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Factors affecting Magellanic Penguin mortality at coastal trawlers in Patagonia, Argentina

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ABSTRACT

Incidental capture at trawlers has been recognized as a significant source of seabird mortality, and is considered one of the main threats to seabirds at sea. The understanding of seabird–fishery interactions and of factors influencing individual mortality is fundamental to develop management actions and help protect seabird populations. We quantified seasonal and annual variability in Magellanic Penguin (*Spheniscus magellanicus*) incidental captures and explored factors which may be influencing their by-catch at coastal trawlers targeting either Argentine Red Shrimp (*Pleoticus muelleri*) or Argentine Hake (*Merluccius hubbsi*) in the Isla Escondida fishing area, Argentina, for the months encompassing most of the penguin's breeding period (October–February) of the 2008, 2009, 2011 and 2012 fishing seasons ($n = 2\,336$ hauls). A total of 203 penguins were incidentally caught in nets, with rates that varied between months and years. Mean monthly capture rate was 0.087 birds haul^{-1}, and ranged between 0.01 and 2.07 birds per haul. All captured penguins were adult individuals. Incidental capture occurred almost exclusively when targeting Argentine Hake (97.5% of cases) and during 2009. Incidental captures were more likely to occur when vessels operated closer to penguin colonies, with 85% of incidental captures occurring at less than 45 km. Vessels targeting hake operated significantly closer to the colonies than those targeting shrimp. Incidental capture of Magellanic Penguins in coastal trawlers in the study area appears to be highly variable and relatively low. Our results suggest that in the event Magellanic Penguin mortality at coastal trawlers becomes a conservation issue, spatial and temporal closures focused on the Argentine hake could be used as potential measures to reduce penguin by-catch, complementing the effective implementation of a marine protected area.

1. Introduction

Incidental capture at trawlers has been recognized as a significant source of seabird mortality, and is considered one of the main threats to seabirds at sea (Croxall et al., 2012). Seabird mortality results from collision in warp cables and entanglement in nets, mostly as a result of the association of birds while foraging for bait fish and discards (Sullivan et al., 2006; González-Zevallos and Yorio, 2006; Bull, 2007; Watkins et al., 2008). The understanding of seabird–fishery interactions and of the factors influencing individual mortality is fundamental to develop management actions and help protect declining seabird populations. Relevant information still needed includes how different fisheries affect a given seabird species throughout its distributional range, as negative effects may vary in different fisheries due to different environmental factors and fishing practices. Several factors have been reported to influence the rate of incidental captures at trawlers, such as vessel size, fishing area and season, pattern of discarding of fish waste, distance to the coast, weather conditions and haul duration (Weimerskirch et al., 2000; González-Zevallos and Yorio, 2006; Sullivan et al., 2006; Watkins et al., 2008; Favero et al., 2011; González-Zevallos et al., 2011; Pierre et al., 2010).

The Magellanic Penguin (*Spheniscus magellanicus*) is a widely distributed seabird in Patagonia, Argentina (Yorio et al., 1999), and due to its numbers, biomass, and role as high-level predator it is likely to be an important component of coastal ecosystems. The Magellanic Penguin is also one of the main ecotourism attractions (Yorio et al., 2001), currently generating important revenues at local and regional scales. This species has been internationally

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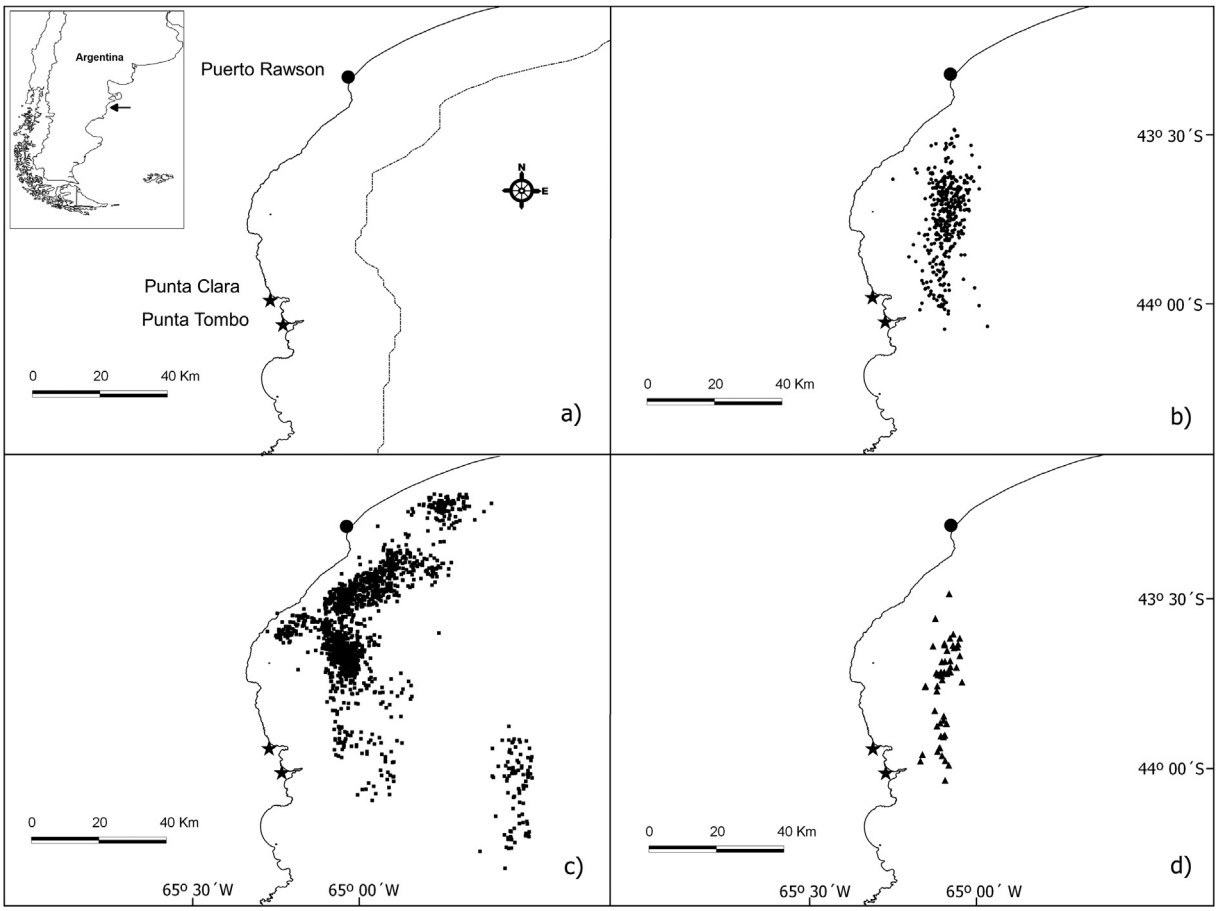

Fig. 1. Study area showing (a) the Province of Chubut jurisdictional waters (12 nautical miles), spatial distribution of hauls made by (b) coastal hake trawlers and (c) coastal shrimp trawlers, and (d) Magellanic Penguin incidental captures at the Isla Escondida fishing area during the penguin breeding season of 2008, 2009, 2011 and 2012. Stars: location of the Punta Tombo and Punta Clara penguin colonies.

recognized as 'Near Threatened' (IUCN, 2013), with main threats driven primarily by commercial fishing, pollution of the marine environment, unregulated tourism and recreational activities, and more recently, the potential consequences of climate change (Boersma et al., 2013). Research during the past two decades has shown that trawl fisheries overlap with foraging Magellanic Penguins, resulting in incidental mortality in several coastal fishing grounds (Gandini et al., 1999; Yorio and Caille, 1999; Tamini et al., 2002; González-Zevallos and Yorio, 2006; Marinao and Yorio, 2011; Seco-Pon et al., 2013), but information for some fisheries and on the factors affecting this interaction is far from being complete.

Studies at the largest known Magellanic Penguin colony worldwide, Punta Tombo, showed that individuals forage in relatively coastal areas during most part of the breeding season (Boersma and Rebstock, 2009), and may be spatially overlapping with coastal trawlers operating in the Isla Escondida fishing area north of this colony (Marinao and Yorio, 2011). An evaluation of the interaction between seabirds and coastal trawlers targeting Argentine Red Shrimp (*Pleoticus muelleri*) in this fishing area has shown that Magellanic Penguins are incidentally killed in nets (Marinao and Yorio, 2011). The coastal trawl fishery operating in the Isla Escondida area also targets Argentine Hake (*Merluccius hubbsi*), and fishing for both target species may often coincide in time and space, so interactions at coastal shrimp and hake trawlers should be assessed in conjunction to adequately asses their potential impact on this relevant penguin population. This assessment would help comply with the Argentine National Plan of Action to reduce seabird by-catch (Consejo Federal Pesquero, 2010), which recommends an increase in the level of observer coverage to include the monitoring of interactions at fisheries not yet evaluated. The information obtained will contribute to ecosystem-based fisheries management (Plagányi, 2007), helping develop needed management actions such as spatio-temporal zoning schemes and set priorities for regional conservation actions aimed at this Near threatened species. The goals of our study were to quantify seasonal and annual variability in Magellanic Penguin incidental captures and to explore factors which may be influencing penguin bycatch at coastal trawlers when targeting shrimp or hake in the Isla Escondida fishing area.

2. Materials and methods

2.1. Study area and characteristics of the fishery

The study area comprised the coastal waters up to 22 km offshore under the jurisdiction of Chubut Province from 43° 20′ S to 44° 02′ S ('Isla Escondida' fishing area) (Fig. 1). The coastal trawl fishery operating in this area targets Argentine Red Shrimp or Argentine Hake depending on resource availability and market demands. The fishery consists of 35–40 coastal ice trawlers, 21 m long, which in recent years operate throughout the year but mostly from September to March. Vessels remain 1 or 2 days in the fishing area, making between 1–8 or 1–3 hauls per day when targeting

Table 1
Incidental captures and estimated mortality of Magellanic Penguins in the coastal fishery operating at the Isla Escondida area, Argentina, throughout the penguin breeding cycle ($n = 2\,336$ hauls). S: coastal shrimp trawlers; H; coastal hake trawlers; Hauls: observed hauls; Dead: numbers of individuals caught and dead; Live: number of individuals caught and alive; Total: total number of individuals captured; Rate: mortality rate. Data source: On-board Observer Program of the Chubut Province, Argentina.

	January		February		October		November		December	
	S	H	S	H	S	H	S	H	S	H
2008										
Hauls	287	114	79	18	90	–	295	–	82	40
Dead	–	3	–	1	–	–	–	–	–	–
Live	–	3	–	–	–	–	–	–	–	–
Total	–	6	–	1	–	–	–	–	–	–
Rate	–	0.05	–	0.06	–	–	–	–	–	–
2009										
Hauls	95	59	10	30	44	6	35	50	–	–
Dead	1	44	–	23	–	–	–	–	–	–
Live	–	68	–	39	–	–	–	–	–	–
Total	1	112	–	62	–	–	–	–	–	–
Rate	0.01	1.9	–	2.07	–	–	–	–	–	–
2011										
Hauls	165	20	69	10	50	0	183	5	99	12
Dead	–	2	4	–	–	–	–	–	–	–
Live	–	–	–	–	–	–	–	–	–	–
Total	–	2	4	–	–	–	–	–	–	–
Rate	–	0.1	0.05	–	–	–	–	–	–	–
2012										
Hauls	65	50	31	6	153	0	30	10	38	6
Dead	–	13	–	–	–	–	–	–	–	–
Live	–	2	–	–	–	–	–	–	–	–
Total	–	15	–	–	–	–	–	–	–	–
Rate	–	0.3	–	–	–	–	–	–	–	–

shrimp or hake, respectively, lasting on average 1–1.5 h each. Vessels that target hake trawl bottom nets at 3.3 knots, while vessels targeting shrimp trawl two bottom nets at 3.1 knots (On-board Observer Program of Chubut Province, unpubl. data).

The coastal trawl fishery based their operations from Puerto Rawson. Argentine Red Shrimp landings were estimated at 4 000–20 000 metric tons between 2008 and 2013, and represented in 2013 41 and 20% of the total shrimp landings at the provincial and national levels, respectively. Argentine Hake landings, in contrast, constitute a minor proportion of provincial and national landings (2 500–6 000 metric tons between 2008 and 2013). Approximately 300 fishermen depend on this coastal fishery, in addition to about 150 stevedores. The coastal trawl fishery supplies hake and shrimp to the fish processing plants located at the cities of Rawson, Trelew and Puerto Madryn.

The study area includes two Magellanic Penguin breeding sites (Yorio et al., 1998) (Fig. 1). Punta Tombo (44° 02′ S, 65° 11′ W), which includes ~200 000 pairs, is one of the Magellanic Penguin main breeding sites on the Patagonian coast. Punta Clara (43° 58′ S, 65° 15′ W), 7 km north of Punta Tombo, includes 70 000 penguin pairs (Boersma et al., 2013). Magellanic Penguins arrive at breeding sites in early September, start laying in early October, eggs start hatching in early November, most chicks fledge in February, and the last adults leave the colony for their winter migration during April (Boersma et al., 1990).

2.2. Magellanic Penguin incidental mortality

We obtained information on incidental captures of Magellanic Penguins in nets, including species' identity and number of birds caught in each haul, from the data base of the On-board Observer Program of Chubut Province, for the months encompassing most of the penguin's breeding period (October–February) of the 2008, 2009, 2011 and 2012 fishing seasons ($n = 2\,336$ hauls). Information from the year 2010 was excluded from the analysis because of the low observer coverage at hake trawlers due to logistical factors (less than 30 hauls in the five month study period). For each haul, observers also recorded target species (hake, shrimp), haul location and duration (from start of haul to when the net is on deck, in min), towing speed (knots), total catch and discard amount (metric tons), sea state (Beaufort scale), and water depth (m). The amount discarded per haul was estimated subtracting the retained catch from the total catch, and the total catch for each haul was obtained averaging the independent estimates made by the vessel captain and the on-board observer. In addition, for each haul with and without incidental captures, we calculated the distance (km) to the nearest coastline and to the Punta Tombo colony using ArcView GIS 3.2 (Environmental Systems Research Institute); the Punta Tombo and Punta Clara colonies are only 7 km apart, and therefore we used the distance to the former in all further analyses.

2.3. Statistical analysis

To test the effects of predictor variables on penguin incidental capture, we employed generalized linear models with negative binomial error distribution and log link function (McCullagh and Nelder, 1989; Crawley, 2007). Target species (hake, shrimp), year (2008, 2009, 2011, 2012) and sea state (Beaufort scale, 12 classes) were included as 2-, 4- and 12-level fixed factors, respectively. Distance to colony, distance to coast, haul duration, towing speed, total catch, and discard amount were included as continuous variables. Month was excluded from the analysis due to the small sample size or no catch of one of the target species during some months, and water depth was excluded as it was correlated with distance to the coast ($\rho = 0.42$, $p < 0.0001$). As almost all incidental captures occurred at hake trawlers (see Results), the effect of predictor variables was also assessed in a second set of models where Target species was excluded.

Model selection was based on information-theoretic procedures (Burnham and Anderson, 2002). This method allows model

uncertainty to be included in both model evaluation and derivation of parameter estimates (Burnham and Anderson, 2002). Models with all possible combinations of predictor variables were considered. Akaike's information criterion (AIC) was calculated for each model (Burnham and Anderson, 2002). Model comparisons were made with ΔAIC, which is the difference between the lowest AIC value (i.e. best of suitable models) and AIC from all other models. The weight of a model (*wi*) signifies the relative likelihood that the specific model is the best of the suite of all models. If model uncertainty existed, we evaluated the support for predictor variables summing *wi* across all models that contained the parameter being considered (parameter likelihood; Burnham and Anderson, 2002). Predictor variables with good support will have high parameter-likelihood values (near 1). To supplement parameter- likelihood evidence of important effects, we also calculated 95% CI of parameter estimates. Upper and lower confidence limits were calculated by adding or subtracting 2 SE, respectively (Burnham and Anderson, 2002).

Comparisons of distances to the colony between hauls made by coastal shrimp and hake trawlers were made using the nonparametric Mann–Whitney test. All statistical analyses were carried out using R software v3.0.12 (R Development Core Team, 2013). Values were reported as means ± SD, except where noted. All tests were 2-tailed, and differences were considered significant at $p < 0.05$.

3. Results

A total of 203 penguins were incidentally caught in nets during the study period, with rates that varied between months and years (Table 1). Mean monthly capture rate was 0.087 birds haul^{-1} ($n = 2\,336$ hauls), and ranged between 0.01 and 2.07 birds per haul (Table 1). All captured penguins were adult individuals. Of the captured penguins, 112 were alive when the net was hauled on board, but their condition and fate after being released is unknown. Number of individuals caught per haul varied between 1 and 20.

When including all predictor variables in the models, main factors explaining the observed variability in penguin incidental captures at coastal trawlers in the study area were target species, year and discard amount (Tables 2a and 3a). The model with these main factors explained 43.6% of the variation. Incidental capture occurred almost exclusively when targeting Argentine Hake (97.5% of cases) and during 2009 (Table 1). Captures occurred only in January and February; these were distributed along three weeks and were recorded at over 10 vessels, indicating mortalities were not isolated events.

Table 2
Generalized linear models explaining the variation in Magellanic Penguin incidental capture at coastal trawlers in the Isla Escondida area, Argentina. TaSp: target species, DistT: distance to Punta Tombo, Disc: discard amount, DistC: distance to coast. (a) model including Target species and (b) model excluding Target species.

Explanatory variable	No. of parameters	AICc	ΔAIC	Wi
(a)				
TaSp, Year, DistT, Disc	7	307.1	0.0	0.115
TaSp, Year, DistT, Disc, Catch	8	308.0	0.9	0.075
TaSp, Year, DistT, Disc, Dur	8	308.8	1.7	0.049
TaSp, Year, DistT, Disc, Towing Speed	8	308.8	1.7	0.049
TaSp, Year, Disc, Catch	7	308.9	1.8	0.046
TaSp, Year, DistT, DistC	8	309.0	1.9	0.045
Nullmodel	1	513.3	206.2	1.93E−46
(b)				
Year, DistT, Catch, Disc	7	355.4	0.0	0.306
Year, DistT, Catch, Disc, Towing Speed	8	356.9	1.5	0.148
Year, DistT, Catch, Disc, Dur	8	357.3	1.8	0.122
Year, DistT, Catch, Disc, DistC	8	357.3	1.9	0.119
Null model	1	513.3	157.9	1.59E−35

Table 3
Parameter estimates (±SE) from generalized linear models describing variation in penguin incidental capture at coastal trawlers in the Isla Escondida area, Argentina. (a) model including Target species and (b) model excluding Target species.

Explanatory variable	Parameter likelihood	Parameter estimate ± SE	CI	
			Lower	Upper
a)				
Intercept		−5.98 ± 0.94	−7.98	−4.25
Target Species Hake[a]	1	3.90 ± 0.67	2.70	5.42
Year 2009[b]	1	1.98 ± 0.45	1.13	2.95
Discard amount	0.79	−0.29 ± 0.13	−0.57	−0.05
Distance to Punta Tombo	0.66	−0.02 ± 0.01	−0.04	−0.003
b)				
Intercept		−3.07 ± 0.65	−4.40	−1.85
Total catch	1	0.20 ± 0.03	0.13	0.27
Distance to Punta Tombo	1	−0.04 ± 0.01	−0.07	−0.02
Year 2009[b]	1	1.84 ± 0.45	0.98	2.80
Discard amount	0.90	−0.29 ± 0.13	−0.57	−0.06

[a] Relative variable to value of Target species shrimp.
[b] Value of year (2008).

When excluding Target species in the models, main factors explaining the observed variability in penguin incidental captures were total catch, distance to the colony, year and discard amount, explaining 33.9% of the variation (Tables 2a and 3b). Incidental captures were more likely to occur when vessels operated closer to the colony ($\beta = -0.05 \pm 0.01$, $z = -3.9$, $p < 0.0001$). While fishing vessels operated up to 120 km from the colony, 85% of incidental captures occurred at less than 45 km. Distances to the Punta Tombo colony of hauls with incidental captures was significantly smaller (30.8 ± 12.5 km, range = 7.3–60.0, $n = 55$) than that of hauls without captures (52.2 ± 17.9; range = 11.9–101.1, $n = 2083$) (Mann–Whitney $U = 19\,793.0$; $p < 0.0001$). Penguin incidental captures occurred when the total catch was higher ($\beta = 0.20 \pm 0.03$, $z = 5.92$, $p < 0.0001$) and when amounts of discards were lower ($\beta = -0.27 \pm 0.12$, $z = -2.33$, $p = 0.02$).

Vessels targeting hake operated significantly closer to Punta Tombo than those targeting shrimp (36.5 ± 11.9, $n = 396$ vs. 55.1 ± 12.4 km; Mann–Whitney $U = 210874.0$; $p < 0.0001$) (Fig. 1).

4. Discussion

Magellanic Penguin mortality was recorded at coastal trawlers when targeting both Argentine Red Shrimp and Argentine Hake, although only in relevant numbers at trawlers targeting hake. Similar rates of incidental captures at coastal trawlers targeting shrimp operating in the Isla Escondida area were recorded during the 2006–2007 fishing seasons, with a mean mortality rate of 0.003 penguins per haul (Marinao and Yorio, 2011); unfortunately there is no comparable information for fishing vessels targeting Argentine Hake, as interactions with coastal hake trawlers could not be assessed in those fishing seasons. The estimated rate of incidental captures reached 2.07 birds per haul in February 2009, being the highest value recorded for Magellanic Penguin mortality in coastal fisheries operating in Argentine waters both during the breeding (Yorio and Caille, 1999: 0.063 birds per haul; Marinao and Yorio, 2011: 0.003 birds per haul) and non-breeding seasons (Tamini et al., 2002: 1.0 birds per haul; SecoPon et al., 2013: 0.039 birds per haul). Values recorded in northern Golfo San Jorge, an area located 150 km south where also an estimated 250 000 Magellanic Penguins pairs breed (Schiavini et al., 2005), ranged between 0.09 and 1.31 birds per haul at high-sea trawlers targeting Argentine Hake (González-Zevallos and Yorio, 2006; González-Zevallos et al.,

2007) and between 0.005 and 0.17 birds per haul in high-sea double-beam trawlers targeting Argentine Red Shrimp (González-Zevallos et al., 2011).

Capture rate at coastal trawlers in the Isla Escondida fishing area was highly variable, and our results show that year, target species, distance to the colony, total catch and amount of discarded waste were variables associated with Magellanic Penguin incidental capture. Significant penguin incidental capture occurred only during one of the study years. The reasons for the high mortality rate observed in 2009 are not clear, but observed differences among years may be related to inter annual variability in the use by breeding birds of marine waters adjacent to their colony. Foraging-trip distance in Magellanic Penguins breeding at Punta Tombo varies among years, and has been argued to be in response to changes in environmental conditions and prey availability (Boersma and Rebstock, 2009). Higher resource availability closer to the colony and inshore waters in 2009 may have resulted in a higher overlap between foraging penguins and coastal trawlers. These contrasting results among years highlight the need for long term monitoring to adequately assess the impact of fisheries related mortality. A clear seasonal pattern in the occurrence of incidental captures was also observed. Despite coastal trawlers operated throughout most of the Magellanic Penguin breeding season, birds were only caught in nets during January and February, suggesting that birds from the Punta Tombo and Punta Clara colonies may be more vulnerable to incidental mortality during the late chick stage. Similar seasonal differences in penguin incidental captures were observed in northern Golfo San Jorge, where Magellanic Penguin mortality in trawl nets was higher during the chick stage (González-Zevallos et al., 2011).

The probability of incidental capture was higher when coastal trawlers operated closer to the Punta Tombo and Punta Clara colonies, and over 85% of captures occurred at less than 45 km. Being central place foragers, the density of Magellanic Penguins at sea is expected to be higher closer to their colony, and therefore mortality is likely to increase given the higher probability of overlap between vessels and commuting individuals. Similar results were found in northern Golfo San Jorge, where Magellanic Penguins were mostly killed in areas closer to their colonies (González-Zevallos et al., 2011). Interestingly, despite Punta Tombo was designated as a protected area in 1979 with breeding Magellanic Penguins as its main conservation target, adjacent waters have not yet received any legal protection despite the high dependence of penguins on the marine environment. Negotiations are currently underway to improve penguin protection through the seaward extension to the breeding colony (P. García Borboroglu, pers. comm.), and our results suggest that a relatively small marine protected area in combination with spatial management of the fishery may reduce the impact of incidental captures on the penguin breeding population.

Almost all of the recorded penguin incidental captures occurred in coastal trawlers targeting hake. This clear difference between fisheries may be the result of differences in the distances to the colonies at which vessels targeting the two alternative resources operated. Most coastal vessels targeting Argentine Red Shrimp operated further north and away from the penguin colonies than those targeting Argentine Hake, very likely reducing the chances of encounter with commuting penguins. In addition, despite both core fishing areas were relatively close, the differences between vessel distributions when harvesting the two target species suggests there were spatial differences in the composition of food resources, which may have in turn influenced penguin foraging distribution. Available information on Magellanic Penguin diet from Punta Tombo and other locations in the Chubut province indicates that they mainly feed on *Engraulis anchoita*, with the contribution of Argentine Hake in some colonies and stages of the breeding cycle (Gosztonyi, 1984; Frere et al., 1996; Scolaro et al., 1999; González-Zevallos and Yorio, unpubl. data). Further studies are needed to understand how the distribution of prey and associated marine organisms relates to the spatial overlap of foraging penguins and coastal trawlers. Coastal trawlers targeting hake and shrimp also differ in their operational and technical characteristics, which in other fisheries have been shown to influence by-catch rates (Bull, 2009). For example, coastal hake and shrimp trawlers differ in the fishing gear deployed and other operational characteristics. Interestingly, Magellanic Penguin mortality was also higher at high-sea trawlers targeting Argentine Hake than those targeting Argentine Red Shrimp in fishing areas located in northern Golfo San Jorge (González-Zevallos and Yorio, 2006; González-Zevallos et al., 2011). In that fishing area, longer hauls increased the chances of a bird being incidentally caught in the net, very likely because more birds are attracted (González-Zevallos et al., 2011). However, despite coastal trawlers targeting hake in the Isla Escondida area showed significantly longer haul durations, we observed no relationship between this variable and penguin mortality.

Incidental capture of Magellanic Penguins in coastal trawlers operating in the Isla Escondida fishing area appears to be highly variable and in general relatively low. Given the number of Magellanic Penguins breeding in the study area (~400 000 individuals; Boersma et al., 2013), it is unlikely that mortality in nets has a significant impact on their population. However, recorded effects should not be underestimated given seabird life-history traits (Sæther and Bakke, 2000) and because impact at the population or species level would depend on mortality from all fisheries throughout their range (Ryan and Watkins, 2008). Penguins breeding at Punta Tombo migrate north during the winter (Stokes et al., 1998), and current information suggests that additional fisheries impact on this breeding populations when in their wintering grounds cannot be ruled out. For example, about 100 penguins were estimated to be incidentally killed by small-scale coastal trawlers targeting the silverside (*Sorgentinia incisa*) in coastal waters of the Buenos Aires province (Tamini et al., 2002), in addition to low numbers at mid-water paired trawlers targeting silversides (*Odontesthes* spp.) (Seco Pon et al., 2013). Moreover, hundreds of penguins are killed annually during winter in fisheries operating in southern Brazil (Petry and Fonseca, 2002; Cardoso et al., 2011). As already mentioned, Magellanic Penguin incidental capture in nets also regularly occurs in Golfo San Jorge, 150 km south of the Isla Escondida fishing grounds (Gandini et al., 1999; González-Zevallos and Yorio, 2006; González Zevallos et al., 2011). Thus, an adequate assessment of the overall impact of fisheries on Magellanic Penguin populations breeding along the Chubut coasts should consider the additive effects of all fisheries operating along the species breeding and winter distributional range.

Despite the apparently low current negative effect from coastal trawlers, the relatively higher number of penguins killed at hake trawlers, changes in fishing effort in the recent past, and the dynamics of target resources, raise concerns in relation to the future impact of incidental captures on Magellanic Penguin populations in the study area. Coastal trawlers operating at Isla Escondida target Argentine Hake or Argentine Red Shrimp depending on resource availability and market demands, showing a preference for the latter because of its higher economic value (Fondacaro and Ruiz, 1996). However, the Argentine Red Shrimp stocks can show high inter annual variability, resulting in wide fluctuations in landings in relation to Argentine Hake (Góngora et al., 2012). Since 2001, revenues from shrimp fishing resulted in the replacement of relatively old wooden vessels by better equipped and more modern vessels, resulting in a yet unquantified increased fishing effort. Further

increases in the fisheries fishing capacity combined with an increase in fishing effort directed at hake during years of reduced shrimp abundance might result in increased threats to the penguin populations. In this potential scenario, it is crucial that the fisheries department and stakeholders work together to define strategies to minimize incidental captures in nets. Several mitigation measures have been proposed to reduce mortality in trawlers (Bull, 2007, 2009; Abraham et al., 2009; Pierre et al., 2012), which should be considered and explored in the study area. Our results suggest that in the event Magellanic Penguin mortality at coastal trawlers becomes a conservation issue, spatial and temporal closures focused on the Argentine Hake could be used as potential measures to reduce penguin by-catch, complementing the effective implementation of a marine protected area. In addition, results indicate that the observed sources of variation in incidental mortality should be considered in future monitoring by the Provincial fisheries on-board observer program, so as to adequately interpret fisheries impacts on Magellanic Penguin populations and explore solutions to minimize incidental captures.

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References

Abraham, E.R., Pierre, J.P., Middleton, D.A.J., Cleal, J., Walker, N.A., Waugh, S.M., 2009. Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel. Fish. Res. 95, 210–219.

Boersma, P.D., Rebstock, G.A., 2009. Foraging distance affects reproductive success in Magellanic penguins. Mar. Ecol. Prog. Ser. 375, 263–275.

Boersma, P.D., Stokes, D.L., Yorio, P.M., 1990. Reproductive variability and historical change of Magellanic Penguins (*Spheniscus magellanicus*) at Punta Tombo, Argentina. In: Davis, L., Darby, J. (Eds.), Penguin Biology. Academic Press, New York, pp. 15–43.

Boersma, P.D., Garcia Borboroglu, P., Frere, E., Kane, O., Pozzi, L.M., Pütz, K., Raya Rey, A., Rebstock, G.A., Simeone, A., Smith, J., Yorio, P., Van Buren, A., 2013. Magellanic Penguin (*Spheniscus magellanicus*). In: Garcia Borboroglu, P., Boersma, P.D. (Eds.), Penguins: Natural History and Conservation. University of Washington Press, Seattle.

Bull, L.S., 2007. Reducing seabird bycatch in longline, trawl and gillnet fisheries. Fish. Fish. 8, 31–56.

Bull, L.S., 2009. New mitigation measures reducing seabird by-catch in trawl fisheries. Fish. Fish. 10, 408–427.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach. Springer-Verlag, New York, NY.

Cardoso, L.G., Bugoni, L., Mancini, P.L., Haimovici, M., 2011. Gillnet fisheries as a major mortality factor of Magellanic penguins in wintering areas. Mar. Pollut. Bull. 62, 840–844.

Consejo Federal Pesquero (Ed.), 2010. Plan de acción nacional para reducir la captura incidental de aves marinas. Buenos Aires, Argentina.

Crawley, M.J., 2007. The R Book. John Wiley & Sons, West Sussex.

Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv. Int. 22, 1–34.

Favero, M., Blanco, G., Garcia, G., Copello, S., Seco Pon, J.P., Frere, E., Quintana, F., Yorio, P., Rabuffetti, F., Cañete, G., Gandini, P., 2011. Seabird mortality associated with ice trawlers in the Patagonian Shelf: effect of discards on the occurrence of interactions with fishing gear. Anim. Conserv. 14, 131–139.

Fondacaro, R., Ruiz, A., 1996. Capturas y esfuerzos en la pesquería de merluza (*Merluccius hubbsi*) del área de Isla Escondida, Patagonia, 1985–1992. Nat. Patagón. 4, 65–74.

Frere, E., Gandini, P.A., Lichtschein, V., 1996. Variación latitudinal en la dieta del Pingüino de Magallanes (*Spheniscus magellanicus*) en la costa Patagónica, Argentina. Ornitol. Neotrop. 7, 35–41.

Gandini, P.A., Frere, E., Pettovello, A.D., Cedrola, P.V., 1999. Interaction between Magellanic penguins and shrimp fisheries in Patagonia, Argentina. Condor 101, 783–789.

Góngora, M.E., González-Zevallos, D., Pettovello, A., Mendía, L., 2012. Caracterización de las principales pesquerías del golfo San Jorge Patagonia, Argentina. Lat. Am. J. Aquat. Res. 40, 1–11.

González-Zevallos, D., Yorio, P., 2006. Seabird use of discards and incidental captures at the Argentine hake trawl fishery in the Golfo San Jorge, Argentina. Mar. Ecol. Prog. Ser. 316, 175–183.

González-Zevallos, D., Yorio, P., Caille, G., 2007. Seabird mortality at trawler warp cables and a proposed mitigation measure: a case of study in Golfo San Jorge, Patagonia, Argentina. Biol. Conserv. 136, 108–116.

González Zevallos, D., Yorio, P., Svagelj, W.S., 2011. Seabird attendance and incidental mortality at shrimp fisheries in Golfo San Jorge, Argentina. Mar. Ecol. Prog. Ser. 432, 125–135.

Gosztonyi, A.E., 1984. La alimentación del pingüino Magallánico (*Spheniscus magellanicus*) en las adyacencias de Punta Tombo, Chubut, Argentina. Contrib. Cent. Nac. Patagón. 95, 1–19.

IUCN, 2013. IUCN red list of threatened Species. Version 2013.1. http://www.iucnredlist.org (accessed 19.07.13).

McCullagh, P., Nelder, J.A., 1989. Generalized Linear Models. Chapman & Hall, New York.

Marinao, C., Yorio, P., 2011. Use of fishery discards and incidental mortality of seabirds attending coastal shrimp trawlers in Isla Escondida, Patagonia, Argentina. Wilson J. Ornithol. 123, 709–719.

Petry, M.V., Fonseca, V.S. da Silva, 2002. Effects of human activities on the marine environment on seabirds along the coast of Rio Grande do Sul, Brazil. Ornitol. Neotrop. 13, 137–142.

Pierre, J.P., Abraham, E.R., Middleton, D.A.J., Cleal, J., Bird, R., Walker, N.A., Waugh, S.M., 2010. Reducing interactions between seabirds and fisheries: responses to foraging patches provided by fish waste batches. Biol. Conserv. 143, 2779–2788.

Pierre, J.P., Abraham, E.R., Richard, Y., Cleal, J., Middleton, D.A.J., 2012. Controlling trawler waste discharge to reduce seabird mortality. Fish. Res. 131–133, 30–38.

Plagányi, É.E., 2007. Models for an Ecosystem Approach to Fisheries. FAO Fisheries Technical Paper. No. 477. FAO, Rome, p. 108.

R Development Core Team, 2013. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org. Available from:

Ryan, P.G., Watkins, B.P., 2008. Estimating seabird bycatch by fisheries and its impact on seabird populations. Anim. Conserv. 11, 260–262.

Sæther, B.E., Bakke, Ø., 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology 81, 642–653.

Seco Pon, J.P., Copello, S., Moretinni, A., Lértora, H.P., Bruno, I., Bastida, J., Mauco, L., Favero, M., 2013. Seabird and marine-mammal attendance and by-catch in semi-industrial trawl fisheries in near-shore waters of northern Argentina. Mar. Freshw. Res. 64, 237–248.

Schiavini, A., Yorio, P., Gandini, P., Raya Rey, A., Boersma, D., 2005. Los pingüinos de las costas argentinas: estado poblacional y conservación. El Hornero 20, 5–23.

Scolaro, J.A., Wilson, R.P., Laurenti, S., Kierspel, M.A., Gallelli, H., Upton, J.A., 1999. Feeding preferences of the Magellanic Penguin *Spheniscus magellanicus* over its breeding range in Argentina. Waterbirds 22, 104–110.

Stokes, D.L., Boersma, P.D., Davis, L.S., 1998. Satellite tracking of Magellanic penguin (*Spheniscus magellanicus*) migration. Condor 100, 376–381.

Sullivan, B.J., Reid, T.A., Bugoni, L., 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. Biol. Conserv. 131, 495–504.

Tamini, L.L., Perez, J.E., Chiaramonte, G.E., Cappozzo, H.L., 2002. Magellanic penguin (*Spheniscus magellanicus*) and fish as bycatch in the cornalito (*Sorgentinia incisa*) fishery at Puerto Quequén, Argentina. Atlant. Seabirds 4, 109–114.

Watkins, B.P., Petersen, S.L., Ryan, P.G., 2008. Interactions between seabirds and deep water hake-trawl gear: an assessment of impacts in South African waters. Anim. Conserv. 11, 247–254.

Weimerskirch, H., Capdeville, D., Duhamel, G., 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. Polar Biol. 23, 236–249.

Yorio, P., Caille, G., 1999. Seabird interactions with coastal fisheries in Northern Patagonia: use of discards and incidental captures in nets. Waterbirds 22, 207–216.

Yorio, P., Frere, E., Gandini, P., Conway, W., 1999. Status and conservation of seabirds breeding in Argentina. Bird Conserv. Int. 9, 299–314.

Yorio, P., Frere, E., Gandini, P., Schiavini, A., 2001. Tourism and recreation at seabird breeding sites in patagonia, Argentina: current concerns and future prospects. Bird Conserv. Int. 11, 231–245.

Yorio, P., Frere, E., Gandini, P., Harris, G. (Eds.), 1998. Atlas de la distribución reproductiva de aves marinas en el litoral Patagónico Argentino. Fundación Patagonia Natural and Wildlife Conservation Society, Buenos Aires, Argentina. Plan de Manejo Integrado de la Zona Costera Patagónica. Instituto Salesiano de Artes Gráficas.