

RESEARCH ARTICLE

High mortality of adult female Magellanic penguins by gillnet fisheries in southern Brazil

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Abstract

1. Bycatch in gillnet fisheries is one of the main threats to several penguin species. Magellanic penguins (*Spheniscus magellanicus*) are caught by gillnets during their wintering in southern Brazil. However, current information is based only on a small number of sets observed during a single fishing trip.
2. This study assesses bycatch rates of bottom and drift gillnets operating in southern Brazil, and describes the sex and age classes of individuals captured.
3. In 80 bottom gillnet sets, 33 penguins were captured (85% adults), 14 were sexed of which 13 were females. In 41 drift gillnet sets, four penguins were captured, three of which were juveniles.
4. The mean bycatch rates, measured as number of penguins km⁻² of net and number of penguins km⁻² h⁻¹, were significantly higher for the drift gillnets.
5. Despite the lower bycatch rates, owing to the higher fishing effort in terms of number of boats, net length, net area, soak time and fishing season, the magnitude of penguin bycatch in the bottom gillnet fishery cannot be ignored.
6. Despite based on small sample size, the predominance of adult and female Magellanic penguins as bycatch in gillnet fisheries in southern Brazil agrees with previous studies suggesting that females disperse further north than males. In addition, such evidence contributes to the male-biased sex ratio in breeding grounds, and the long-term decline of major Patagonian colonies owing to higher female mortality during winter.

KEYWORDS

bycatch rates, entanglement, non-breeding areas, seabird, *Spheniscus magellanicus*, winter migration

1 | INTRODUCTION

Hundreds of thousands of seabirds of at least 378 species are injured or killed annually in 18 different types of fishing gear worldwide (Pott & Wiedenfeld, 2017; Tasker et al., 2000), with gillnet fisheries

accounting for 138 seabird species of various taxonomic groups (Pott & Wiedenfeld, 2017). The annual bycatch in longline and trawl fisheries is estimated at 300,000 individuals, while gillnets account for over 400,000 seabird fatalities worldwide (Anderson et al., 2011; Żydelski, Small, & French, 2013). Pursuit-diving seabirds are particularly

susceptible to bycatch in gillnet fisheries (Žydelis et al., 2013). As the most well-adapted bird group for diving, penguins are among the most vulnerable waterbirds, comprising 14 of the 18 species incidentally captured in fisheries, with eight of them entangled in gillnet fisheries (Crawford et al., 2017).

Majluf, Babcock, Riveros, Schreiber, and Alderete (2002) reported an annual bycatch of about 400 Humboldt penguins (*Spheniscus humboldti*) in drift gillnets between 1991 and 1998, in Punta San Juan, Peru, and Simeone, Bernal, and Meza (1999) 605 Humboldt and 58 Magellanic penguins (*Spheniscus magellanicus*) in drift gillnets in breeding areas between 1991 and 1996 in the Valparaíso Region, Chile. On the New Zealand South Island, the major cause of yellow-eyed penguin (*Megadyptes antipodes*) population decline was attributed to gillnet bycatch during its breeding season (Darby & Dawson, 2000). In southern Brazil, Cardoso, Bugoni, Mancini and Haimovici (2011) reported the mortality of 68 Magellanic penguins in 17 gillnet sets during a single 8 day gillnet fishing trip. They found that this fishing gear was a major cause of death for wintering Magellanic penguins in the area. Thus, a recent global review on penguin bycatch in fisheries (Crawford et al., 2017) identified these three species and the areas reported above as hotspots of penguin bycatch and deserving further attention. Furthermore, although the impact of bycatch has been mostly investigated near penguin breeding grounds, it is clear that it also occurs in non-breeding areas, which increases the year-round mortality and the decline of populations (Gownaris & Boersma, 2019), highlighting the need for studies on a year-round basis and throughout each species' range.

In addition to estimates of seabird mortality rates and the number of individuals caught by fishing, other characteristics such as the sex and age of individuals killed are also important for population-level assessments of bycatch impacts (Bugoni, Griffiths, & Furness, 2011; Lewison et al., 2012). In a recent review, it was reported that sex and age biases were common characteristics of seabird species incidentally killed in global fisheries (Gianuca, Phillips, Townley, & Votier, 2017). Biases appear to be frequently associated with differences in at-sea distributions (Gianuca et al., 2017). These authors also reported that the bycatch of adults and males was higher in sub-polar regions, whereas in subtropical waters females and immature penguins predominated. Unbalanced adult mortality of a specific sex can have severe consequences for monogamous species such as penguins, albatrosses and many other waterbirds (Coulson, 2001).

The Magellanic penguin breeds along the coasts of southern Argentina, Chile and the Falkland/Malvinas Islands (Boersma et al., 2013). The latest global population estimate was between 1.1 and 1.6 million breeding pairs, with a declining trend mainly attributed to climatic and anthropogenic factors (BirdLife International, 2017). The main current threats are oil pollution (Boersma, 2008; García-Borboroglu et al., 2006), fishery interactions (Boersma, Rebstock, & García-Borboroglu, 2015; Suazo et al., 2014) and climate change (Boersma & Rebstock, 2014). Climate changes includes increasing frequency and intensity of rain and storms near breeding colonies, which increase chick mortality by drowning or collapse of nests (Boersma & Rebstock, 2014). Thus, Magellanic penguins are listed as

'Near Threatened' in the IUCN Red List, which reinforces the need for mortality estimates and identification of the main threats to support the implementation of appropriate conservation measures (BirdLife International, 2017).

At the end of the breeding season, which spans from September to March, Magellanic penguins leave Patagonian colonies to carry out long pelagic migrations to wintering areas northward (Pütz, Ingham, & Smith, 2000; Pütz, Schiavini, Raya-Rey, & Lüthi, 2007; Schiavini, Yorio, Gandini, Rey, & Boersma, 2005; Stokes, Boersma, Casenave, & García-Borboroglu, 2014; Stokes, Boersma, & Davis, 1998). Pütz et al. (2007) reported that penguins from colonies in the extreme south of Argentina could migrate to the Península Valdés region during winter (at ~42°S). Penguins breeding in the northern colonies such as Península Valdés, Punta Tombo (44°S) and Cabo dos Bahías (~45°S) migrate further north to feed off northern Argentina, Uruguay and southern Brazil (Pütz et al., 2000; Stokes et al., 1998; Yamamoto, Yoda, Blanco, & Quintana, 2019). Only a few studies have investigated the winter distribution of Magellanic penguins. In a recent study, Yamamoto et al. (2019) tracked 14 males and females with geolocators, showing that both sexes move northward, but females reach areas further north with their core wintering ground located in front of the Rio de La Plata mouth, while males remain over the Patagonian continental shelf. The migratory movements of birds from the northern Patagonia colonies into Brazilian coastal waters are related to feeding mainly upon the Argentine anchovy (*Engraulis anchoita*) (Marques, Cardoso, Haimovici, & Bugoni, 2018; Yorio, González-Zevallos, Gatto, Biagioni, & Castillo, 2017).

In southern Brazil, the Argentine anchovy is one of the main food items of Magellanic penguins (Marques et al., 2018; Silva et al., 2015) and at the same time is one of the main food items of important fish predators, such as the bluefish (*Pomatomus saltatrix*) and the striped weakfish (*Cynoscion guatucupa*), which are also important targets for gillnet fishing fleets in southern Brazil (Lucena, Vaske, Ellis, & O'Brien, 2000; Secchi et al., 1997). The food overlap between penguins, bluefish and striped weakfish is one of the factors that makes penguins vulnerable to incidental catches in gillnet fisheries (Cardoso, Bugoni, Mancini, & Haimovici, 2011). During the austral winter, approximately 70 industrial fishing boats operate with drift gillnets targeting the bluefish and more than 280 fishing boats operate with bottom gillnets targeting the demersal striped weakfish in southern Brazil (Pio, Pezzuto, & Wahrlich, 2016; Vasconcellos, Haimovici, & Ramos, 2014). As highlighted by Cardoso et al. (2011), the bycatch of Magellanic penguins by this fleet is probably the main source of mortality of adults in their wintering areas.

During the last decade, the number of penguin strandings along the Brazilian coast has increased (García-Borboroglu et al., 2006, 2010; Mäder, Sander, & Casa, 2010). Concomitantly, the increase in fishing effort (net size and number of boats) by the gillnet fishery in southern Brazil has increased the incidental mortality of various marine megafauna, especially the Franciscana dolphins (*Pontoporia blainvillei*) and green turtles (*Chelonia mydas*) (Monteiro et al., 2016; Prado, Mattos, Silva, & Secchi, 2016; Secchi, Kinan, & Muelbert, 2004). Similar to these megafauna species, penguins are long-lived and low-fecundity animals

with delayed maturity (Boersma, 2008). These life-history characteristics make the fishing bycatch, in addition to other anthropogenic impacts, a potential significant threat to populations.

Little is known about the impact of the gillnet fisheries on Magellanic penguins in their wintering areas in southern Brazil and this has been identified as a knowledge gap of global importance (Crawford et al., 2017). Thus, the objective of this study was to provide a detailed evaluation of catch rates and the sex and age of individuals captured by bottom and drift gillnet fisheries. The outcomes are expected to contribute to understanding of the impact of the gillnet fishery in southern Brazil on the Magellanic penguins and to help identify and implement mitigation measures.

2 | MATERIALS AND METHODS

Data on bottom and drift gillnet fisheries and incidental catches of Magellanic penguins were collected by scientific observers during 27 June to 30 August 2013, 2 May to 1 October 2014 and 17 July to 3 August 2015. The nets were set off the coast of Rio Grande do Sul State in southern Brazil (Figure 1). For each set, onboard observers recorded the fishing characteristics including net length and height (m), date, depth, position (latitude and longitude) and time of net deployment and retrieval (Table 1; Figure 1). Observers also recorded the number of dead penguins and their age classes (juvenile/adult) based on their plumage (Williams & Boersma, 1995). When allowed by the captain of the boat, penguins were collected randomly from each drift and bottom set and kept on ice for laboratory necropsies. The sex of individuals was determined by gonadal examination following Proctor and Lynch (1993).

Incidental catch rates were calculated as the number of dead penguins per net area (km²) and by net area (km²) per soak time (h), for all

TABLE 1 Summary of fishing data and characteristics of the bottom and drift gillnet fleet from southern Brazil; mean \pm 1 standard deviation

	Bottom gillnet	Drift gillnet
Number of fishing boats sampled	3	4
Length of fishing boats (m)	18–20	10–22
Motor power (hpp)	260	170–250
Storage capacity (t)	35	10–35
Number of fishing trips	8	6
Number of sets	80	41
Mean number of sets per trip	10 \pm 7.9	7 \pm 2.3
Mean number of fishing days	7.1 \pm 4	3 \pm 1
Mean net soak time (h)	12.9 \pm 5.4	3.4 \pm 3.6
Mean net length (km)	10.6 \pm 4	1.23 \pm 0.6
Minimum–maximum net length (km)	5.5–17.6	0.4–2.9
Mean net height (m)	2.2 \pm 0.1	11.85 \pm 1.9
Minimum–maximum net height (m)	2–3	10–18
Mean net area (km ²)	0.02 \pm 0.01	0.01 \pm 0.0

sets of each net type. Since all drift gillnet sets occurred in waters shallower than 21 m, the catch rates for the bottom gillnet sets within that depth limit ($n = 53$) were also calculated for comparison. The soak time of drift gillnet sets ranged from 35 min to 17 h, and bottom gillnet sets from 2.5 h to 24 h. The net immersion time (IT ; in h), was calculated as:

$$IT = ((TR_f) - (TD_s)) - \left(\frac{TR_f - TR_s}{2} + \frac{TD_f - TD_s}{2} \right) \quad (1)$$

where, TD_f and TD_s are the time (hour of the day) at the final and at the start of net deployment, respectively; TR_f and TR_s are

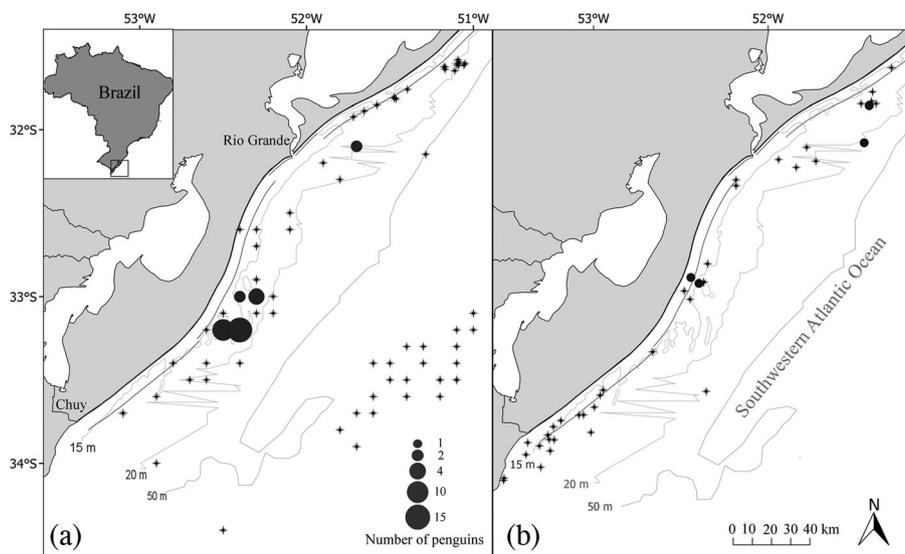


FIGURE 1 Distribution of bottom (a) and drift (b) gillnet sets and Magellanic penguin (*Spheniscus magellanicus*) catches in southern Brazil from 2013 to 2015. Crosses represent the midpoint between initial and final set position; circles indicate the number of penguins caught; grey lines correspond the isobaths 15, 20 and 50 m of depth; and fishing exclusion area lies from the coastline to the thin black line (INI-MPA/MMA no. 12, 2012)

the time of the final and at the start of the net retrieval. The half net deployment time, $(TD_f - TD_s)/2$, corresponds to the time (hour of the day) when half of the net was not yet deployed in the water, and the other half was already being used for fishing. The half net retrieval time, $(TR_f - TR_s)/2$, is the time when half of the net had already been retrieved and the other half was still in water.

Owing to the low number of sets with penguins captured and to obtain the confidence intervals and compare statistically the penguin bycatch rates between the two net types, 2000 samples of bottom and drift gillnet sets were generated by bootstrap, from the samples obtained in the field. The bootstrap was performed with a random samples and permutations tool that resamples with replacement (Manly, 2006). The normality of the data was tested using the bootstrapped distribution with Shapiro–Wilk's test, but because residuals were not normally distributed, capture rates between both fisheries were compared with a Wilcoxon's rank test (Zar, 1999) using R software, version 3.2.3 (R Core Team, 2016).

3 | RESULTS

Eighty bottom gillnet sets and 41 drift gillnet sets (Figure 1) were sampled. Bottom gillnet sets occurred at depths from 9 to 115 m while drift gillnets were set in waters 11–21 m deep.

Thirty-three penguins were caught in five bottom gillnet sets (Figure 1a; Table 2). Adults accounted for 85% ($n = 28$) of penguins killed in bottom gillnet sets. Among adults, 14 individuals had their sex determined and 93% were females ($n = 13$). A single adult was caught alive and released back to sea. It was not included in the total numbers of penguins reported.

Four penguins (three juveniles and one adult) were killed in four drift gillnet sets (Figure 1b; Table 2), one juvenile penguin was caught alive and released back to sea.

The number of penguins km^{-2} and penguins $\text{km}^{-2} \text{h}^{-1}$ was significantly greater in drift gillnets (penguins km^{-2} , $Z = 1\ 144\ 500$; penguins $\text{km}^{-2} \text{h}^{-1}$, $Z = 182\ 150$, both $P < 0.0001$) in comparison with bottom gillnets (Table 2). The comparison between sets performed at depths <21 m showed the same pattern, i.e. penguins km^{-2} and penguins $\text{km}^{-2} \text{h}^{-1}$ were significantly higher for drift gillnet (penguins

km^{-2} , $Z = 1\ 769\ 200$; penguins $\text{km}^{-2} \text{h}^{-1}$, $Z = 334\ 210$, both $P < 0.0001$ (Table 2).

4 | DISCUSSION

This study confirmed that Magellanic penguins are vulnerable to both bottom and drift gillnet sets in coastal waters off southern Brazil, as reported by Cardoso et al. (2011) based on a limited dataset. Furthermore, this is the first study to provide data on the sex and age classes of Magellanic penguins incidentally caught in this non-breeding area. Despite the small number of penguins that had their sex determined, these findings show a bias towards adult females.

The higher mean bycatch rates in drift than bottom gillnet sets (measured as penguins km^{-2} and penguins $\text{km}^{-2} \text{h}^{-1}$) is similar to those in the previous study (Cardoso et al., 2011). This is probably because drift gillnet fishery targets mainly bluefish shoals in shallow coastal waters, and Magellanic penguins are likely to be present in large numbers searching for the same prey, the Argentine anchovy (Lucena et al., 2000). Costa (2016) showed that higher densities of Magellanic penguins are strongly correlated to higher densities of Argentine anchovy on the southern Brazilian continental shelf. The feeding overlap between bluefish and penguins suggests that both species may occur together, which would make penguins more vulnerable to drift gillnets targeting bluefish.

However, despite the lower catch rates, the bottom gillnet may negatively affect Magellanic penguins overall to a greater degree than drift gillnets in southern Brazil. In this region, it is estimated that ~ 70 vessels are licensed to deploy drift gillnets (Brasil, 2013), while more than 280 vessels are allowed to fish using bottom gillnets (Vasconcellos et al., 2014). Additionally, penguins can be observed between May and November each year (Mäder et al., 2010), and the drift gillnets are allowed to fish for only 75 days, between June and August (Brasil, 2013), while bottom gillnets are deployed year-round (Secchi et al., 1997; Vasconcellos et al., 2014). The higher fishing effort in terms of number of boats, net dimensions, soak time and length of the fishing season probably makes the bottom gillnet a greater threat to penguins in southern Brazil.

Although it was not possible to know whether bottom gillnets captured penguins near the bottom or during their deployment or hauling,

TABLE 2 Summary of bycatch rates and number of Magellanic penguins (*Spheniscus magellanicus*) caught by drift and bottom gillnet; CI95%, 95% confidence interval

Depth	Drift gillnet		Bottom gillnet			
	<21 m	CI95%	<115 m	CI95%	<21 m	CI95%
Number of sets	41		80		53	
Mean number of dead penguins km^{-2} of net area	21.05	2.25–36.45	13.64	0.00–24.68	19.80	0.00–36.18
Mean number of dead penguins km^{-2} per soak time of net	5.06	0.45–9.00	1.04	0.05–1.82	1.54	0.13–2.77
Number of adult dead penguins	1		28		28	
Number of juvenile dead penguins	3		5		5	
Total number of dead penguins	4		33		33	

it is probable that they were captured near the sea floor during foraging dives. First, the time period during which bottom gillnets remain near the surface when they are being deployed or hauled is much shorter than the fishing time of drift gillnets. This makes the time window in which penguins can be captured near the surface very short. Secondly, all penguins caught by bottom gillnet were adults, and it is known that they dive deeper than juveniles when foraging (Orgeret, Weimerskirch, & Bost, 2016), at depths well within the depth range where nets are deployed, i.e. up to 97 m (Walker & Boersma, 2003 and references therein). Thirdly, all sets in which penguins were captured fished mostly during the day, a period when its main prey, the Argentine anchovy, is near the sea bed, often in large shoals (Madureira & Rossi-Wongtschowski, 2005).

The catch rates estimated by Cardoso et al. (2011) were higher than those estimated for the two gillnet types in the current study. This may be due to the low number of sets sampled in a single fishing trip. Capture rates based on limited sampling designed for other purposes tend to over-estimate capture rates (Bugoni, Mancini, Monteiro, Nascimento, & Neves, 2008).

Penguins captured in bottom gillnets were all adults. Age-skewed seabird bycatch is common in several fisheries around the globe, with 68% of seabird bycatch samples biased towards adults (Gianuca et al., 2017). Juveniles and adults could segregate in flocks according to age or could use different foraging areas that might overlap to a greater or lesser degree with fisheries (Stokes et al., 2014).

In southern Brazil, a high proportion (97.5%, of 14,033 carcasses registered between 1990 and 2008) of penguins that wash ashore every year are juveniles (Mäder et al., 2010), which contrasts with the predominant bycatch of adult penguins observed in this study. Oil contamination, ingestion of anthropogenic debris, severe gastrointestinal parasite infections and fatal interaction with fishing gear are the most common causes of mortality of beached penguins in southern Brazil (Azevedo & Schiller, 1991; Mäder et al., 2010; Vanstreels et al., 2011). Between 1985 and 1989, Barbieri and Vooren (1993) sampled 282 penguin carcasses and 29% had oil contamination in their plumage. Between 1997 and 1998, 3376 dead penguins were observed with oil stains or signs of interaction with fishing nets, or with marine debris in their stomachs (Petry, Fonseca, & Jost, 2004).

Despite the low number of sexed penguins among adult penguins caught by bottom nets, the proportion of females was higher (ratio 13:1). A female-biased mortality has been observed in stranded penguin carcasses on the Brazilian coast (Nunes et al., 2015; Reis et al., 2011; Vanstreels et al., 2013). Vanstreels et al. (2013) and Nunes et al. (2015) recorded an asymmetric sex ratio of 2.84 and 1.86 females per male, respectively, with even sexes only among survivors and oiled birds from rehabilitation centres (Vanstreels et al., 2013), suggesting that males are more resistant to death, before and after being rescued. Reis et al. (2011) analysed stranded carcasses from the coast of Rio Grande do Sul, Rio de Janeiro and Sergipe, and also reported a predominance of females. Finally, Yamamoto et al. (2019), tracked year-round at-sea distributions of Magellanic penguins with geolocators and revealed that females reached areas further north than males. This evidence suggests that females occur in greater

numbers than males along the Brazilian coast. The potential explanation would be mechanisms related to sexual size dimorphism, such as the avoidance of intraspecific competition for food resources (Raya-Rey, Pütz, Scioscia, Lüthi, & Schiavini, 2012), different thermal preferences (Ciancio, Quintana, Sala, & Wilson, 2016), differences in the ability to withstand the northward flowing ocean circulation (Clarke et al., 2003), as proposed by Yamamoto et al. (2019), or differences in survival, as has been reported for African penguins (*Spheniscus demersus*) in South Africa (Pichegru & Parsons, 2014), and suggested by the higher survival of male Magellanic penguins in rehabilitation centres in Brazil (Vanstreels et al., 2013). However, in Punta Tombo, in the largest colony of the *S. magellanicus* and the origin of a substantial portion of penguins found in southern Brazil, the ratio is skewed toward males at a rate of 1.5:1 (Boersma et al., 2013). The higher bycatch of females in the present study agrees with the pattern of a greater presence of females in wintering grounds, including southern Brazil, and taking into account that (a) larger males dive deeper, thus would be potentially more (not less) susceptible to capture in bottom nets and (b) the adult breeding population in colonies is skewed toward males, instead of females, it can be inferred that females compose the bulk of the population of penguins wintering in southern Brazil, and thus account for a larger number of bycaught birds. Because the sex ratio at fledging is 1:1 in Magellanic penguins (Gownaris & Boersma, 2019) and in wild birds in general (reviewed by Donald, 2007), the predominance of females in both juvenile and adult samples seems to indicate that the sexes segregate in non-breeding areas in both juvenile and adult stages. Segregation in foraging areas according to sex has been reported in other seabirds such as in wandering albatrosses (*Diomedea exulans*), with males staying in more southern areas compared with females (Shaffer, Weimerskirch, & Costa, 2001), and also in other albatrosses and petrels off southern Brazil (Bugoni et al., 2011). Notwithstanding the reasons for gillnets killing more females, which should be further investigated using, for instance, long-term tracking during the wintering period, a higher mortality of individuals of one sex in monogamous species, such as the predominance of females in bycaught penguins, exacerbates the effect on population stability, by reducing the effective population size, as some adults will remain unpaired in monogamous species. In fact, Gownaris and Boersma (2019) demonstrated that the lower non-breeding-season survival of females made the greatest contribution to a long-term decline of the Magellanic penguin population at Punta Tombo, Argentina. A reduction in the number of breeding females directly reduces birth rates and hence, population productivity (Hesketh, Lu, & Xing, 2005), whereas an over-abundance of males may increase violence and aggression, such that both male and female survival rates are reduced (Le Galliard, Fitze, Ferrière, & Clobert, 2005; Seddon & van Heezik, 1991). In other words, reproduction and population growth are most sensitive to perturbations in survival of the limiting sex (Eberhart-Phillips et al., 2017).

Considering the size of the fleet and the net dimensions of both fisheries, the magnitude of penguin mortality seems to be high in southern Brazil. Beside penguins, other threatened species with low intrinsic potential for population growth, such as the Franciscana

dolphin (Prado, Secchi, & Kinan, 2013; Secchi, 2010), sea turtles (Monteiro et al., 2016; Vasconcellos et al., 2014) and elasmobranchs (Vooren & Klippel, 2005), are affected by the bycatch in gillnets in the region. The highest levels of incidental mortality of these species occur near the coast owing to the high overlap between the fishing effort and the distribution areas of animals (e.g. Monteiro et al., 2016). In 2012, the Brazilian government regulated gillnet fisheries allowing a maximum net length of 16 km and established closure areas for this activity in southern Brazil in neritic waters (Brasil, 2012), with the expectation of reducing the bycatch of several components of the marine megafauna.

Some gillnets killed penguins inside the no-fishing area and some nets exceeded the allowed length of 16 km (Figure 1). Furthermore, a study showed that the current mortality of the Franciscana dolphin remains similar to that before the implementation of this novel regulation (Prado et al., 2016). Our data suggest that current fisheries regulations in the region, including closures and gear restrictions, are ineffective at preventing Magellanic penguin mortality. Another possible explanation could be a lack of enforcement since there is a general pattern of over-exploitation of several fishing resources which led some of them to be at risk of commercial unviability (Haimovici & Cardoso, 2016). An alternative with the potential to decrease bycatch is modifications in the net such as increasing its visibility without a significant reduction in its efficiency to catch target species (Hanamseth, Baker, Sherwen, Hindell, & Lea, 2018; Martin & Crawford, 2015). However, there is a clear lack of proper management measures or enforcement in the study area, as several threatened marine megafauna species are killed annually in high numbers and most of the fishing resources are over-exploited (Haimovici & Cardoso, 2016). In such a governance context of lack of enforcement or ineffective management or conservation strategies, Dowling et al. (2016) suggest that the most effective measures would be spatial and temporal approaches, such as for example, the establishment of no-fishing zones or seasonal closures.

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REFERENCES

- Anderson, O. R. J., Small, C. J., Croxall, J. P., Dunn, E. K., Sullivan, B. J., Yates, O., & Black, A. (2011). Global seabird bycatch in longline fisheries. *Endangered Species Research*, 14, 91–106. <https://doi.org/10.3354/esr00347>
- Azevedo, T. D., & Schiller, A. (1991). Notes on the diet and the ingestion of plastic material by the Magellanic penguin *Spheniscus magellanicus* on Santa Catarina Island and mainland (Brazil). *Research Report*, 457, 1–8.
- Barbieri, E., & Vooren, C. M. (1993). Técnicas de recuperação de pinguins oleados. *Ambiente: Revista CETESB de Tecnologia*, 7, 18–22.
- BirdLife International. (2017). Species factsheet: *Spheniscus magellanicus*. <http://www.birdlife.org/> [05 April 2017].
- Boersma, P. D. (2008). Penguins as marine sentinels. *Bioscience*, 58, 597–607. <https://doi.org/10.1641/B580707>
- Boersma, P. D., Frere, E., Kane, O., Pozzi, L. M., Pütz, K., Raya-Rey, A., ... García-Borboroglu, P. (2013). Magellanic penguins (*Spheniscus magellanicus*). In P. García-Borboroglu, & P. D. Boersma (Eds.), *Penguins: natural history and conservation* (pp. 232–263). Seattle, WA: University of Washington Press.
- Boersma, P. D., & Rebstock, G. A. (2014). Climate change increases reproductive failure in Magellanic penguins. *PLoS ONE*, 9, e85602. <https://doi.org/10.1371/journal.pone.0085602>
- Boersma, P. D., Rebstock, G. A., & García-Borboroglu, P. (2015). Marine protection is needed for Magellanic penguins in Argentina based on long-term data. *Biological Conservation*, 182, 197–204. <https://doi.org/10.1016/j.biocon.2014.12.005>
- Brasil. (2012). Instrução Normativa Número MPA/MMA 12, de 22 de agosto de 2012.
- Brasil. (2013). Instrução Normativa MPA/MMA Número 04 de 16 de outubro de 2013.
- Bugoni, L., Griffiths, K., & Furness, R. W. (2011). Sex-biased incidental mortality of albatrosses and petrels in longline fisheries: Differential distributions at sea or differential access to baits mediated by sexual size dimorphism? *Journal of Ornithology*, 152, 261–268. <https://doi.org/10.1007/s10336-010-0577-x>
- Bugoni, L., Mancini, P. L., Monteiro, D. S., Nascimento, L., & Neves, T. S. (2008). Seabird bycatch in the Brazilian pelagic longline fishery and a review of capture rates in the southwestern Atlantic Ocean. *Endangered Species Research*, 5, 137–147. <https://doi.org/10.3354/esr00115>
- Cardoso, L. G., Bugoni, L., Mancini, P. L., & Haimovici, M. (2011). Gillnet fisheries as a major mortality factor of Magellanic penguins in wintering areas. *Marine Pollution Bulletin*, 62, 840–844. <https://doi.org/10.1016/j.marpolbul.2011.01.033>
- Ciaccio, J. E., Quintana, F., Sala, J. E., & Wilson, R. P. (2016). Cold birds under pressure: Can thermal substitution ease heat loss in diving penguins? *Marine Biology*, 163, 43. <https://doi.org/10.1007/s00227-016-2813-2>
- Clarke, J., Kerry, K., Fowler, C., Lawless, R., Eberhard, S., & Murphy, R. (2003). Post fledging and winter migration of Adélie penguins *Pygoscelis adeliae* in the Mawson region of East Antarctica. *Marine Ecology Progress Series*, 248, 267–278. <https://doi.org/10.3354/meps248267>
- Costa, P. L. (2016). Condicionantes ambientais e as relações entre *Engraulis anchoita*, zooplâncton e aves marinhas na Plataforma Continental do Rio Grande do Sul, Brasil. (PhD thesis). Federal University of Rio Grande-FURG, Brazil.
- Coulson, J. C. (2001). Colonial breeding in seabirds. In E. A. Schreiber, & J. Burger (Eds.), *Biology of marine birds* (pp. 87–113). Boca Raton, FL: CRC Press. <https://doi.org/10.1201/9781420036305.ch4>

- Crawford, R., Ellenberg, U., Frere, E., Hagen, C., Baird, K., Brewin, P., ... Small, C. (2017). Tangled and drowned: A global review of penguin bycatch in fisheries. *Endangered Species Research*, 34, 373–396. <https://doi.org/10.3354/esr00869>
- Darby, J. T., & Dawson, S. M. (2000). Bycatch of yellow-eyed penguins (*Megadyptes antipodes*) in gillnets in New Zealand waters 1979–1997. *Biological Conservation*, 93, 327–332. [https://doi.org/10.1016/S0006-3207\(99\)00148-2](https://doi.org/10.1016/S0006-3207(99)00148-2)
- Donald, P. F. (2007). Adult sex ratios in wild bird populations. *Ibis*, 149, 671–692. <https://doi.org/10.1111/j.1474-919X.2007.00724.x>
- Dowling, N. A., Wilson, J. R., Rudd, M. B., Babcock, E. A., Caillaux, M., Cope, J., ... & Gutierrez, N. (2016). FishPath: A decision support system for assessing and managing data-and capacity-limited fisheries. In: Tools and strategies for assessment and management of data-limited fish stocks. *30th Lowell Wakefield Fisheries Symposium*.
- Eberhart-Phillips, L. J., Küpper, C., Miller, T. E., Cruz-López, M., Maher, K. H., Dos Remedios, N., ... Székely, T. (2017). Sex-specific early survival drives adult sex ratio bias in snowy plovers and impacts mating system and population growth. *Proceedings of the National Academy of Sciences of the United States of America*, 114, E5474–E5481. <https://doi.org/10.1073/pnas.1620043114>
- García-Borboroglu, P., Boersma, P. D., Ruoppolo, V., Pinho-da-Silva-Filho, R., Corrado-Adornes, A., Conte-Sena, D., ... Serra, S. (2010). Magellanic penguin mortality in 2008 along the SW Atlantic coast. *Marine Pollution Bulletin*, 60, 1652–1657. <https://doi.org/10.1016/j.marpolbul.2010.07.006>
- García-Borboroglu, P., Boersma, P. D., Ruoppolo, V., Reyes, L., Rebstock, G. A., Griot, K., ... Silva-Filho, R. P. (2006). Chronic oil pollution harms Magellanic penguins in the Southwest Atlantic. *Marine Pollution Bulletin*, 52, 193–198. <https://doi.org/10.1016/j.marpolbul.2005.11.004>
- Gianuca, D., Phillips, R. A., Townley, S., & Votier, S. C. (2017). Global patterns of sex-and age-specific variation in seabird bycatch. *Biological Conservation*, 205, 60–76. <https://doi.org/10.1016/j.biocon.2016.11.028>
- Gownaris, N. J., & Boersma, P. D. (2019). Sex-biased survival contributes to population decline in a long-lived seabird, the Magellanic penguin. *Ecological Applications*, 29, e01826. <https://doi.org/10.1002/eap.1826>
- Haimovici, M., & Cardoso, L. G. (2016). Long-term changes in the fisheries in the Patos Lagoon estuary and adjacent coastal waters in Southern Brazil. *Marine Biology Research*, 13, 135–150. <https://doi.org/10.1080/17451000.2016.1228978>
- Hanamseth, R., Baker, B. G., Sherwen, S., Hindell, M., & Lea, M. A. (2018). Assessing the importance of net colour as a seabird bycatch mitigation measure in gillnet fishing. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 28, 175–181. <https://doi.org/10.1002/aqc.2805>
- Hesketh, T., Lu, L., & Xing, Z. W. (2005). The effect of China's one-child family policy after 25 years. *New England Journal of Medicine*, 353, 1171–1176. <https://doi.org/10.1056/NEJMhr051833>
- Le Galliard, J. F., Fitze, P. S., Ferrière, R., & Clobert, J. (2005). Sex ratio bias, male aggression, and population collapse in lizards. *Proceedings of the National Academy of Sciences of the United States of America*, 102, 18231–18236. <https://doi.org/10.1073/pnas.0505172102>
- Lewis, R. L., Oro, D., Godley, B. J., Underhill, L., Bearhop, S., Wilson, R. P., ... Yoroi, P. (2012). Research priorities for seabirds: Improving conservation and management in the 21st century. *Endangered Species Research*, 17, 93–121. <https://doi.org/10.3354/esr00419>
- Lucena, F. M., Vaske, T., Ellis, J. R., & O'Brien, C. M. (2000). Seasonal variation in the diets of bluefish, *Pomatomus saltatrix* (Pomatomidae) and striped weakfish, *Cynoscion guatucupa* (Sciaenidae) in southern Brazil: Implications of food partitioning. *Environmental Biology of Fishes*, 57, 423–434. <https://doi.org/10.1023/A:1007604424423>
- Mäder, A., Sander, M., & Casa, G. Jr. (2010). Ciclo sazonal de mortalidade do pinguim-de-magalhães, *Spheniscus magellanicus* influenciado por fatores antrópicos e climáticos na costa do Rio Grande do Sul, Brasil. *Revista Brasileira de Ornitologia*, 18, 228–233.
- Madureira, L. S. P., & Rossi-Wongtschowski, C. L. D. B. (2005). *Prospecção de recursos pesqueiros pelágicos na Zona Econômica Exclusiva da Região Sudeste-Sul do Brasil: Hidroacústica e biomassas*. Série documentos REVIZEE-Score Sul. Instituto Oceanográfico, Universidade do São Paulo, São Paulo.
- Majluf, P., Babcock, E. A., Riveros, J. C., Schreiber, M. A., & Alderete, W. (2002). Catch and bycatch of sea birds and marine mammals in the small-scale fishery of Punta San Juan, Peru. *Conservation Biology*, 16, 1333–1343. <https://doi.org/10.1046/j.1523-1739.2002.00564.x>
- Manly, B. F. (2006). *Randomization, bootstrap and Monte Carlo methods in biology* (2nd ed.). Boca Raton, FL: CRC Press.
- Marques, F. P., Cardoso, L. G., Haimovici, M., & Bugoni, L. (2018). Trophic ecology of Magellanic penguins (*Spheniscus magellanicus*) during the non-breeding period. *Estuarine, Coastal and Shelf Science*, 210, 109–122. <https://doi.org/10.1016/j.ecss.2018.06.001>
- Martin, G. R., & Crawford, R. (2015). Reducing bycatch in gillnets: A sensory ecology perspective. *Global Ecology and Conservation*, 3, 28–50. <https://doi.org/10.1016/j.gecco.2014.11.004>
- Monteiro, D. S., Estima, S. C., Gandra, T. B. R., Silva, A. P., Bugoni, L., Swimmer, Y., ... Secchi, E. R. (2016). Long-term spatial and temporal patterns of sea turtle strandings in southern Brazil. *Marine Biology*, 163, 247. <https://doi.org/10.1007/s00227-016-3018-4>
- Nunes, G. T., Leal, G. R., Barreto, J. S., Mäder, A., Freitas, T. R. O., Lopes, D. D., & Fernández, G. P. (2015). Razão sexual assimétrica entre carcaças de *Spheniscus magellanicus* na costa norte do Rio Grande do Sul. *Ornitologia*, 2, 75–77.
- Orgeret, F., Weimerskirch, H., & Bost, C. A. (2016). Early diving behaviour in juvenile penguins: Improvement or selection processes. *Biology Letters*, 12, 20160490. <https://doi.org/10.1098/rsbl.2016.0490>
- Petry, M. V., Fonseca, V. S. S., & Jost, A. H. (2004). Registro de pinguins-de-Magalhães (*Spheniscus magellanicus*) mortos no Rio Grande do Sul. *Acta Biologica Leopoldensia*, 26, 139–144.
- Pichegru, L., & Parsons, N. J. (2014). Female-biased mortality in African penguins. *African Journal of Marine Science*, 36, 279–282. <https://doi.org/10.2989/1814232X.2014.920728>
- Pio, V. M., Pezzuto, P. R., & Wahrlich, R. (2016). Only two fisheries? Characteristics of the industrial bottom gillnet fisheries in southeastern and southern Brazil and their implications for management. *Latin American Journal of Aquatic Research*, 44, 882–897. <https://doi.org/10.3856/vol44-issue5-fulltext-2>
- Pott, C., & Wiedenfeld, D. A. (2017). Information gaps limit our understanding of seabird bycatch in global fisheries. *Biological Conservation*, 210, 192–204. <https://doi.org/10.1016/j.biocon.2017.04.002>
- Prado, J. H., Mattos, P. H., Silva, K. G., & Secchi, E. R. (2016). Long-term seasonal and interannual patterns of marine mammal strandings in subtropical Western South Atlantic. *PLoS ONE*, 11, e0146339. <https://doi.org/10.1371/journal.pone.0146339>
- Prado, J. H. F., Secchi, E. R., & Kinas, P. G. (2013). Mark-recapture of the endangered Franciscana dolphin (*Pontoporia blainvillei*) killed in gillnet fisheries to estimate past bycatch from time series of stranded carcasses in southern Brazil. *Ecological Indicators*, 32, 35–41. <https://doi.org/10.1016/j.ecolind.2013.03.005>
- Proctor, N. S., & Lynch, P. J. (1993). *Manual of ornithology: Avian structure and function*. New Haven, CT: Yale University Press.

- Pütz, K., Ingham, R. J., & Smith, J. G. (2000). Satellite tracking of the winter migration of Magellanic penguins *Spheniscus magellanicus* breeding in the Falkland Islands. *Ibis*, *142*, 614–622. <https://doi.org/10.1111/j.1474-919x.2000.tb04461.x>
- Pütz, K., Schiavini, A., Raya-Rey, A., & Lüthi, B. H. (2007). Winter migration of Magellanic penguins (*Spheniscus magellanicus*) from the southern-most distributional range. *Marine Biology*, *152*, 1227–1235. <https://doi.org/10.1007/s00227-007-0770-5>
- R Core Team. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. <https://www.R-project.org/> [15 November 2016].
- Raya-Rey, A., Pütz, K., Scioscia, G., Lüthi, B., & Schiavini, A. (2012). Sexual differences in the foraging behaviour of Magellanic penguins related to stage of breeding. *Emu*, *112*, 90–96. <https://doi.org/10.1071/MU11065>
- Reis, E. C., Aires, R. M., Moura, J. F., Matias, C. A. R., Tavares, M., Ott, P. H., ... Lôbo-Hajdu, G. (2011). Molecular sexing of unusually large numbers of *Spheniscus magellanicus* (Spheniscidae) washed ashore along the Brazilian coast in 2008. *Genetics and Molecular Research*, *10*, 3731–3737. <https://doi.org/10.4238/2011.December.5.7>
- Schiavini, A., Yorio, P., Gandini, P., Rey, A. R., & Boersma, P. D. (2005). Los pingüinos de las costas Argentinas: Estado poblacional y conservación. *Hornero*, *20*, 5–23.
- Secchi, E. R. (2010). Review on the threats and conservation status of Franciscana, *Pontoporia blainvillei* (Cetacea, Pontoporiidae). In J. M. Shostell, & M. Ruiz-Garcia (Eds.), *Biology, evolution and conservation of river dolphins within South America and Asia* (pp. 323–339). Hauppauge: Nova Science Publishers Inc.
- Secchi, E. R., Kinas, P. G., & Muelbert, M. (2004). Incidental catches of Franciscana in coastal gillnet fisheries in the Franciscana Management Area III: Period 1999–2000. *The Latin American Journal of Aquatic Mammals*, *3*, 61–68. <https://doi.org/10.5597/lajam00049>
- Secchi, E. R., Zerbini, A. N., Bassoi, M., Dalla Rosa, L., Moller, L. M., & Rocha-Campos, C. C. (1997). Mortality of franciscanas, *Pontoporia blainvillei*, in coastal gillnetting in southern Brazil: 1994–1995. *Reports of the International Whaling Commission*, *47*, 653–658.
- Seddon, P. J., & van Heezik, Y. (1991). Effects of hatching order, sibling asymmetries, and nest site on survival analysis of Jackass penguin chicks. *Auk*, *108*, 548–555. <https://doi.org/10.2307/4088094>
- Shaffer, S. A., Weimerskirch, H., & Costa, D. P. (2001). Functional significance of sexual dimorphism in wandering albatrosses, *Diomedea exulans*. *Functional Ecology*, *15*, 203–210. <https://doi.org/10.1046/j.1365-2435.2001.00514.x>
- Silva, L. A., Siles, L., Cardona, L., Tavares, M., Crespo, E., & Gandini, P. (2015). Diferencias estacionales en la dieta de individuos juveniles del Pingüino Patagónico (*Spheniscus magellanicus*) reveladas en base al análisis de isótopos estables en uñas. *Hornero*, *30*, 45–54.
- Simeone, A., Bernal, M., & Meza, J. (1999). Incidental mortality of Humboldt penguins *Spheniscus humboldti* in gill nets, central Chile. *Marine Ornithology*, *27*, 157–161.
- Stokes, D. L., Boersma, P. D., Casenave, J. L., & García-Borboroglu, P. (2014). Conservation of migratory Magellanic penguins requires marine zoning. *Biological Conservation*, *170*, 151–161. <https://doi.org/10.1016/j.biocon.2013.12.024>
- Stokes, D. L., Boersma, P. D., & Davis, L. (1998). Satellite tracking of Magellanic penguin migration. *Condor*, *100*, 376–381. <https://doi.org/10.2307/1370280>
- Suazo, C. G., Cabezas, L. A., Moreno, C. A., Arata, J. A., Luna-Jorquera, G., Simeone, A., ... Robertson, G. (2014). Seabird bycatch in Chile: A synthesis about its impacts and local strategies to reduce a global phenomenon. *Pacific Seabirds*, *41*, 1–12.
- Tasker, M. L., Camphuysen, C. J., Cooper, J., Garthe, S., Montevecchi, W. A., & Blaber, S. J. (2000). The impacts of fishing on marine birds. *ICES Journal of Marine Science*, *57*, 531–547. <https://doi.org/10.1006/jmsc.2000.0714>
- Vanstreels, R. E. T., Adornes, A. C., Canabarro, P. L., Ruoppolo, V., Amaku, M., Silva-Filho, R. P., & Catão-Dias, J. L. (2013). Female-biased mortality of Magellanic penguins (*Spheniscus magellanicus*) on the wintering grounds. *Emu*, *113*, 128–134. <https://doi.org/10.1071/MU12060>
- Vanstreels, R. E. T., Adornes, A. C., Ruoppolo, V., Canabarro, P. L., Silva-Filho, R. P., & Catão-Dias, J. L. (2011). Gender determination from morphometrics in migrating Magellanic penguins *Spheniscus magellanicus*. *Marine Ornithology*, *39*, 215–220.
- Vasconcellos, M., Haimovici, M., & Ramos, K. (2014). Pesca de emalhe demersal no sul do Brasil: Evolução, conflitos e (des)ordenamento. In M. Haimovici, J. M. Andriquetto-Filho, & P. S. Sunye (Eds.), *A pesca marinha e estuarina no Brasil estudos de casos multidisciplinares* (pp. 29–40). Rio Grande, RS: Editora da FURG.
- Vooren, C. M., & Klippel, S. (Eds.) (2005). *Ações para a conservação de tubarões e raias no sul do Brasil*. Porto Alegre, RS: Igaré.
- Walker, B. G., & Boersma, P. D. (2003). Diving behavior of Magellanic penguins (*Spheniscus magellanicus*) at Punta Tombo, Argentina. *Canadian Journal of Zoology*, *81*, 1471–1483. <https://doi.org/10.1139/z03-142>
- Williams, T. D., & Boersma, P. D. (1995). Magellanic penguin. In T. D. Williams (Ed.), *Bird families of the world, the penguins* (pp. 249–258). Oxford: Oxford University Press.
- Yamamoto, T., Yoda, K., Blanco, G. S., & Quintana, F. (2019). Female-biased stranding in Magellanic penguins. *Current Biology*, *29*, PR12–R13. <https://doi.org/10.1016/j.cub.2018.11.023>
- Yorio, P., González-Zevallos, D., Gatto, A., Biagioni, O., & Castillo, J. (2017). Relevance of forage fish in the diet of Magellanic penguins breeding in northern Patagonia, Argentina. *Marine Biology Research*, *13*, 603–617. <https://doi.org/10.1080/17451000.2016.1273529>
- Zar, J. H. (1999). *Biostatistical analysis* (5th ed.). New Jersey, NJ: Prentice-Hall.
- Žydelis, R., Small, C., & French, G. (2013). The incidental catch of seabirds in gillnet fisheries: A global review. *Biological Conservation*, *162*, 76–88. <https://doi.org/10.1016/j.biocon.2013.04.002>

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