Received: 29 June 2017 | Revised: 18 January 2018 | Accepted: 8 February 2018
DOI: 10.1002/aqc.2907

RESEARCH ARTICLE

WILEY

Seabird interactions and by-catch in the anchovy pelagic trawl fishery operating in northern Argentina

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Funding information
Universidad Nacional de Mar del Plata, Grant/Award Number: 15/E695, EXA 745/15; Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina, Grant/Award Number: PIP CONICET 00070; Agencia Nacional de Promoción Científica y Tecnológica, Grant/Award Numbers: PICT 2013-711 and PICT 2012-295

Abstract

1. Commercial fishing has been identified as one of the main threats affecting the survival of most seabird species. Although seabird mortality in Argentine longline and demersal trawl fisheries has already been characterized and quantified, the interactions with pelagic trawl fisheries targeting anchovy (*Engraulis anchoita* Hubbs & Marini, 1935) remains unknown.
2. The goal of this study was to characterize seabird assemblages attending pelagic trawl vessels and to analyse their interactions (i.e. contact of the birds with the vessel and/or fishing gear and by-catch). Data were obtained by on-board observers during three consecutive fishery runs, 2011–2013.
3. From a total of 333 observations, seabird abundance averaged 157.3 ± 229.7 birds per haul (totalling 23 species). Procellariiform followed by Charadriiform birds were the more frequent and abundant groups. The black-browed albatross (*Thalassarche melanophris* (Temminck, 1828)), shearwaters (*Ardenna* spp. and *Puffinus* spp.), white-chinned petrel (*Procellaria aequinoctialis* Linnaeus, 1758), and the kelp gull (*Larus dominicanus* Lichtenstein, 1823) were the most frequent and abundant attending species.
4. The seabird abundance increased when the swell and the number of neighbouring vessels decreased.
5. Seabird interactions with the vessel and/or fishing gear occurred in approximately 70% of the observations, with most of these representing interactions with the net (92%). The estimated contact rate was 16.7 birds h^{-1} per haul. A total of 121 birds were by-caught and the average mortality rate was 0.55 birds h^{-1} per haul. Shearwaters and Magellanic penguins (*Spheniscus magellanicus* (Forster, 1781)) were the main by-caught species (101 and 12 individuals, respectively). Lower levels of mortality were recorded in black-browed albatrosses and white-chinned petrels.
6. The interactions increased in the presence of fishing discards and during haulback operations.
7. This study is relevant to the implementation of the Argentine National Plan of Action – Seabirds, as well as for the continuing certification process in the anchovy fishery.

KEYWORDS

biodiversity, birds, conservation evaluation, fishing, ocean, trawling

1 | INTRODUCTION

Seabirds and marine mammals are amongst the most important vertebrates in predator assemblages of marine ecosystems (Croxall & Wood, 2002; Tasker, 2006). Another key factor for which they are considered a priority is the particular life-history traits of these groups (e.g. deferred sexual maturity, longevity, and low productivity) as well as their key ecological role as apex consumers and/or nutrient transporters (Adame, Fry, Gamboa, & Herrera-Silveira, 2015; Baum & Worm, 2009; Heithaus, Frid, Wirsing, & Worm, 2008; Jackson et al., 2001). The impact caused by human activities such as fishing on these predators can alter the structure of the food chain and affect the equilibrium between species (Arcos, Louzao, & Oro, 2008; Baum & Worm, 2009; Furness, 2003; Heithaus et al., 2008). In particular, the conservation status of seabirds has worsened more rapidly than other comparable groups (Croxall et al., 2012). Among the main causes of this deterioration are the existence of invasive alien species in breeding areas (Milberg & Tyrberg, 1993; Tennyson & Martinson, 2006) and incidental mortality associated with fishing (ACAP (Agreement on the Conservation of Albatrosses and Petrels), 2015). Interactions between seabirds and fisheries are a consequence of the overlap between waters used by seabirds as foraging areas and those used by the fisheries as fishing grounds. Moreover, interactions are enhanced by the attraction generated by fishery discards and offal, which is consumed by seabirds (Dayton, Thrush, Agardy, & Hofman, 1995). One of the most common and negative effects of these interactions is the direct contact of birds with the vessel and/or fishing gears, which most often results in death or injury (Montevecchi, 2002). As a result of the negative effects of fishing on a number of seabird species, in 1999 the Food and Agriculture Organization of the United Nations developed the International Plan of Action-Seabirds (IPOA-Seabirds), aimed at reducing the incidental catch of seabirds in longline fisheries (FAO (Food and Agriculture Organization), 1999). These guidelines, originally targeting longline fisheries, were further updated and extended to trawl fisheries (FAO, 2009) to provide advice on the development and implementation of national and regional plans of action.

The Argentinean Continental Shelf is within the Southwest Atlantic Ocean (Bisbal, 1995), and covers an area of about 1.7 million square kilometres. It has several frontal areas (Acha, Mianzan, Guerrero, Favero, & Bava, 2004) and the Malvinas/Falklands and Brazil currents are the major ocean flows (Bisbal, 1995). This shelf is an important foraging area for several seabird species breeding in the region and in others areas of the globe (Arata et al., 2009; Croxall & Wood, 2002; Favero & Rodriguez, 2005; Guilford et al., 2009; Hedd, Montevecchi, Otley, Phillips, & Fifield, 2012; Pütz et al., 2009; Quintana et al., 2009; Ronconi, 2007). Ten of these species are listed as 'threatened' with extinction by the International Union for Conservation of Nature (IUCN), and another ten are listed as 'near threatened' (BirdLife International, 2016).

The Argentinean fishing industry has increased significantly in recent decades (Anticamara, Watsona, Gelchua, & Pauly, 2011). Trawlers represent the main fishing fleet in terms of fishing effort, number, and type of vessels. Between 2011 and 2013, landings by trawlers accounted on average for almost 90% of the total annual landings (around 650 000 tons; Navarro, Rozycki, & Monsalvo, 2014). Strikes with the vessel, warp cable, and net-sonde cable, and entanglements with the net or other components of the fishing gear, are the recorded causes of mortalities and serious injuries to seabirds in the trawl fleet, including ice trawlers and factory vessels operating in coastal waters and the high seas (Favero et al., 2011; Seco Pon, 2014; Tamini et al., 2015). The species most affected include Procellariiformes such as the black-browed albatross (*Thalassarche melanophris* (Temminck, 1828)) and the white-chinned petrels (*Procellaria aequinoctialis* Linnaeus, 1758) (Favero et al., 2011; Favero et al., 2013; González-Zevallos, Yorio, & Caille, 2007; Seco Pon, 2014; Tamini et al., 2015). As with other trawl fisheries, interactions between fishing activities and seabirds are more frequent and abundant in the presence of discards and/or offal (Bertellotti & Yorio, 2000; Favero et al., 2011; Gómez-Laich et al., 2006; Gómez-Laich & Favero, 2007; González-Zevallos & Yorio, 2006, 2011; Seco Pon, 2014; Tamini et al., 2015).

So far, all research on seabird by-catch in Argentine fisheries has focused on demersal longline and bottom trawl fisheries, with an important asymmetry on what is known from other fisheries, in particular those targeting pelagic fish. One of the most important pelagic fish resources inhabiting the Argentinean Continental Shelf is the Argentine anchovy (*Engraulis anchoita* Hubbs & Marini, 1935) (Hansen, 2004). The anchovy is widely distributed from the south of Brazil (24°S) to southern Argentina (48°S) (Revina & Baranov, 1973). It is the most abundant pelagic fish in the Southwest Atlantic and comprises an estimated biomass of 30 000 000 tons (Hansen, Buratti, & Garciarena, 2009; Hansen, Garciarena, & Buratti, 2009). It is also a key prey for many other fish species, mammals, and seabirds (Castello & Castello, 2003; Mariano-Jelicich et al., 2012; Marinao & Yorio, 2011; Sánchez & Ciechomski, 1995; Silva Rodríguez, Favero, Berón, Mariano-Jelicich, & Mauco, 2005). The species has been split into two stocks for fishery management purposes (i.e. the Bonaerense (northern) and Patagonian (southern) stocks separated at approximately 41°S; Hansen, 2004; Sánchez & Ciechomski, 1995). The Argentine anchovy is targeted by coastal and high seas trawl fisheries in Argentina and Uruguay, although it was (and still is) considered an underexploited resource with catches of about 18 200 tons on average between 2011 and 2013 (Navarro et al., 2014). Interestingly, the fishery targeting the Bonaerense stock was the first anchovy fishery in the world certified under the Marine Stewardship Council (MSC) scheme. This scenario facilitated the implementation of a research programme aimed to assess for the first time the impact of its activities on the marine ecosystem (Prenski, Morales-Yokobori, Bridi, Gasalla, & Minte-Vera, 2011).

In this context, the aim of this study was to conduct the first characterization of the interactions between seabirds and the anchovy pelagic trawl fishery in Argentina, including an analysis of: (i) the distribution of fishing effort; (ii) the composition of seabird assemblages attending fishing operations; (iii) seabird interactions (contacts and by-catch) with vessel and gear during fishing operations; and (iv) the effects of environmental and operational variables on seabird abundance and interactions with the fishery.

2 | METHODS

2.1 | Study area and data collection

The study area was located in the northern Argentine Continental Shelf. The distribution of fishing vessels targeting the Argentine anchovy was obtained from the national vessel monitoring system (VMS), which provides the hourly GPS position of each vessel. Data on seabird abundance and interactions were recorded by observers from the national observers programme (Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP)) assigned to vessels fishing under the MSC certification scheme. Observers followed standardized protocols already adopted for the local trawl fisheries (Favero et al., 2011; Seco Pon et al., 2013). The total effort of the fishery run during 2011–2013 was 5471 hauls and 60 vessels (Sistema de Información Oceanográfico Pesquero, INIDEP), of which five vessels were included in the certification process. A total of 452 hauls were observed between August and November 2011–2013. Seabird attendance and interactions were monitored in approximately 50% of these hauls (for all years combined). Observations were made throughout all stages of the fishing operation: (i) setting (deployment of the net); (ii) towing (dragging the net); and (iii) haulback (recovery of the net). A haul was defined as a complete sequence of setting, towing, and haulback, including the sorting of the catch.

2.2 | Seabird abundance and interactions with the vessel

Seabirds were identified to species level when possible, and for the two most abundant species (black-browed albatross and kelp gull) the age class was determined by considering plumage and beak coloration (Harrison, 1983). The abundance of seabirds attending vessels was estimated by counts lasting 10 minutes performed from the stern of the vessel and covering an area of 200 m × 200 m (adapted from Tasker, Jones, Dixon, & Blake, 1984). These counts were conducted prior to the setting of the net, during towing (the average total towing time was 1.5 hours), and shortly before haulback.

Altogether warp and net-sonde monitor cables pose the greatest threat to seabirds attending trawlers (Bartle, 1991; Favero et al., 2011; Seco Pon, 2014; Tamini et al., 2015), and thus our observations focused on interactions with these cables. Interactions were recorded through setting and haulback operations, and for periods lasting 15 minutes during towing. Types of contact with the vessel or the fishing gear were defined as: light (on the water or flying, without apparent injury); heavy (on the water or flying, usually causing severe injuries or mortality); birds snagged on cable splices; and snared in the net. Contact points included the vessel, net-sonde cable, warp cable, trawl doors, brides, or net. The fate of birds making contact with the gear or the vessel was classified as: (i) no apparent injury; (ii) minor injury; (iii) major injury; (iv) death; (v) unknown; or (vi) bird snared on warp cable or net-sonde cable (suspected death) (see Favero et al., 2011; Seco Pon, 2014).

Each record was linked to the geographical position of the vessel, and included operational variables such as type of fishing operation, occurrence of fishery discard, and number of trawlers operating in the vicinity (0, no vessels; 1, between one and five vessels; and 2, more than five vessels), as well as environmental variables such as sea state (Beaufort scale: 1, ≤ 2; 2, 3; 3, 4; and 4, ≥ 5, as a proxy for wind intensity), swell (scored as: 1, 0–0.5 m; 2, 0.6–1.0 m; and 3, >1.0 m), and cloudiness (1, clear sky to 25% cloudy; 2, >25% to 50% cloudy; 3, >50% to 75% cloudy; and 4, >75% cloudy to 100% overcast).

2.3 | Data analysis

Data obtained from the vessel monitoring system were filtered by speed and time to obtain fishing locations, following the criteria used by Copello, Seco Pon, and Favero (2014). To determine the distribution of fishing effort (estimated as number of fishing positions), a Kernel analysis was used that calculates the magnitude of points per unit area using a smoothing algorithm (Worton, 1989). The kernel area of 50% was used to identify core areas, whereas areas of 75 and 95% were used to identify focal and rank areas, respectively (Copello et al., 2014).

A total of 333 counts were obtained. The number of individuals per haul was determined using the maximum number of individuals recorded per operation. In general, only one count was performed in each operation. The overall abundance (total number of individuals in all counts), frequency of occurrence (*FO*%, the percentage of counts in which a particular species was present), the relative importance (*RI*, the number of individuals of a particular species in relation to the total number of individuals), the mean and standard deviation, richness (S', total number of species), diversity (Shannon index H'; Shannon & Weaver, 1963), and evenness (J', H'/H'_{max}; Pielou, 1969) were calculated for each count.

Significant differences in the assemblage composition of seabirds between fishing operations and years were tested using a multivariate analysis (ANOSIM) implemented in PRIMER 5.2.9. ANOSIM uses the Bray–Curtis similarity matrix to compute the *R* statistic. This statistic varies between −1 and 1, reaching its maximum value when all between-group dissimilarities are greater than all within-group dissimilarities. Statistical significance was determined by comparing the sample *R* with those produced by randomly assigning samples to groups (Clarke & Warwick, 2001). The *P* value of the test was calculated using the proportion of random arrangements with *R* values higher than the sample value. Similarity percentages (SIMPER) were employed to determine the species that contributed most to the dissimilarities between groups (Clarke & Gorley, 2001; Clarke & Warwick, 2001). The Kruskal–Wallis (*H*) and multiple-comparisons test (post-hoc Kruskal–Wallis) (Zar, 2010) were performed to determine differences in the following parameters: (i) richness, diversity, and evenness between fishing operations (for the same year), and between the same operation (for different years); (ii) age groups for the most abundant species (all operations and years together); and (iii) the point, type of contact, as well as the outcome for the bird (all operations and years together). Differences were considered significant at $P < 0.05$.

A total of 251 observations (corresponding to 165 hauls) were used to analyse seabird–fisheries interactions (all years combined). The maximum number of contacts was used in the case of replicates (4.3% of the total observations). The contact rate was estimated as the number of contacts standardized per hour of trawl/towing, per haul (sum of contacts of all operations), during towing and haulback, regardless of the fate of the seabirds. The mortality rate was estimated as the number of by-caught individuals per hour.

The effect of operational and environmental variables on seabird abundance and interaction was evaluated using generalized linear models (GLM) with a negative binomial distribution (Zuur, Ieno, Walker, Saveliev, & Smith, 2009). Only surveys with complete information about environmental and operational variables were used (n = 64 and n = 50 for abundance and contact variables, respectively). The operational variables included number of neighbouring vessels, type of fishing operation, and presence/absence of discards. Regarding environmental variables (wind intensity, swell, and cloudiness), strongly correlated predictors ($r > 0.5$) were identified a priori by estimating all pairwise Pearson rank correlation coefficients. After this analysis, wind speed was removed from the GLM model. Only operational variables were used for interaction modeling, given that these could be handled to achieve conservation measures that may reduce the likelihood of capturing seabird species. The fitting of the models was performed by estimating the inflation factor variance ($\hat{c}$). The explained variance was defined as $D^2 = (dn - dr)/dn$, where dn is the deviance of null model and dr is the residual deviance. The Akaike information criterion corrected for small samples (AICc) was used for model selection. Candidate models were compared using the difference between the AICc for each respective model and the lowest observed value (ΔAICc ≤2 indicates important support for the model). The Akaike weighting (Burnham & Anderson, 2002) provides relative-likelihood normalization for each model based on the value of ΔAICc.

All analyses were performed using R (R Core Team, 2015) and a Geographical Information System using ARCGIS (ESRI (Environmental Systems Research Institute), 2010).

3 | RESULTS

3.1 | Fishing effort

Overall, pelagic trawlers operated between 34°S and 47°S, and from coastal waters to the continental shelf break (200-m isobath; Figure 1). The fishing depth averaged 58 ± 29 m, ranging between 8 and 473 m (for all years combined). Two core areas (Kernel 50%) of fishing effort were identified, both located on the 50-m isobath, covering an area of 14 501 km^2 in the north (near Mar del Plata harbour) and 24 869 km^2 in the south (near El Rincón). The majority of the surveys conducted by on-board observers took place within these core areas (Figure 2).

3.2 | Seabirds attending pelagic trawlers

Twenty-three seabird species were identified attending fishing vessels. For all years combined, albatrosses and petrels were recorded in almost all counts. The most frequently recorded birds were the black-browed albatross (94%), shearwaters (*Ardenna* spp. and *Puffinus* spp.: 86%), white-chinned petrel (71%), southern giant petrel (*Macronectes giganteus* (Gmelin, 1789): 25%), storm petrel (*Oceanites* spp.: 22%), and cape petrel (*Daption capense* (Linnaeus, 1758); 16%). The kelp gull (*Larus dominicanus* Lichtenstein, 1823) and South American tern (*Sterna hirundinacea* Lesson, 1831) occurred in 64 and 21% of the surveys, respectively (Table 1).

Seabird abundance averaged 157.3 ± 229.7 birds per haul, ranging from three to 1760 birds (for all years combined). Procellariiform birds accounted for 78% of the observed individuals, with the black-browed albatross, shearwaters, and white-chinned petrel being the most abundant species (Table 1). Subadult (SA) black-browed albatrosses were more abundant than adults (A) and juveniles (J) (Kruskal–Wallis $H_{2,\ 567} = 20.18$; $P < 0.001$; post-hoc $H_{SA-A} = 43.94$; $H_{SA-J} = 77.85$; $P < 0.05$). Charadriiform birds showed an overall abundance of 22%, with the kelp gull being the most abundant species followed by the South American tern (Table 1). Adult kelp gulls were more abundant than subadults and juveniles ($H_{2,\ 279} = 43.07$; $P < 0.001$; post-hoc $H_{A-SA} = 43.94$; $H_{A-J} = 115.81$; $P < 0.05$; Table 1).

The composition of seabird assemblages significantly differed between years (comparing the same fishing operation) and between operations (only during 2011) (ANOSIM $P < 0.001$; Table S1). Differences were mainly linked to the relative contributions of black-browed

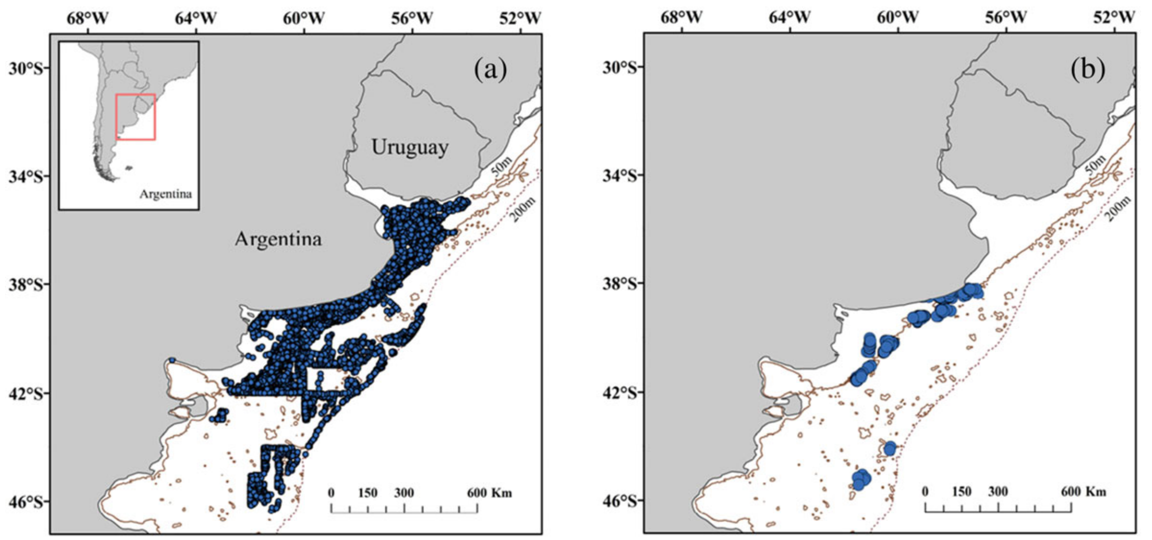

FIGURE 1 Distribution of fishing vessels, indicated by hourly vessel monitoring system (VMS) locations (a) and distribution of censuses locations (b) for the pelagic trawl fishery targeting anchovy (*Engraulis anchoita*) between 2011 and 2013

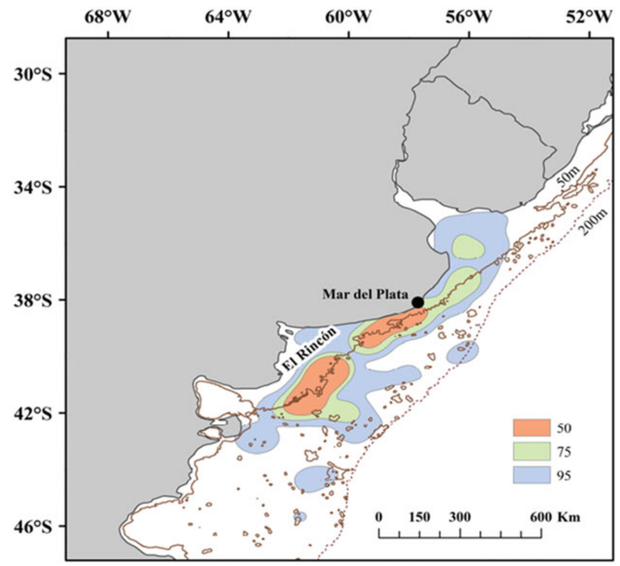

FIGURE 2 Fishing effort of the pelagic trawl fishery targeting the Argentine anchovy between 2011 and 2013

albatrosses, kelp gulls, great shearwaters (*Ardenna gravis* (O'Reilly, 1818)), and white-chinned petrels (Tables S2, S3). These species showed greater mean abundance during 2012 when compared with 2011 and 2013 for all fishing operations, and during haulback when compared with the other operations (Table S4).

The diversity and species richness of seabird assemblages were significantly higher in 2012 when compared with other years within the same operation (post-hoc $H_{2,\ 79,\ \text{SETTING},\ H'} \leq 29.27$; $H_{2,\ 79,\ \text{SETTING},\ S'} \leq 23.46$; $H_{2,\ 107,\ \text{TOWING},\ H'} \leq 28.16$; $H_{2,\ 107,\ \text{TOWING},\ S'} \leq 31.84$; $H_{2,\ 140,\ \text{HAULBACK},\ H'} \leq 36.92$; $H_{2,\ 140,\ \text{HAULBACK},\ S'} \leq 42.27$; $P < 0.05$). Meanwhile, evenness was higher in 2013 only during hauling operations (post-hoc $H_{2,\ 139,\ \text{HAULBACK},\ J'} = 22.59$; $P < 0.05$). Comparing different operations, the only difference found was in 2011, with a greater evenness during setting when compared with haulback operations, whereas richness was greater during haulback operations (post-hoc $H_{2,\ 194,\ 2011,\ J'\ \text{and}\ S'} = 35.87$; $P < 0.05$; Table S5).

The global model showed a good fit of the data ($\hat{c}$ = 1.05), accounting for 38% of the explained deviance. The model with greatest support showed a significant effect of swell and number of

TABLE 1 Abundance (*AB*), relative importance (*RI*), frequency of occurrence (*FO*), mean and standard deviation (SD) per count of seabird species attending a pelagic trawl fishery targeting anchovy in the Argentine Continental Shelf during 2011–2013

Order	Scientific name	Common name	Conservation status	*AB*	*RI*	*FO*	Mean ± SD
Procellariiformes	*Thalassarche melanophris*	Black-browed albatross	Near threatened	15 537	34.1	93.7	46.7 ± 103.1
Procellariiformes	*Procellaria aequinoctialis*	White-chinned petrel	Vulnerable	4789	10.5	70.9	14.4 ± 38.8
Procellariiformes	*Ardenna* spp./*Puffinus* spp.	Shearwater ND	–	3906	8.6	47.2	11.7 ± 26.4
Procellariiformes	*Ardenna gravis*	Great shearwater	Least concern	8426	18.5	37.5	25.3 ± 60.8
Procellariiformes	*Ardenna grisea*	Sooty shearwater	Near threatened	231	0.5	2.4	0.7 ± 5.5
Procellariiformes	*Daption capense*	Cape petrel	Least concern	1075	2.4	15.9	3.2 ± 15.4
Procellariiformes	*Macronectes halli*	Northern giant petrel	Least concern	209	0.5	3.9	0.6 ± 3.9
Procellariiformes	*Oceanites* spp.	Storm petrel	–	393	0.9	20.7	1.2 ± 3.9
Procellariiformes	*Oceanites oceanicus*	Wilson's storm petrel	Least concern	25	0.1	1.2	0.1 ± 0.8
Procellariiformes	*Diomedea epomophora*	Southern royal albatross	Vulnerable	47	0.1	3.3	0.1 ± 1.1
Procellariiformes	*Thalassarche chrysostoma*	Grey-headed albatross	Endangered	61	0.1	1.8	0.2 ± 1.5
Procellariiformes	*Macronectes giganteus*	Southern giant petrel	Least concern	678	1.5	24.6	2.0 ± 6.4
Procellariiformes	*Thalassarche chlororhynchos*	Atlantic yellow-nosed albatross	Endangered	61	0.1	2.1	0.2 ± 1.3
Procellariiformes	*Diomedea exulans*	Wandering albatross	Vulnerable	12	0.0	0.9	0.0 ± 0.6
Procellariiformes	*Procellaria conspicillata*	Spectacled petrel	Vulnerable	10	0.0	0.3	0.0 ± 0.5
Procellariiformes	*Pachyptila turtur*	Fairy prion	Least concern	40	0.1	1.2	0.1 ± 1.1
Procellariiformes	*Thalassarche salvini*	Salvin's albatross	Vulnerable	1	0.0	0.3	0.0 ± 0.1
Charadiiformes	*Larus dominicanus*	Kelp gull	Least concern	7158	15.7	64.3	21.5 ± 59.7
Charadiiformes	*Larus atlanticus*	Olrog's gull	Near threatened	425	0.9	5.4	1.3 ± 11.8
Charadiiformes	*Sterna hirundinacea*	South American tern	Least concern	1295	2.8	21.3	3.9 ± 19.7
Charadiiformes	*Thalasseus sandvicensis*	Sandwich tern	Least concern	19	0.0	1.2	0.1 ± 0.6
Charadiiformes	*Thalasseus maximus*	Royal tern	Least concern	314	0.7	5.7	0.9 ± 5.2
Charadiiformes	*Sterna* spp.	Tern ND	–	360	0.8	2.1	1.1 ± 12.4
Charadiiformes	*Catharacta* spp.	Skua ND	Least concern	206	0.5	5.1	0.6 ± 4.3
Charadiiformes	*Larus cirrocephalus* or *Larus maculipennis*	Hooded gull	Least concern	70	0.2	0.6	0.2 ± 3.7
Sphenisciiformes	*Spheniscus magellanicus*	Magellanic penguin	Near threatened	186	0.4	5.7	0.6 ± 4.3
ND	ND	Seabird ND	–	28	0.1	1.2	0.1 ± 0.9

ND, not determined. The scientific and common names of the birds, including their conservation status, are indicated according BirdLife International (2016).

neighbouring vessels (Tables 2, 3). The second model with great support (ΔAICc ≤2) also included the occurrence of fishery discards. Attending seabirds were more abundant during a calm swell and bird abundance diminished with an increase in the number of neighbouring vessels (Table 2).

3.3 | Seabird–fishery interactions

Seabird contacts with the vessel or fishing gear were recorded in 70% of the surveys, with 4316 interactions (i.e. observed contacts) observed throughout the sampling period. The majority of these interactions (97%) corresponded to light contact, whereas the remaining interactions comprised heavy contact and/or birds incidentally caught. Significant differences were found in the contact point ($H_{3,\ 485}$ = 28.42; $P < 0.001$): the number of interactions with the net were significantly more abundant than the number of interactions with the net-sonde cable (92% versus 7%, post-hoc $H_{\mathrm{SONDE\ CABLE/NET}}$ = 107.63; $P < 0.05$). Likewise, there were significant differences in the type of contact ($H_{4,\ 484}$ = 33.44; $P < 0.001$): light contact with birds on the water (WL) was more common than the contact that occurred when birds were flying (FL) or when birds were captured in the net (CAUGHT) (post-hoc $H_{\mathrm{WL/FL}}$ = 110.97; $H_{\mathrm{WL/CAUGHT}}$ = 82.67; $P < 0.05$). Similarly, the outcome of the interactions varied significantly ($H_{3,\ 485}$ = 12.51; $P < 0.05$): contact without any apparent injury (OK) was more common than contact that led to the death of the birds (DE) (post-hoc $H_{\mathrm{OK/DE}}$ = 74.68, $P < 0.05$). Interactions were dominated by great shearwaters (27%), followed by other shearwaters (24%), kelp gulls (18%), and black-browed albatrosses (16%) (Table 4).

A total of 121 birds were by-caught during the study period. Of these, 71 birds were by-caught in 2011 (n = 98 hauls), five in 2012 (n = 18), and 45 in 2013 (n = 56). The shearwaters and Magellanic penguins (*Spheniscus magellanicus* (Forster, 1781)) showed the highest mortalities in relation to the total number of contacts. The remaining by-caught species included the black-browed albatrosses, white-chinned petrels, and unidentified seabirds (Table 4). All observed mortalities were recorded during haulback operations, with the majority of them incidentally captured in the net. Only one bird died by collision with the net-sonde cable. The estimated contact rate was 16.7 birds h^{-1} per haul, 2.6 birds h^{-1} during towing, and 25.2 birds h^{-1} during haulback. The estimated overall mortality rate was 0.55 birds by-caught per hour or one bird by-caught every two hauls.

When analysing the number of seabird contacts in relation to operational variables, the global model showed a good fit ($\hat{c}$ = 0.94) and explained approximately 39% of the observed variation. The best model included the occurrence of discards and type of fishing operation (Table 5). The occurrence of discards and haulback operation increased the number of contacts with the fishing gear by twofold and fourfold, respectively (Table 6).

TABLE 2 Generalized Linear Models explaining the effect of operational and environmental variables on the abundance of seabirds attending trawl pelagic vessels

Candidate model	K	AICc	ΔAICc	w_i
Shi + Swell	**8**	**853.16**	**0**	**0.45**
Shi + Swell + Dis	**10**	**854.64**	**1.47**	**0.22**
Shi + Swell + Cloud	12	856.24	3.07	0.09
Shi + Swell + Dis + Cloud + Operation (global model)	17	860.66	7.49	0.01

Models are listed in decreasing order of importance, and those with strong support (ΔAICc ≤2) are highlighted in bold. Abbreviations: *K*, number of estimated parameters; AICc, Akaike information criterion, corrected; w_i, Akaike weight; Shi, number of ships near the monitored vessel; Cloud, cloudiness; Dis, occurrence pf discard (presence/absence); Operation, fishing operation.

TABLE 3 Parameter likelihoods from generalized linear models explaining the variation between the abundance of seabirds attending the anchovy fishery and the factors included in the minimal adequate models

Variable	Parameter likelihood	K	Estimated parameter ± SE	CI Inf.	CI Sup.
Swell		Swell 2	0.27 ± 0.40	−0.53	1.06
	1	**Swell 3**	**−1.21 ± 0.33**	**−1.87**	**−0.55**
Shi		Shi 1	−0.20 ± 0.43	−1.06	0.65
		Shi 2	**−1.01 ± 0.41**	**−1.84**	**−0.19**
	0.93	**Shi 3**	**−2.48 ± 0.73**	**−3.92**	**−1.06**
Dis	0.35	Dis 1	0.50 ± 0.42	−0.35	1.35
Cloud		Cloud 2	−0.65 ± 0.49	−1.62	0.32
		Cloud 3	0.46 ± 0.43	−0.41	1.33
	0.17	Cloud 4	−0.14 ± 0.42	−0.96	0.68
Operation		Operation 2	−0.46 ± 0.36	−1.18	0.26
	0.13	Operation 3	−0.21 ± 0.33	−0.88	0.46

Independent variables for which the confidence intervals exclude zero are present in the candidate model (highlighted in bold). Abbreviations: *K*, parameters; SE, standard error; CI, confidence interval of estimated coefficient; Inf., inferior; Sup., superior; Shi, number of ships near the monitored vessel; Cloud, cloudiness; Dis, occurrence of discard (presence/absence); Operation, fishing operation. The first level of each factor was taken as the reference in all models.

4 | DISCUSSION

The distribution area of the southern (Patagonian) stock extends from 41°S to 48°S, and lies mainly between 41°S and 45°S during the last quarter of the year (Figure 1).

From an oceanographic point of view, a large portion of this zone, especially the area close to the Valdés Peninsula (42°30′S), offers several conditions that favour the formation of sea fronts in spring and summer.

The observed seabird species attending pelagic trawl vessels, as well as the dominance of Procellariiform birds in the assemblages, were similar to those recorded attending demersal trawl fisheries operating on the Argentine Continental Shelf (Favero et al., 2011; González-Zevallos et al., 2007; González-Zevallos & Yorio, 2006; Seco Pon, 2014; Seco Pon et al., 2013; Tamini et al., 2015; Yorio & Caille, 1999). The abundance of shearwaters was higher in the present study, however. Shearwaters exhibit a very broad distribution range, with some species displaying transequatorial migrations flying from the North Atlantic into the Southwest Atlantic, particularly into Argentine waters (Brooke, 2004;Hedd et al., 2012 ; Ronconi, 2007). Greater and sooty shearwaters begin their southbound migration during September–October (Hedd et al., 2012; Ronconi, 2007), so the presence of

TABLE 4 Number of contacts and mortalities of seabirds attending anchovy trawlers on the Argentine Continental Shelf during setting (S), towing (T), and haulback (H) operations during 2011–2013

		TYPE OF CONTACTS									
		Light[a]			Heavy[b]			ND			
Order	Species	S	T	H	S	T	H	S	T	H	Mortality
Procellariiformes	**Black- browed albatross**	104	46	528	1	–	4	1	–	11	4 (0.6)
Procellariiformes	White-chinned petrel	14	1	255	–	–	4	1	–	5	2 (0.7)
Procellariiformes	**Unidentified shearwater**	58	20	873	–	–	43	–	–	47	58 (5.6)
Procellariiformes	**Great shearwater**	122	8	949	–	–	95	–	–	3	43 (3.7)
Procellariiformes	Sooty shearwater	–	–	6	–	–	–	–	–	–	–
Procellariiformes	Cape petrel	1	–	13	–	–	–	–	–	–	–
Procellariiformes	Northern giant petrel	–	–	7	–	–	–	–	–	–	–
Procellariiformes	Southern giant petrel	–	–	21	–	–	–	1	–	1	–
Procellariiformes	Fairy prion	–	–	3	–	–	–	–	–	–	–
Procellariiformes	Salvin's albatross	–	–	1	–	–	–	–	–	–	–
Charadriiformes	**Kelp gull**	23	3	651	–	1	–	–	–	105	–
Charadriiformes	Olrog's gull	–	–	31	–	–	–	–	–	8	–
Charadriiformes	South American tern	–	–	115	–	–	–	1	–	1	–
Charadriiformes	Unidentified skua	–	–	33	–	–	–	–	–	10	–
Charadriiformes	Unidentified hooded gull	20	–	44	–	–	–	–	–	–	–
Sphenisciformes	Magellanic penguin	–	–	–	–	–	12	–	–	–	12 (100)
Not determined	Unidentified seabirds	4	–	5	–	–	2	–	–	–	2 (18.2)

ND, contacts include those that were not categorized. The species in bold are those that contributed more than 10% of the total number of observed contacts. Percentages of mortality relative to total observed contacts for each species are given in parentheses.

[a]Bird on the water or bird flying, light contact with vessel/fishing gear (bird does not deviate its course).

[b]Bird on the water or bird flying, heavy contact with vessel/fishing gear, causing at least part of the bird to be dragged under water or for bird to deviate from its course; birds snagged on loose wire ends; birds caught in net.

TABLE 5 Generalized linear models explaining the effect of operational variables on the number of contacts of seabirds with the vessel or the fishing gear in pelagic trawl vessels

Candidate model	*K*	AICc	ΔAICc	w_i
Operation + Dis	**6**	**256.10**	**0**	**0.64**
Operation	**4**	**257.79**	**1.68**	**0.27**
Operation + Dis + Shi (global model)	**10**	260.63	4.53	0.07

Models are listed in descending order of importance, and those with strong support (ΔAICc ≤2) are highlighted in bold. Abbreviations: *K*, number of estimated parameters; AICc, Akaike information criterion, corrected; w_i, Akaike weight; Shi, number of ships near the monitored vessel, Dis, occurrence of discard (presence/absence); Operation, fishing operation.

these species in the area coincides with the seasonal behaviour of the fishery under study.

A predominance of subadult black-browed albatrosses was observed attending the anchovy trawl fishery. This could, at least partially, be a consequence of the period of data collection and fishing season, as during the austral spring–summer adult black-browed albatrosses show a distribution range more restricted to southern waters around breeding colonies (ACAP, 2010). In contrast, adult kelp gulls outnumbered juveniles attending the trawlers, which is in line with previous studies conducted in other fisheries operating in northern coastal areas of Argentina (Seco Pon et al., 2013), and in the vicinity of the San Jorge and San Matías gulfs and adjacent waters

TABLE 6 Parameter likelihoods from generalized linear models explaining the variation between the contacts of seabirds associated with the anchovy fishery and the factors included in the minimal adequate models

				CI	
Variable	Parameter likelihood	*K*	Estimated parameter ± SE	Inf.	Sup.
Operation		Operation 2	1.13 ± 1.02	−0.89	3.15
	1	**Operation 3**	**3.74 ± 0.93**	**1.88**	**5.59**
Dis	0.7	**Dis1**	**2.06 ± 0.81**	**0.44**	**3.68**
Shi		Shi1	0.71 ± 0.95	−1.19	2.60
	0.09	Shi2	0.54 ± 0.93	−1.32	2.41

Independent variables with confidence intervals that exclude zero are present in the candidate model (highlighted in bold). Abbreviations: *K*, parameters; SE, standard error; CI, confidence interval of estimated coefficient; Inf., inferior; Sup., superior; Shi, number of ships near the monitored vessel; Dis, occurrence of discard (presence/absence); Operation, fishing operation. The first level of each factor was taken as the reference in all models.

(González-Zevallos et al., 2007; González-Zevallos & Yorio, 2006; Marinao & Yorio, 2011; Yorio & Caille, 1999).

In line with previous studies on coastal fisheries (González-Zevallos & Yorio, 2006; Marinao & Yorio, 2011; Seco Pon et al., 2012), the highest abundance of seabirds occurred during haulback operations (in 2011), probably as a result the higher availability of prey during this operation compared with towing and setting. The presence of discards was important in explaining the abundance of seabirds, as recorded in other studies (Bertellotti & Yorio, 2000; González-Zevallos & Yorio, 2006; Marinao & Yorio, 2011). Other variables such as swell and number of vessels operating in neighbouring waters also had an effect on the abundance of birds attending vessels. An increase in the swell caused a decrease in the number of associated birds; rough swell conditions could reduce the visibility and decrease the availability of discards, causing a lowered abundance of birds surrounding the vessel (e.g. modifying the sink rate, see Hill & Wassenberg, 2000). Finally, the decrease in the abundance of birds attending the vessel in relation to the increase in the number of ships in the vicinity could be linked to the dispersion of birds among the vessels using the same fishing area (González-Zevallos & Yorio, 2006). This effect could also explain at a broader scale the higher abundances of main seabird species attending trawlers in 2012, given the lower fishing effort reported during that season (Navarro, pers. comm., November 2015).

The estimated contact rate during towing (2.6 birds h^{-1}) in the pelagic fishery under study was lower than in previous studies (>25.5 birds h^{-1}), but was similar during haulback (25.2 birds h^{-1}) (Favero et al., 2011; Seco Pon, 2014; Tamini et al., 2015). Seabird interaction occurred mostly in the net, with shearwaters showing a higher number of contacts compared with other studies of demersal trawl fisheries, where the main interacting species were the black-browed albatross and white-chinned petrel (Favero et al., 2011; Seco Pon, 2014; Tamini et al., 2015). In demersal trawl fisheries, however, most of the interactions occurred with the warps (Favero et al., 2011; Seco Pon, 2014; Tamini et al., 2015) and the net-sonde cable (Seco Pon, 2014). These differences could arise from the particularities of the vessel (e.g. overall length and size of the net and its mesh, and length of the warp cables), differences in fishing operations (e.g. duration of towing and hauling operation), as well as the biological features of the bird assemblages attending the vessels. For example, shearwaters and penguins have better diving capabilities compared with black-browed albatrosses that largely capture their prey at the surface (Prince, Huin, & Weimerskirch, 1994; Ronconi, Ryan, & Ropert-Coudert, 2010; Scolaro & Suburo, 1991; Weimerskirch & Sagar, 1996).

The estimated seabird mortality rate (0.55 birds h^{-1}) was relatively high compared with other studies in demersal trawlers operating in waters of the Argentine Continental Shelf: $\leq$0.15 birds h^{-1} (Favero et al., 2011; Tamini et al., 2015), but lower when compared with studies conducted in trawl vessels operating in the San Jorge Gulf: 1.2 and 0.9 birds h^{-1} (González-Zevallos et al., 2007; González-Zevallos & Yorio, 2006). In our study, the by-caught species included great and other unidentified shearwaters, Magellanic penguins, black-browed albatrosses, and white-chinned petrels. Shearwaters have not been reported as by-catch in other Argentine fisheries in the area, except in the trawl fishery operating within waters of the San Jorge Gulf (González-Zevallos et al., 2007; González-Zevallos & Yorio, 2006). In the North Pacific, shearwaters were previously reported as being incidentally captured in pelagic driftnet fisheries (Uhlmann, Fletcher, & Moller, 2005; Veit, McGowan, Ainley, Wahl, & Pyle, 1997; Veit, Pyle, & McGowan, 1996). The number of penguin mortalities recorded in the pelagic fishery were higher than those observed in coastal trawl vessels operating in waters adjacent to the Mar del Plata port, and nearby Isla Escondida (Rawson) (Seco Pon et al., 2013; Yorio & Caille, 1999), but lower than in trawlers operating in San Jorge Gulf (González-Zevallos & Yorio, 2006, 2011).

The analysis of operational variability affecting the interactions of attending seabirds indicated a significant increase of contacts with the presence of discards and during haulback operations, most likely because of the greater availability of food. Similar to other fisheries operating on the Argentine Continental Shelf and other areas of the Southern Hemisphere (Crofts, 2006; Favero et al., 2011; Gómez-Laich et al., 2006; Gómez-Laich & Favero, 2007; González-Zevallos & Yorio, 2006, 2011; Sullivan, Reid, & Bugoni, 2006; Tamini et al., 2015; Watkins, Petersen, & Ryan, 2008).

Around one-third of the observed species (mainly albatrosses and petrels) attending the vessels are classified as threatened according to the IUCN: 9% are listed as 'endangered' and 22% are listed as 'vulnerable'. Other species are listed as 'near threatened' or 'least concern' (17% and 52%, respectively; BirdLife International, 2016). To assess the effect of the incidental mortality over the population trends, modelling of the population dynamics of the by-caught species would be necessary. Studies on albatrosses carried out at breeding sites at South Georgia (Georgias del Sur) have demonstrated that fisheries by-catch (trawl and longline) had a very important role in the population declines since the 1990s, but its influence might now be lower (Pardo et al., 2017). A rough extrapolation of our observed rates to the total fishing effort provides annual mortality numbers ranging from 382 to 1658 birds; however, this mortality should be considered conservative given the background indicating the significant occurrence of undetected mortality (Parker, Brickle, Crofts, Pompert, & Wolfaardt, 2013; Waugh, MacKenzie, & Fletcher, 2008; Weimerskirch & Sagar, 1996).

The core areas of fishing effort by the pelagic trawl fishery overlapped with marine fronts of high productivity (Acha, Piola, Iribarne, & Mianzan, 2015; Ciechomski, 1996) and those of maximum anchovy spawning during spring (Sánchez & Ciechomski, 1995). The area of operation of the pelagic trawl fishery under study overlaps with the foraging ranges of threatened species such as the black-browed albatross, the white-chinned petrel, and the Magellanic penguin (Copello et al., 2014; Phillips, Silk, Croxall, & Afanasyev, 2006; Yorio, Quintana, Dell'Arciprete, & González Zevallos, 2010). Other megafaunal species including mammals and turtles also exploit waters where the fishery under study operates, and might also be at risk from this fleet (Crespo, Dans, Koen Alonso, & Pedraza, 2007; González Carman et al., 2011). Seabird by-catch produces not only a negative impact on seabird populations but also in the fishery industry (affecting the performance of the fishing operation, for example; Seco Pon et al., 2015). Several mitigation measures aimed at reducing the interactions of seabirds with the net and/or net-sonde cable exist, and are being used around the world with variable levels of implementation (Abraham et al., 2009; González-Zevallos et al., 2007; Melvin, Dietrich, Fitzgerald, & Cardoso, 2011; Pierre et al., 2010; Sullivan, Brickle, Reid, Bone, & Middleton, 2006; Tamini et al., 2015). Although there is a variety of mitigation measures for reducing seabird interactions with trawlers, one critical matter to address should be reducing the attraction to fishing vessels generated by fishery by-products like discards and offal, either through their retention on vessels or through minimizing the volume of discard and subsequent release (Abraham et al., 2009; Pierre et al., 2010). Argentina has tackled the issue of seabird by-catch in demersal longline and trawl fleets through the adoption of binding measures in 2008 and 2017, respectively, for the use of mitigation measures in these fleets (Federal Fisheries Council Resolutions 08/08 and 03/17, respectively), as well as the adoption of a National Plan of Action-Seabirds in 2010 for the reduction of incidental mortality in all fisheries (Federal Fisheries Council, Resolution 03/10). In spite of the limited size of the fishery under study, the reduction of seabird (and other top predators) by-catch in the Argentinean anchovy fishery is crucial when taking into account: (i) the above referred conservation status of seabirds attending the fishery; (ii) the domestic obligations linked to the current legislation and international commitments, including the accession to the Agreement on the Conservation of Albatrosses and Petrels; and (iii) the fact that this is the first anchovy fishery under the Marine Stewardship Council scheme.

ACKNOWLEDGEMENTS

This study was financially supported by grants from the Agencia Nacional de Promoción Científica y Tecnológica, PICT 2012-295, 2013-711, the Consejo Nacional de Investigaciones Científicas y Técnicas PIP CONICET 00070, and the Universidad Nacional de Mar del Plata 15/E695, EXA 745/15. The authors thank the on-board observers of the national observers programme (INIDEP) that contributed to the development of this study by following specific sampling protocols. We would like to thank Gabriela Navarro and Laura Prosdocimi (Under-Secretariat of Fisheries, Argentina), who facilitated the access to VMS data. The authors have no conflicts of interest to declare.

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How to cite this article: Paz JA, Seco Pon JP, Favero M, Blanco G, Copello S. Seabird interactions and by-catch in the anchovy pelagic trawl fishery operating in northern Argentina. *Aquatic Conserv: Mar Freshw Ecosyst*. 2018;1–11. https://doi.org/10.1002/aqc.2907