation, the geographical coordinates, time of day (afterwards pooled in time block (TB) 1 = sunrise + 4 h, TB 2 = end of TB 1 + 8 h), time of the year (afterwards pooled in late summer (mid-February to mid-May) and autumn (late May to mid-June) for MWPT, and in winter 2007 (early June) and autumn 2008 (late April) for BOPT), wind intensity (divided in three categories, as follows: 1 = 0–4 kn, 2 = 5–10 kn and 3 = >10 kn), wind direction relative to the vessel (divided in 1 = ahead, 2 = 45–135° and 3 = astern), sea state (in Beaufort scale, in three categories, as follows: 1 = ≤1, 2 = 2 and 3 = ≥3) and cloudiness (afterwards pooled in cloud coverage in quarters (CCQ), as follows: CCQ 1 = 0–25%, CCQ 2 = 26–50%, CCQ 3 = 51–75% and CCQ 4 = 76–100%).

All marine top-predator (i.e. seabirds and sea lions, hereinafter TOP) interactions (i.e. contacts with fishing gear and/or vessel) with the vessel or fishing gear were recorded in two periods, during shooting/early trawling and late trawling/hauling. Observations were focused on the side of the vessel were the catch was loaded and sorted, to have first-hand access to any animal interacting or being caught incidentally. Contact point of a given TOP with gear was classified as follows: (1) warp cable, (2) trawl door, (3) wings or walls (either considered as net hereinafter), (4) vessel, and (5) other. In general terms high-seas protocols were followed (see Wienecke and Robertson 2002) and further used in neighbouring waters (Sullivan *et al.* 2006; Favero *et al.* 2010). Contact types with the vessel or fishing gear were defined as follows: (1) bird on water, light contact; sea lion near gear without contact; (2) bird on water, heavy contact, causing at least part of the bird to be dragged underwater; sea lion, light contact; (3) bird flying, light contact, bird does not deviate from course; sea lion climbs on the net; (4) bird flying, heavy contact, bird deviates from course and/or dragged underwater; sea lion caught on the net; (5) bird caught in net; (6) bird snagged on net while attempting to feed; and (7) sea lion snagged on net while attempting to feed. The fate of TOP contacting with gear/vessel was classified as (1) no apparent damage, (2) possible minor injury, (3) possible major injury, (4) death and (5) unknown (Wienecke and Robertson 2002).

Statistical analysis

Analyses of marine TOPs were restricted to counts of kelp and Olrog's gulls (the only species where age composition is detailed), because they comprised >76% of the total individuals counted (pooled fisheries).

We used the total abundances (i.e. pooled counts) for each species within a day in any given operation (e.g. setting, trawling), because we did not find a correlation between consecutive counts for a given gull species within a day ($r^2 > 0.07$, $P > 0.05$).

The distribution and abundance of gulls attending coastal trawlers were analysed in conjunction with the fishing effort, by using kernel plots (Worton 1989). The fishing effort was modelled so as to define range (95%), focal (75%) and core (50%) areas (Louzao *et al.* 2011).

The effect of predictor variables (e.g. sea state, wind direction and intensity, time of day, time of the year, cloudiness, fishing depth and number of trawlers in the vicinity of the monitored vessel) on the abundance of kelp and Olrog's gulls in each coastal trawl fishery was tested with generalised linear models (GLM) with Poisson error distribution and log-link function (McCullagh and Nelder 1989; Crawley 2007). When over-dispersion in a model was detected, the standard errors were corrected using a quasi-GLM model where the variance is given by $\varphi \times \mu$, where μ is the mean and φ the dispersion parameter (Zuur *et al.* 2009).

Time of day (Time blocks 1 and 2), time of the year (late summer and autumn for MWPT and autumn and winter for BOPT), wind intensity (calm, moderate and intense), wind direction relative to the vessel (from the bow, beam and stern), sea state (Beaufort 1, 2 and 3), and cloudiness (in CCQs) were included as categorical variables. The fishing depth and the number of trawlers within 3 km of the observer vessel were included as continuous variables.

To fit the models of kelp and Olrog's gulls attending MWPT vessels, 'full' cloud coverage was not considered in the models because birds did not occur when these conditions were met during the surveys. Further, wind blowing 'ahead' was not considered in the models of Olrog's gulls attending BOPT vessels because the presence of this species was negligible during these conditions (see Nicholls 1989).

In all analyses, we followed a backward selection procedure, removing non-significant terms from the model, one by one, to select the respective minimal model of best fit (Crawley 2007; Zuur *et al.* 2009). All models were carried out using R software v2.13.1 (R Development Core Team 2011). We used a Student's *t*-test to compare the counts of juvenile and adult kelp and Olrog's gulls within the study area. Values were reported as means ± s.d., except where noted. The level of significance in all tests was set to $P = 0.05$.

Results

Characterisation of semi-industrial trawl fisheries

Overall, observed MWPT vessels operated within an area of 209 km^2 and at an average distance to MdPH of 4.4 ± 0.7 km (range = 4.3–10 km) (Fig. 1*a*). The number of trawlers operating within 3 km of the vessel under study varied from zero to 33, with a mean of 13.2 ± 9.3 vessels. Overall, the setting of the MWPT net was carried out at a mean speed of 2.6 kn, with each fishing trip starting about 0630 hours and finishing about 1430 hours local time (−3 GMT), and comprising from one to four sets. Trawling was the longest of the three sections in the fishing operation (compared to setting and hauling), lasting between 26 and 177 min (median 112 ± 40.6 min, $n = 33$ hauls).

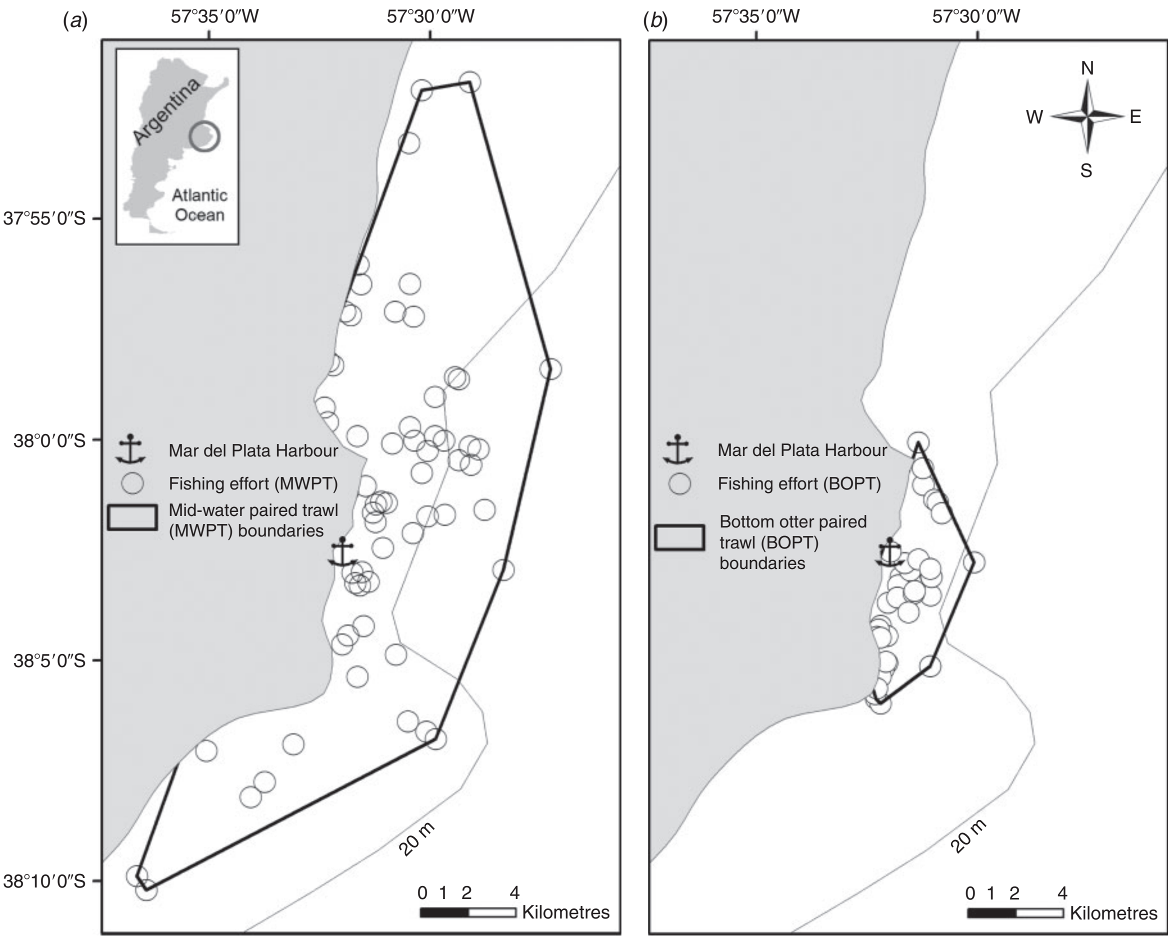

Fig. 1. Distribution of the surveyed fishing effort in the (*a*) mid-water (MWPT) and (*b*) bottom otter (BOPT) semi-industrial pair trawlers operating from Mar del Plata harbour along the south-eastern coast of Buenos Aires Province, Argentina. Each open circle represents an individual fishing operation (trawl). Continuous line represents the maximum boundary of the observed fishing effort.

The MPWT nets were set at a mean fishing depth of 6.4 ± 2.5 m (range = 3.4–10.5 m). Nets were made of multifilament nylon, with variable mesh size ranging from 10 to 350 mm. Fishery discards were recorded in <7% of the overall monitored hauls ($n = 77$ fishing operations). Although *Odontesthes* fishes were the target species of this fishery, observed by-catch comprised another silverside species, *O. incisa*, locally known as 'cornalito'.

Overall, observed BOPT vessels operated within an area of 22.2 km^2 and at a mean distance to MdPH of 4.3 ± 0.1 km (range = 4.2–4.3 km) (Fig. 1*b*). The number of trawlers operating within 3 km of the vessel under study varied from zero to nine, with a mean of 5.3 ± 2.3 vessels. Overall, the setting of the BOPT net was carried out at a mean speed of 2.2 kn. Each fishing trip comprised between one and four sets, starting about 0600 hours and finishing about 1500 hours local time. Likewise, trawling was the longest of the three sections in the fishing operation, lasting between 48 and 200 min (median 133 ± 35.4 min, $n = 23$ hauls). The BOPT nets were made of multifilament nylon, with a fix mesh size of 45 mm, which were set at a mean fishing depth of 12.7 ± 4.7 m (range = 3.6–21 m). Fishery discards were recorded in 7% of the overall monitored hauls ($n = 40$ fishing operations). By-catch species in this fishery included several species of both pelagic and demersal fish (chiefly Scianidae, Carangidae, Percophididae and Phycodae), benthic fish (chiefly Paralichthydae and Rajidae) and crabs (Platyxanthidae and Portunidae).

No mitigation devices (e.g. tori-lines or turtle exclusion) were or are being used by the studied fleet to avoid or minimise interactions with TOPs.

Seabird and marine mammals attending trawl fisheries

From a total of 3758 top predators counted attending MWPTs during the 62 observed surveys, kelp gulls accounted for 66% of top predators attending this fleet, followed only by Olrog's gulls (10%). Other species each comprised less than 10% of individuals sighted. The most abundant marine-mammal species was the South American sea lion, which comprised <0.2% ($n = 6$) of overall individuals (Table 1). Kelp and Olrog's gulls were present, respectively, in 98% and 37% of overall surveys. With regards to kelp gulls, adult individuals were more abundant than juveniles (t-test$_{1,62} = 2.307$, $P = 0.022$), whereas, in Olrog's gulls, juvenile and adult individuals were represented in almost all counts (t-test$_{1,54} = 0.480$, $P = 0.634$).

Overall, 1428 TOPs were counted attending BOPT in the 41 observed surveys. Kelp gulls accounted for 70% of overall TOPs, followed by Olrog's gulls (14%). Other species individually comprised less than 10% of sighted birds. The South American sea lion, the most abundant marine-mammal species around BOPTs, comprised ~2% ($n = 27$) of overall individuals (Table 1). Kelp and Olrog's gulls were present in 95% and 66% of overall surveys, respectively. In regards to kelp gulls, again adult individuals were more abundant than juveniles (t-test$_{1,29} = 2.368$, $P = 0.002$), whereas, in Olrog's gulls, the number of juvenile and adult individuals did not differ significantly among all counts (t-test$_{1,41} = 1.736$, $P = 0.089$).

Factors affecting the abundance of gull species

Modelling performed showed a significant effect of time of day, wind intensity, trawling speed and fishing depth on the

Table 1. Proportion, mean (± 1 s.d.) and minimum and maximum abundances of top-predator species attending semi-industrial mid-water (MWPT) ($n = 62$ counts) and bottom otter (BOPT) ($n = 41$ counts) pair trawlers operating in near-shore waters of Mar del Plata, Buenos Aires Province, Argentina

Species	MWPT			BOPT		
	% Total	Mean (SD)	Range	% Total	Mean (SD)	Range
Birds						
Kelp gull (*Larus dominicanus*)	65.99	40 (48.12)	0–243	70.31	24.48 (20.26)	0–82
Olrog gull (*Larus atlanticus*)	9.61	5.82 (13.70)	0–78	14.08	4.90 (7.42)	0–38
Common tern (*Sterna hirundo*)	8.25	5 (19.61)	0–118	1.26	0.43 (1.46)	0–8
Brown-hooded Gull (*Chroicocephalus maculipennis*)	5.30	3.21 (5.51)	0–29	3.08	1.07 (2.64)	0–16
Neotropic cormorant (*Phalacrocorax olivaceus*)	4.18	2.53 (13.63)	0–90	2.59	0.90 (3.24)	0–19
Gray-hooded Gull (*Chroicocephalus cirrocephalus*)	3.94	2.39 (7.43)	0–48	2.59	0.90 (1.17)	0–9
Great shearwater (*Puffinus gravis*)	0.85	0.52 (2.83)	0–19	–	–	–
South American tern (*Sterna hirundinacea*)	0.56	0.34 (1.66)	0–12	0.07	0.02 (0.15)	0–1
Unidentified terns (*Sterna* spp.)	0.56	0.34 (1.63)	0–12	0.21	0.07 (0.34)	0–2
Cayenne tern (*Sterna eurygnatha*)	0.24	0.15 (0.51)	0–3	–	–	–
Black-browed albatross (*Thalassarche melanophris*)	0.11	0.06 (0.36)	0–2	–	–	–
Sooty shearwater (*Puffinus puffinus*)	0.11	0.06 (0.31)	0–2	–	–	–
Royal tern (*Sterna maxima*)	0.05	0.03 (0.25)	0–2	–	–	–
Great grebe (*Podiceps major*)	0.05	0.03 (0.18)	0–1	0.56	0.19 (0.10)	0–7
White-chinned petrel (*Procellaria aequinoctialis*)	0.03	0.02 (0.13)	0–2	–	–	–
Unidentified jaegers (*Stercorarius* spp.)	0.03	0.02 (0.13)	0–1	–	–	–
Doves (*Columba* spp.)	–	–	–	2.80	0.97 (4.90)	0–30
Sheathbill (*Chionis alba*)	–	–	–	0.35	0.12 (0.78)	0–5
Magellanic penguin (*Spheniscus magellanicus*)	–	–	–	0.21	0.07 (0.26)	0–1
Mammals						
South American sea lion (*Otaria flavescens*)	0.16	0.10 (0.35)	0–2	1.89	0.65 (0.96)	0–3

abundance of kelp gulls attending the MWPT (Table 2). Kelp gulls were more abundant during the advanced hours of the fishing day, during intense winds and with increasing trawl speed and fishing depth (Table 3, explained deviance = 32%). In regards to Olrog's gulls, models showed a significant effect of wind direction, wind intensity and fishing depth (Table 2), with the greatest gull abundances occurring during intense winds blowing to the side of the vessel and with increasing fishing depth (Table 3, explained deviance = 59%). Kernel analysis showed that the abundance of both gull species attending vessels was largely explained by the distribution of the fishing effort of MWPTs (i.e. >71% of the birds were observed within 50% of core area) (Fig. 2*a*, *b*).

Regarding BOPT fishery, the abundance of kelp gulls was significantly affected by the time of the year sampled (Table 2), with greatest abundances of gulls occurring during June (Table 3, explained deviance = 40%). In regards to Olrog's gulls, models also showed a significant effect of time of day, as well as cloudiness and fishing depth (Table 2); these gulls were more abundant during the mid-hours of a cloudy-sky fishing day, and with increasing fishing depth (Table 3, explained deviance = 72%). The abundance of both gull species was largely explained by the distribution of the fishing effort of BOPTs (i.e. >67% of the birds were observed within 50% of core area) (Fig. 2*c*, *d*).

Table 2. Generalised linear model analysis on the influence of different predictor variables (i.e. seasonality, sea state, wind direction and intensity, time of day, cloudiness, fishing depth and number of trawlers) on the abundance of kelp and Olrog's gulls

Only factors included in the minimal adequate model are shown in the table. The number of counts included in the models is given in parentheses. MWPT: mid-water pair trawlers; BOPT: bottom otter pair trawlers

Trawl fishery/species	Explanatory variables	*F*-test	df	*P*
MWPT				
Kelp gull (69)	Time of day	4.35	1	0.04
	Wind intensity	3.93	2	0.02
	Trawl Speedy	4.13	1	0.04
	Fishing depth	13.46	1	<0.001
Olrog gull (23)	Wind direction	6.41	2	<0.01
	Wind intensity	7.41	2	<0.01
	Fishing depth	17.73	1	<0.001
BOPT				
Kelp gull (39)	Season	3.72	1	<0.05
Olrog gull (26)	Time of day	11.78	1	<0.01
	Cloudiness	6.25	3	<0.05
	Fishing depth	16.37	1	<0.001

Interaction between TOPs and trawl fisheries

Overall, a total of 22 TOP interactions (i.e. observed contacts) during 77 MWPT fishing operations was observed during 28 days at sea (Table 4). All observed interactions were recorded during hauling operations. The majority of observed contacts corresponded to sea lions (65%), followed by kelp gulls (~10%), among others (Table 4). The majority of these interactions corresponded to light contacts of sea lions near gear and climbing on the fishing net. A total of three Magellanic penguins

Table 3. Coefficients (± s.e.) from generalised linear models describing the relationship between the abundance of the kelp and Olrog's gulls attending coastal trawlers and the factors included in the minimal adequate model (see Table 2)

Time block sunrise + 8 h, wind intensity 0–5 kn, wind blowing from ahead, time of the year winter 2007, and cloudiness 0–25% were used as the reference category in all cases. The number of counts included in the models is given in parentheses. MWPT = mid-water pair trawlers; BOPT = bottom otter pair trawlers

Fishery/species	Explanotory variables	Categories	Coefficients ± s.e.	*t*-value	*P*
MWPT					
Kelp gull (59)	Intercept		3.54 ± 0.68	5.19	<0.001
	Time of day	End of Sunrise + 8 h	0.54 ± 0.27	2.00	<0.05
	Wind intensity	5–10 knots	0.08 ± 0.31	0.27	0.78
		>10 knots	1.17 ± 0.48	2.44	<0.05
	Trawl speed		0.52 ± 0.25	2.05	<0.05
	Fishing depth		1.10 ± 0.03	3.37	<0.01
Olrog gull (23)	Intercept		1.61 ± 1.83	0.88	0.39
	Wind intensity	5–10 knots	0.50 ± 0.55	0.90	0.37
		>10 knots	3.48 ± 1.03	3.37	<0.01
	Wind direction	From the beam	3.99 ± 1.88	0.88	0.39
		From the stern	2.39 ± 1.88	2.12	<0.05
	Fishing depth		0.25 ± 0.06	3.88	<0.01
BOPT					
Kelp gull (39)	Intercept		3.05 ± 0.17	17.68	<0.001
	Season	Early June	0.48 ± 0.25	1.87	<0.05
Olrog gull (26)	Intercept		0.15 ± 0.59	0.26	0.79
	Time of day	End of Sunrise + 8 h	0.80 ± 0.23	3.42	<0.01
	Cloudiness	51–75%	0.31 ± 0.33	0.94	0.04
		76–100%	1.25 ± 0.52	2.40	<0.05
	Fishing depth		0.34 ± 0.08	3.88	<0.001

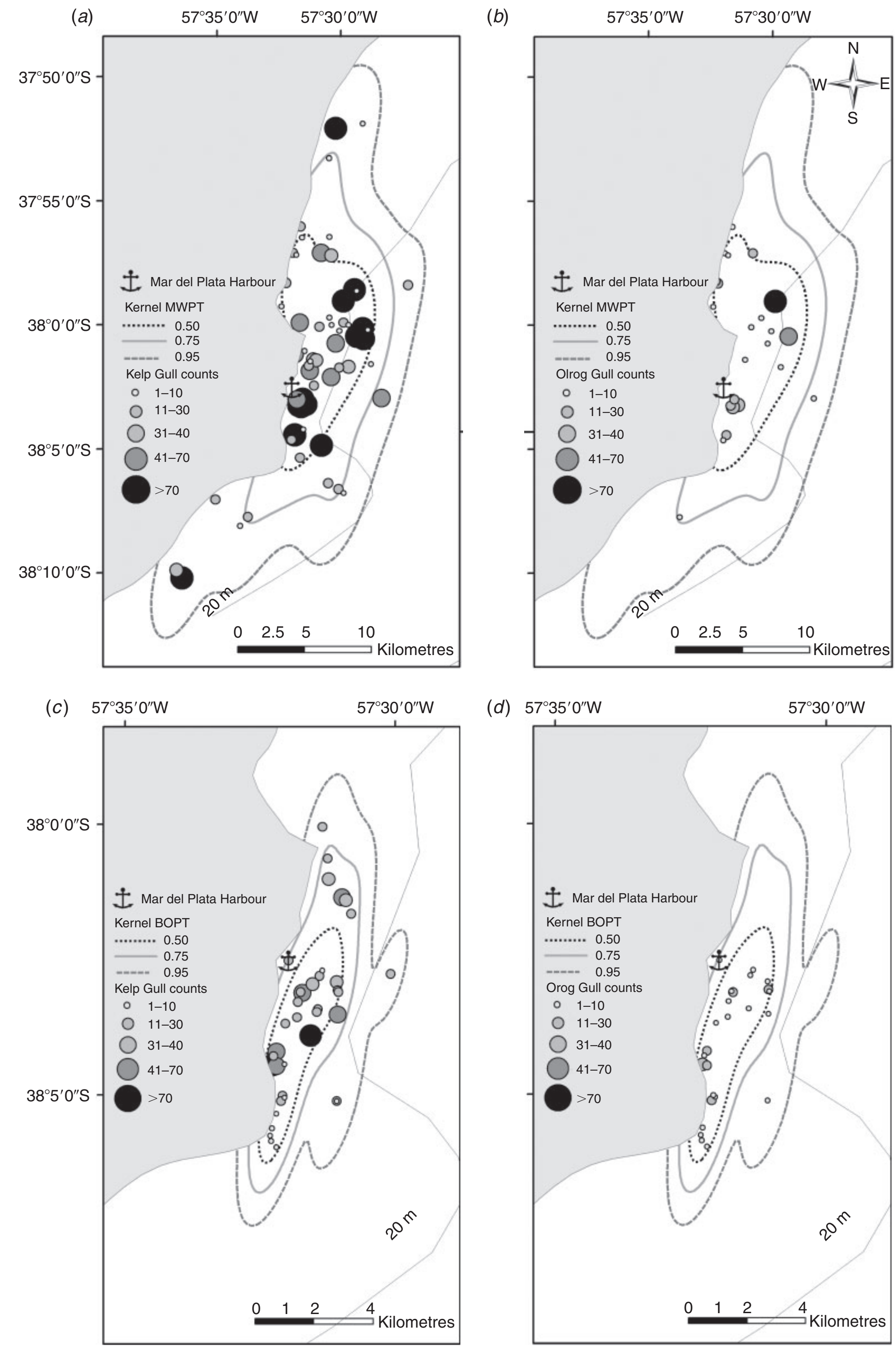

Fig. 2. Kernel contour distribution of the fishing effort, superimposed with the abundances of (*a*, *c*) kelp and (*b*, *d*) Olrog's gulls attending mid-water (MWPT) and bottom otter (BOPT) pair trawlers, respectively.

Table 4. Summary of contacts (in percentages) among main marine top predators attending coastal trawlers during hauling operations
The number of fishing operations observed is shown in parentheses. All observed contacts occurred with the net. MWPT = mid-water pair trawlers; BOPT = bottom otter pair trawlers; KPG = kelp gull; SGP = southern giant petrel; SSL = South American sea lion; MAG = Magellanic penguin. All observed contacts occurred with the net

	MWPT (77)			BOPT (40)	
	KPG	SSL	MAG	SGP	SSL
Contact type					
1. Bird on water, light contact with gear; sea lion near gear but not contact	100	0	0	100	100
2. Bird flying, light contact with gear; sea lion climbs on net	0	82	0	0	0
3. Bird on water, heavy contact with gear; sea lion caught on net	0	6	0	0	0
4. Bird caught in net	0	0	100	0	0
5. Sea lion snagged on net while feeding attempt	0	12	0	0	0
Fate					
1. Individual with no apparent injury	100	88	0	100	100
2. Individual with possible major injury	0	12	0	0	0
3. Individual captured dead	0	0	100	0	0
Total number of observations	2	17	3	1	7

(one adult male, one adult female and one unidentified bird) was observed to be incidentally caught during the MWPT fishery run sampled.

A total eight top predator interactions (observed contacts) was recorded associated with the 40 fishing operations of BOPTs observed during 9 days at sea (Table 4). Overall, observed interactions were registered during hauling operations. Most of the interactions corresponded to South American sea lions (>87%) and southern giant petrels, *Macronectes giganteus* (13%) (Table 4). These interactions corresponded to light contacts or sea lions near gear (without contact) with the fishing net. Neither seabird nor marine-mammal species were observed to be incidentally taken during the BOPT fishery runs sampled (Table 4).

Discussion

Marine TOPs attending semi-industrial trawl fisheries

To our knowledge, the present study is the first to investigate the direct interactions between marine TOPs and the semi-industrial trawl vessels (both mid-water and bottom otter gear) in the fishing fleet operating from Mar del Plata harbor in the near-shore waters of northern Patagonia in the south-east of Buenos Aires Province. Our results indicated that local marine TOPs are associated with coastal trawlers, with 14 seabird species and the South American sea lion being observed attending these fisheries. In regards to sea lions, the association of the species with coastal fisheries has been recorded previously in virtually all areas where breeding and non-breeding colonies occur (Bastida *et al.* 2007, and references therein) and also the number of sea lions observed during the present study was in line with previous reports in the coastal purse-seine fishery operating off Mar del Plata (Seco Pon *et al.* 2012). In the case of seabirds, all assemblages were largely dominated by kelp gulls, these being birds very well known for making an extensive use of fishery waste-food resources as well as fishery discards or marine organisms, facilitated during coastal fishing operations in waters of Argentina (Bertellotti and Yorio 2000*a*; Yorio and Giaccardi 2002; Silva Rodríguez *et al.* 2005; González-Zevallos and Yorio 2011; Marinao and Yorio 2011), Brazil (Branco 2001; Carniel and Krul 2011), Chile (Weichler *et al.* 2004; Ludynia *et al.* 2005), Uruguay (Segura *et al.* 2008), South Africa (Abrams 1983) and New Zealand (Fordham 1970; Steele and Hockey 1990). Adult gulls outnumbered juveniles around coastal trawlers, observation that was in line with a previous study from southern Patagonia (Bertellotti and Yorio 2000*b*); the difference between the number of adults and juveniles may be due to the lowered skill of young birds and adult dominance (Bertellotti and Yorio 2000*b*).

The Olrog's gull, an endemic species of the Atlantic coast of southern South America and currently considered '*Vulnerable*' to extinction (IUCN, BirdLife International 2011), was also commonly recorded attending coastal trawlers. This is novel information because the species is generally referred to as a near-shore forager feeding primarily on crabs in estuaries and intertidal pools during the breeding and non-breeding seasons (Delhey *et al.* 2001; Copello and Favero 2001; Herrera *et al.* 2005; Berón and Favero 2010; Berón *et al.* 2011). There are few records of Olrog's gulls making use of anthropogenic resources (but see Martínez *et al.* 2000; Berón *et al.* 2007). However, very recent information indicates that Olrog's gulls also attend purse seiners in waters off Mar del Plata during the non-breeding season (Seco Pon *et al.* 2012) and high-seas trawlers off northern Patagonia while breeding (Seco Pon and Favero, in press), although in lower numbers than in the present study. We hypothesise that the species might have changed its foraging behaviour in the past decades, primarily as a result of the massive expansion of local commercial and artisanal and/or coastal fisheries, as well as possible effects of degradation of its coastal habitats in the restricted breeding and non-breeding grounds of the species. This may indicate that Olrog's gulls may show a greater degree of ecological plasticity than previously thought, at least during the non-breeding season (Petracci *et al.* 2007; Seco Pon *et al.* 2012; M. P. Berón, J. P. Seco Pon, G. O. García, C. A. Paterlini, R. Mariano-Jelicich and M Favero, unpubl. data). Based on our results, two gull species, the abundant kelp gull and the threatened Olrog's gull, attended coastal trawlers. Further studies are needed to evaluate the degree of competition between these two species and coastal trawlers, the impact of kelp gulls on the structure and functioning of seabird assemblages attending vessels (in particular Olrog's gulls), as well as to evaluate the relative contribution of target species and fishery discards in the diet of gulls.

Factors affecting the abundance of attending gulls

The analysis of operational and environmental variability affecting the abundance of kelp and Olrog's gulls attending coastal trawlers indicated a significant increase in abundance with fishing depth (except for kelp gulls attending BOTP). This could be, at least partially, related to the variation in the quali- and quantitative composition of the captures and the type and size of fish and/or crustaceans facilitated or discarded by the vessels. Hence, we hypothesise that seabird attendance and behaviour are affected by the species composition, the actual volume and its energetic content of the fisheries by-catch. None of these pieces of information is currently available and, this will require further research. Although attending species are considered primarily coastal, the observed differences in the distribution of gulls may be as well the result of (1) species-specific patterns of distribution (e.g. linked with variation in body size), (2) intra- and inter-specific dominance relationships in flocks of gulls attending fishing vessels or (3) the result of a larger ecological plasticity in the kelp gull (see Yorio *et al.* 2005).

Operational factors, such as time of day (in the case of kelp gulls in MWPT and Olrog's gulls in BOPT nets), also affected the abundance of focal gull species, with maximum attendance of kelp and Olrog's gulls by mid-afternoon. This can be due to the behaviour of the fishery, as, for example, an increased availability of discards as the fishing operation passes. Finally, trawling speed also affected positively the abundance of kelp gulls attending MWPT nets. This is clearly due to the fact that the trawling speed must be suited for the fish species that are being sought (Brabant and Nédélec 1984).

Environmental variables also affected the abundance of gull species. The effect of wind conditions on the observed abundances of kelp and Olrog's gulls could be linked to the fact that heavy weather can alter the flight direction and manoeuvrability in seabirds (Broni *et al.* 1985; Spear and Ainley 1997). Moreover, heavy weather can also affect the performance and capture of fish by small-scale trawlers, hence decreasing the amount of fish discarded after hauling (Brabant and Nédélec 1984; Ercoli *et al.* 2000).

In relation to the temporal variable, kelp gulls were more abundant during autumn 2007 while attending BOPTs. Landings of the total argentine semi-industrial fleet directed to the prawn–shrimp fishery were ~1.5 times higher in autumn 2007 (6101 t) than in 2008 (4151 t) for the same target species and fleet strata (see MAGYP 2012). According to our results, seasonality – via variability in the fishery effort and catches and, consequently, the fishery waste food facilitated or discarded by the trawlers– could be also playing a role in the attendance of kelp gull. Thus, routine monitoring of fishing activity and catches of coastal trawlers and seabird vessel attendance should be further conducted to provide critical information for the ongoing management and conservation strategies in the study area.

Interactions between trawl fisheries and marine TOPs

The actual by-catch for seabirds and marine mammals in the studied fleets seems to be not problematic and even null for some taxa. Still, the MWPT fishery accounted for the greatest abundance and diversity of TOP species attending the coastal trawl fleet, and was the only fishery in which incidental mortality was recorded. Regionally speaking, commercial mid-water trawling off northern and central Patagonia represents an important source of marine-mammal mortality – but not seabird mortality – for species such as South American sea lions and dusky, *Lagenorhynchus obscurus*, and Commerson's, *Cephalorhynchus commersonii*, dolphins, among others (Crespo *et al.* 1997, 2007; Dans *et al.* 2003). Although previous studies have shown that artisanal fishing camps along the coasts of Buenos Aires Province, chiefly at Necochea–Puerto Quequén and Claromecó (123 and 259 km south of Mar del Plata harbour, respectively) –which include boats aimed with other gear, namely gill-nets – pose more a threat to dolphins, particularly the franciscana dolphin (Corcuera 1994; Corcuera *et al.* 1994; Crespo *et al.* 1994) than other species, no marine-mammal species was retrieved alive or dead in the overall (pooled fisheries) observed trawl hauls.

Incidental mortality of seabirds only comprised Magellanic penguins in the MWPT nets. With a maximum of 33 coastal mid-water trawlers observed operating during the study period, and assuming a conservative mean number of 2.5 sets per fishing day per boat as a proxy of the fishing effort during the run for silverside, an estimated 82.5 sets day^{-1}, in total, were conducted by trawlers during the period surveyed ($n = 2310$ sets, 28 fishing days). The estimated total number of Magellanic penguins killed during the fishery run sampled was 84 birds. Considering the relatively low penguin mortality levels associated with this fishery and the total population estimated for the species in Argentina (about one million breeding individuals, Schiavini *et al.* 2005), the mid-water trawl fishery in near-shore waters of Mar del Plata would appear to have a low impact on non-target (by-catch) species. Still, incidental catches of the species during trawling operations for silverside fishes in northern Argentine fisheries are in line with those reported in previous studies. About 100 penguins were incidentally taken by small-scale MWPTs targeting Cornalito at Quequén harbour in 1998 (Tamini *et al.* 2002).

The area of operation of the fisheries under study overlaps with the foraging ranges of threatened species such as the Olrog's gull, the black-browed albatross, *Thalassarche melanophris*, the white-chinned petrel, *Procellaria aequinoctialis*, and the Magellanic penguin (Isacch and Chiurla 1997; Savigny and Favero 2005), all of them known to interact with coastal fisheries (see e.g. González-Zevallos and Yorio 2006; González-Zevallos *et al.* 2011; Marinao and Yorio 2011; Seco Pon *et al.* 2012). The endemic and threatened franciscana dolphin also exploits waters where the fisheries under study operate (Crespo *et al.* 2010) and might be at risk in this fleet as well. So as to develop and implement an ecosystem-based management system in the area, a comprehensive analysis of the natural history of predators and their relationships with prey and fisheries, coupled with spatio-temporal oceanographic features, is needed. Given the great array of coastal fishing gears being used in the region and the elevated fishing effort (Perrotta *et al.* 2007), the gathering of high-quality long-term data is essential to comprehensively understand the impact of coastal fishing on the Northern Argentine Continental Shelf ecosystem.

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