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Spatial use of multiple jurisdictions by Magellanic penguins and assessment of potential conflicts in the face of changing trawl fisheries scenarios

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ABSTRACT: Seabirds often have wide distribution ranges and may travel relatively long distances to breeding grounds, often crossing jurisdictional boundaries. When engaged in foraging behaviour, seabirds are prone to interact with different fisheries and suffer incidental mortality. We assessed the spatial use of foraging Magellanic penguins *Spheniscus magellanicus* breeding at 3 colonies within the Patagonia Austral Marine Park (San Jorge Gulf, Argentina) in relation to different jurisdictions. We also quantified their spatial overlap with 3 trawl fisheries and bycatch (incidental mortality), an interaction previously reported in the region. Breeding Magellanic penguins mainly used waters under provincial jurisdiction within the gulf, with some use of federal waters depending on the breeding season and colony location. Spatial use by breeding penguins resulted in a variable but relatively low overlap with the operations of the 3 fishing fleets in 2014–2016 (1.1–26.3%). Changes in the spatial distribution of fishing operations in recent years resulted in a lower overlap than in 2005–2007 (12.1–60.8%). Incidental mortality during 2008–2014 was also variable and relatively low (0.0–0.363 birds per haul). Breeding Magellanic penguins foraged outside protected area boundaries where they can spatially overlap with and face potential threats from different fishing fleets that operate in waters of provincial and/or federal jurisdiction. Despite the current low spatial overlap, the relatively fast changes in fishing patterns in the recent past draw attention to the need for continuous monitoring. Data obtained in this study may prove valuable in case the implementation of spatial and temporal closures of fishing operations is needed.

KEY WORDS: Magellanic penguin · *Spheniscus magellanicus* · Trawl fisheries · Multiple jurisdictions · Spatial conflicts · Incidental mortality · Argentina

1. INTRODUCTION

Commercial fisheries are one of the main threats faced by seabirds at sea (Croxall et al. 2012, Dias et al. 2019). Seabird foraging distributions often overlap with fishing operations in areas of high productivity, which may result in positive or negative effects on their populations (Montevecchi 2002). Among negative effects, spatial overlap may lead to competition for common resources (Crawford 2007, Pichegru et al. 2009, Bertrand et al. 2012) or to incidental mortality in fishing gear (bycatch) as a result of individual attraction to fishing vessels to take advantage of discards (Watkins et al. 2008, Favero et al. 2011). While

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breeding, most seabirds are wide ranging and travel relatively large distances to foraging grounds, and even coastal species may cross state, federal or international jurisdictional boundaries during a foraging trip (Yorio 2009, Jodice & Suryan 2010). In their regular foraging movements, seabirds are also prone to interact with different fisheries, which may in turn be under different administrative authorities (Copello & Quintana 2009). Knowledge of spatial use by seabirds in areas subject to fisheries, particularly when moving across different jurisdictions, is of great value to predict conflicts and inform management decisions.

The Magellanic penguin *Spheniscus magellanicus* breeds along the Atlantic and Pacific coasts of South America (Boersma et al. 2013). It is the most abundant breeding seabird in Argentine Patagonia (Yorio et al. 1999) and one of the main ecotourism attractions, generating important revenues at local and regional scales (Yorio et al. 2001a). The Magellanic penguin is internationally categorized as Least Concern (BirdLife International 2020), but is one of the most vulnerable penguin species to commercial fisheries (Trathan et al. 2015, Crawford et al. 2017). One of the main coastal sectors for breeding Magellanic penguins throughout their breeding range is the San Jorge Gulf, in central Patagonia, Argentina (Yorio et al. 1998, Boersma et al. 2013). The northern sector of this gulf includes a marine protected area, the Patagonia Austral Marine Park, where over 100 000 Magellanic penguin breeding pairs nest at 17 colonies during the austral spring and summer (Yorio et al. 1998, P. García Borboroglu pers. comm.). The waters of San Jorge Gulf and adjacent areas are subject to important commercial trawl fisheries targeting Argentine red shrimp *Pleoticus muelleri* and Argentine hake *Merluccius hubbsi* (Góngora et al. 2012). However, the relative importance of fishing grounds and fishing effort directed at these 2 target species has varied during the last 2 decades as a result of changes in resource availability and management regulations in the different jurisdictions (Navarro et al. 2014, Subsecretaría de Pesca de Chubut pers. comm.).

A previous study at San Jorge Gulf showed a clear overlap between Magellanic penguins foraging during the early chick-rearing stage and trawlers operating in waters under provincial jurisdiction outside the boundaries of the marine protected area (Yorio et al. 2010). However, results were derived from a single colony, during only 1 stage of the breeding cycle and with a relatively low sample size. A proper understanding of Magellanic penguin–fishery interactions would require information from different colonies encompassing the coastal area used by fishing fleets and the assessment of seasonal changes in the spatial pattern of foraging penguins. Several seabird studies have shown the use of mutually exclusive foraging areas by individuals breeding in neighbouring colonies (Wanless & Harris 1993, Masello et al. 2010, Wakefield et al. 2013), and thus threats posed by fisheries may differ between colonies spatially associated with the same fishing ground if fishing effort varies spatially. In addition, spatial requirements by seabirds may change throughout the reproductive cycle (Huin 2002, Suárez et al. 2012, Poupart et al. 2017), and Magellanic penguins have been reported foraging farther away from the colony during the incubation and late chick-rearing stages than when provisioning small chicks (Boersma & Rebstock 2009). Therefore, Magellanic penguins breeding at San Jorge Gulf may forage farther during earlier and later stages of the breeding cycle, which could result in their crossing of provincial and federal jurisdictional boundaries, leading to more complex management scenarios than previously assumed. As in other seabird–fisheries spatial interactions, the observed overlap with commercial trawlers during Magellanic penguin foraging trips at San Jorge Gulf and nearby areas results in incidental mortality in fishing nets (Gandini et al. 1999, González-Zevallos & Yorio 2006, González-Zevallos et al. 2011, Marinao et al. 2014), highlighting the need for further assessments and monitoring. Our goals were to (1) assess the spatial use in relation to different jurisdictions by foraging Magellanic penguins breeding at 3 colonies within San Jorge Gulf across breeding stages and across years, (2) quantify the spatial overlap with trawl fisheries, considering spatial and temporal variation in Magellanic penguin foraging patterns and fishing operations, (3) explore the consequences of the observed spatial overlap in terms of incidental mortality, based on new and published information, and (4) discuss the complexities for predicting potential conflicts between Magellanic penguin populations and fishing operations in the context of changing fisheries scenarios.

2. MATERIALS AND METHODS

2.1. Study area and species

The San Jorge Gulf extends from Cabo Dos Bahías (44° 55′ S, 65° 32′ W) to Cabo Tres Puntas (47° 06′ S, 65° 52′ W), and includes an area of more than 32 000 km^2 under the provincial jurisdiction of Chubut and Santa Cruz to the north and south of 46° S, respectively (Fig. 1). Waters outside the gulf are

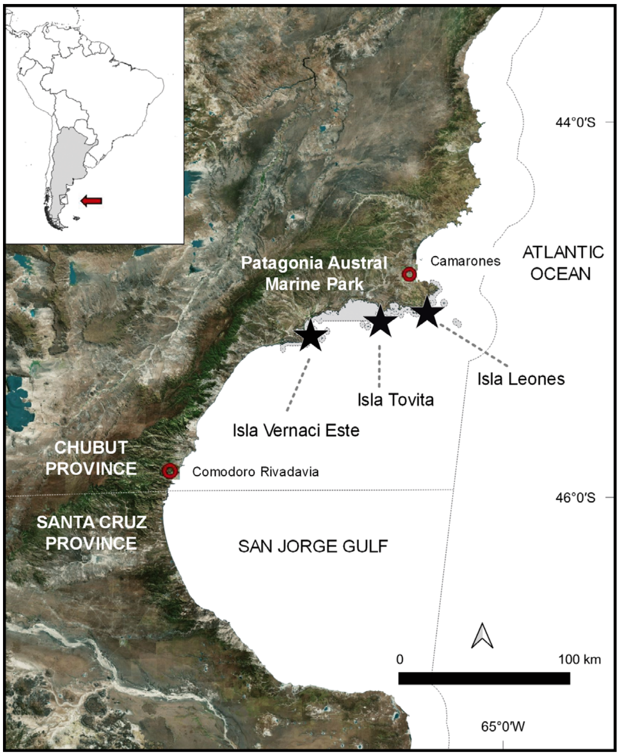

Fig. 1. Location of San Jorge Gulf, Argentina, and the 3 Magellanic penguin colonies at Isla Vernaci Este, Isla Tovita and Isla Leones. Jurisdiction limits for the study area are shown by dotted lines. Waters within the gulf north and south of 46° S are under the jurisdiction of Chubut and Santa Cruz Provinces, respectively. Waters east of the provincial limit are under the jurisdiction of the Federal Government. The grey area corresponds to the Patagonia Austral Marine Park

under federal jurisdiction. Within the gulf, Magellanic penguins breed at 17 colonies of between 30 and 36 000 nests totalling over 100 970 breeding pairs (Schiavini et al. 2005, P. García Borboroglu pers. comm.). All nesting sites are included within the inter-jurisdictional Patagonia Austral Marine Park, a 750 km^2 protected area extending 1 nautical mile (1.85 km) offshore from the high tide mark under the joint administration of the Government of the Province of Chubut and the National Parks Administration of Argentina (Fig. 1). These colonies are distributed in 3 island groups located in the northeast, central and southwest sectors of the Marine Park. Islands and islets in each group are separated by less than 10 km.

Provincial waters within San Jorge Gulf and adjacent federal waters were subject during the study period to 3 types of commercial trawlers: freezer trawlers, high-sea ice trawlers and coastal trawlers (Góngora et al. 2012). In addition to trawl vessels, 3 crabber vessels capture southern king crab *Lithodes santolla* using pots, which pose no threat for Magellanic penguins (M. E. Gongora pers. obs.). No commercial fisheries using longlines or gillnets operate in the study area (Consejo Federal Pesquero 2010). A total of 70–90 freezer trawlers, depending on the year, targeted Argentine red shrimp and operated in waters under the provincial jurisdiction of San Jorge Gulf and/or in federal waters both east and north of the gulf. A fishing moratorium for this fishery was established in 2003, covering in most fishing seasons the months of December, January and the first half of February. Between 5 and 15 high-sea ice trawlers, depending on the year, targeted Argentine hake and Argentine red shrimp within San Jorge Gulf. A growing number of high-sea ice trawlers also targeted shrimp in federal waters (e.g. 7 in 2010 and 49 in 2017). Finally, between 5 and 15 small coastal trawlers also fished Argentine hake, Argentine red shrimp and to a lesser extent other species in waters within San Jorge Gulf. An additional coastal fishery consisting of about 40 coastal and 35 artisanal vessels targeting Argentine shrimp and Argentine hake operated from the port of Rawson, Chubut (43° 18′ S, 65° 06′ W), in waters north of San Jorge Gulf. Total number of hauls d^{-1} per vessel was generally 5–8 in the 3 fisheries (On-board Observer Program of Chubut Province unpubl. data).

The study was conducted at 3 Magellanic penguin island colonies representing the 3 groups of colonies distributed along the Marine Park: Isla Vernaci Este (45° 10′ S, 66° 29′ W), located near the mouth of Caleta Malaspina and consisting of 1330 pairs; Isla Tovita (45° 06′ S, 65° 57′ W), with 9930 pairs; and Isla Leones (45° 03′ S, 65° 36′ W), with 23 430 pairs (Pozzi et al. 2015, P. García Borboroglu pers. comm.; Fig. 1). Isla Vernaci Este and Isla Leones are separated by 70 km, and Isla Tovita is located in between, about 43 and 27 km from the former 2 islands, respectively (Fig. 1). Within each of the Isla Vernaci Este, Isla Tovita and Isla Leones groups of islands and islets, colonies are separated by less than 6, 3 and 10 km, respectively. The total number of nests in the Isla Vernaci Este, Isla Tovita and Isla Leones groups of colonies was estimated at 25 200, 46 370 and 29 400, representing 25.0, 45.9 and 29.1 %, respectively, of the overall population breeding within the gulf. In the study area, Magellanic penguins arrive to their colonies in September, start laying in mid-October, eggs start hatching in mid-November, chicks start fledging in late January, and all individuals leave between March and April (Yorio et al. 2001b, P. Yorio unpubl. data).

2.2. Magellanic penguin foraging patterns

Foraging patterns of breeding Magellanic penguins were assessed using CatLog-S GPS loggers (15–18 g, L × W × H: 70 × 40 × 20 mm, Catnip Technologies), sealed using a rubber shrink tube. A total of 156 breeding adults were equipped during the incubation (October, November and early December), early chick-rearing (mid-December) and late chick-rearing (mid-January) stages between 2014 and 2017 (see Table 1 for sample sizes in each breeding stage and colony). A similar number of male and female penguins were captured at their nest in each combination of colony, breeding stage and year, initially sexed by visual inspection of their morphometry in the field and later sexed based on length (culmen) and bill depth measured with digital callipers to the nearest 0.1 mm (Bertellotti et al. 2002). GPS loggers were attached to the feathers of the lower back with TESA® tape and were programmed to collect locations every 1 min, with accuracy within 5–10 m range. GPS logger weight represented less than 0.5% of Magellanic penguin mean adult body mass (males: 4.6 kg; females: 3.8 kg; Boersma et al. 2013). To explore the distribution in the water column of feeding Magellanic penguins, a subset of birds were simultaneously fitted with G5 temperature–depth recorders (TDRs; 3 g, CEFAS Technology), which recorded depth at 1 s intervals to <1 m, during the early chick-rearing stage at Isla Vernaci Este in 2016 (n = 12) and 2017 (n = 6). Nests were marked and devices retrieved after between 5 and 21 d to download information. Capture and recapture procedures were completed in less than 10 min, and the study birds were returned to their nests. Every effort was taken to minimize the stress caused to the birds during manipulation.

GPS logger positions were assigned to a foraging trip when they were beyond 500 m from the colony centroid. All trips made by each of the equipped penguins (see Table 1 for sample sizes) were used to characterize spatial use and overlap with fisheries, considering records from both complete and incomplete trips (those which included the trajectory of the individual since the departure to the return at the colony and those incomplete due to battery exhaustion at some point in the trajectory, respectively). Total trip length (total cumulative lineal distance between consecutive GPS fixes along the track; in km), trip duration (time elapsed between the first and last fix; in min) and maximum distance from the colony (maximum straight-line distance between the equipped penguin and the colony centroid, in km) are reported for complete trips only.

The 50, 75 and 95% density contour utilization areas were derived from fixed (bivariate normal) kernel analysis (Wood et al. 2000) on resampled trajectories each 60 s using R, Version 3.6.0 (R Core Team 2019) and the packages 'adehabitatLT' and 'adehabitatHR' (Calenge 2006). After a prospective first passage time analysis (Lascelles et al. 2016), a common smoothing factor (*h*) of 2.5 km was selected for all colonies, years and stages over a grid with cell size of 1.5 km. Complete and incomplete tracks were included in this analysis. The spatial overlap between years in the foraging areas of Magellanic penguins breeding at Isla Vernaci Este and between the foraging areas of penguins breeding at the 3 colonies in 2017 was quantified as the percentage of shared area in relation to the total area used by penguins in the 2 compared years or colonies. In all cases, the areas corresponded to those enclosed by the 95% utilization distribution (UD) contour.

Additional information obtained in a previous study during the early chick-rearing stage of 2006 and 2007 at Isla Vernaci Este (see Yorio et al. 2010) was re-analysed following methods described above to assess the spatial overlap between foraging penguins and fishing vessels (see Section 2.3).

Table 1. Number of breeding Magellanic penguins equipped at San Jorge Gulf, Argentina, and GPS recovered with data during the 2014–2017 breeding seasons. Numbers of foraging trips are shown in parentheses (both complete and incomplete, see Section 2.2). (–): no data available

Colony	Year	Incubation		Early chick rearing		Late chick rearing	
		Equipped	Recovered	Equipped	Recovered	Equipped	Recovered
Isla Vernaci Este	2014	0	–	20	15 (40)	20	13 (45)
	2015	20	8 (17)	18	7 (20)	0	–
	2016	22	9 (12)	25	22 (34)	0	–
	2017	0	–	19	18 (38)	0	–
Isla Tovita	2017	0	–	18	13 (22)	0	–
Isla Leones	2017	0	–	14	13 (21)	0	–

Dives were analysed using Multi Trace Dive Analysis (Jensen Software Systems), with a threshold of 1.5 m (Sala et al. 2012). Diving effort (total vertical travel distance [VTD], defined as the sum of depth of all dives multiplied by 2 to obtain distance, sensu Horning & Trillmich 1997) as well as diving rates (i.e. the number of dives per hour spent at sea), average dive depth and duration, were calculated to estimate the birds' overall foraging effort. Means are reported ± 1 SD.

The effects of breeding stage (early and late chick stage) and year (2014–2017) on trip length and maximum distance reached from the colony by instrumented penguins breeding at Isla Vernaci Este were evaluated using linear mixed-effect models (LMMs) in the package 'nlme' (Pinheiro et al. 2019) in R, version 3.6.0 (R Core Team 2019). The effect of colony (Isla Vernaci Este, Isla Tovita and Isla Leones) on the same foraging parameters during the early stage of chicks in 2017 was also evaluated using LMMs in the package 'lnme'. Unfortunately, the necessary information was not available to perform a single model. In the 3 models performed for both trip length and maximum distance, the breeding stage, the year or the colony were specifically used as a fixed factor, sex was included as a fixed explanatory variable, and individual was included as a random factor to prevent pseudoreplication. In parallel, the effect of year was tested on diving effort and diving rate, using general linear models, and on dive depths and durations with LMMs with the individual as a random factor due to repeated data for individuals. When necessary, models were corrected using a uniform composite symmetry correlation structure (CorCompSyM), specifying the variance weighting function 'varIdent'. Model selection procedures were based on information theory (Burnham & Anderson 2002). Models with all possible combinations of predictor variables were considered, and best-fitting models were selected using Akaike's information criterion (AIC).

2.3. Spatial overlap between breeding penguins and trawlers

Information on the distribution of all fishing vessels operating between 42° 30′ S and 47° 06′ S and from the coast to 63° W was obtained from the Argentinean Vessel Monitoring System (VMS, Secretaría de Agricultura, Ganadería y Pesca of Argentina) for the 2005–2007 and 2014–2016 breeding seasons (Martinez Puljak et al. 2018). Information included vessels operating from October to April, as these months cover most of the Magellanic penguin breeding season (see Section 2.1). The VMS provides the GPS position of each vessel every 60 min. Vessel positions were filtered by speed, considering that trawlers were fishing when moving at 2–5 knots (Martinez Puljak et al. 2018). Positions obtained only during daylight were used, as fishing takes place only during the day. Utilization areas for each fishing fleet were estimated using these positions by the fixed kernel method. Common to all years and fleets, a conservative smoothing factor of 2.5 km and a grid with cell size of 1.5 km were used. This resulted in smaller UD areas than those produced by a kernel with ad hoc selected h. The measure of overlap between foraging Magellanic penguins and fishing fleets in the periods 2005–2007 and 2014–2016 was based on the areas enclosed by the 95% UD kernel contours. This is because Magellanic penguins are often attracted to trawl vessels to take advantage of discards while travelling through fishing grounds (González-Zevallos & Yorio 2006), and therefore potential interactions with vessels may arise during the whole trip and not only in foraging areas. For all cases, the overlap was quantified as the area shared over the total area of distribution.

2.4. Magellanic penguin incidental mortality

Information on the number of Magellanic penguins killed in nets was gathered on board freezer and high-sea ice trawlers for 15 133 hauls (14 637 and 496 hauls, respectively) from January 2008 to December 2014. Information was obtained from the database of the On-board Observer Program of Chubut Province. No information was available for coastal trawlers. Bird mortality was expressed as average rates per haul.

3. RESULTS

3.1. Magellanic penguin foraging patterns

A total of 17 devices were recovered during the incubation stage (2015: n = 8; 2016: n = 9), mostly in October and November, and half of the 29 recorded trips were incomplete due to battery failure precluding an adequate analysis of foraging parameters and at-sea distribution. However, the information obtained indicates that during the incubation period of both years, Magellanic penguins travelled either south of the colony within San Jorge Gulf, reaching coastal waters of the Santa Cruz Province, or north outside the gulf into federal waters (Fig. 2). In 2015, the maximum distance from the colony recorded

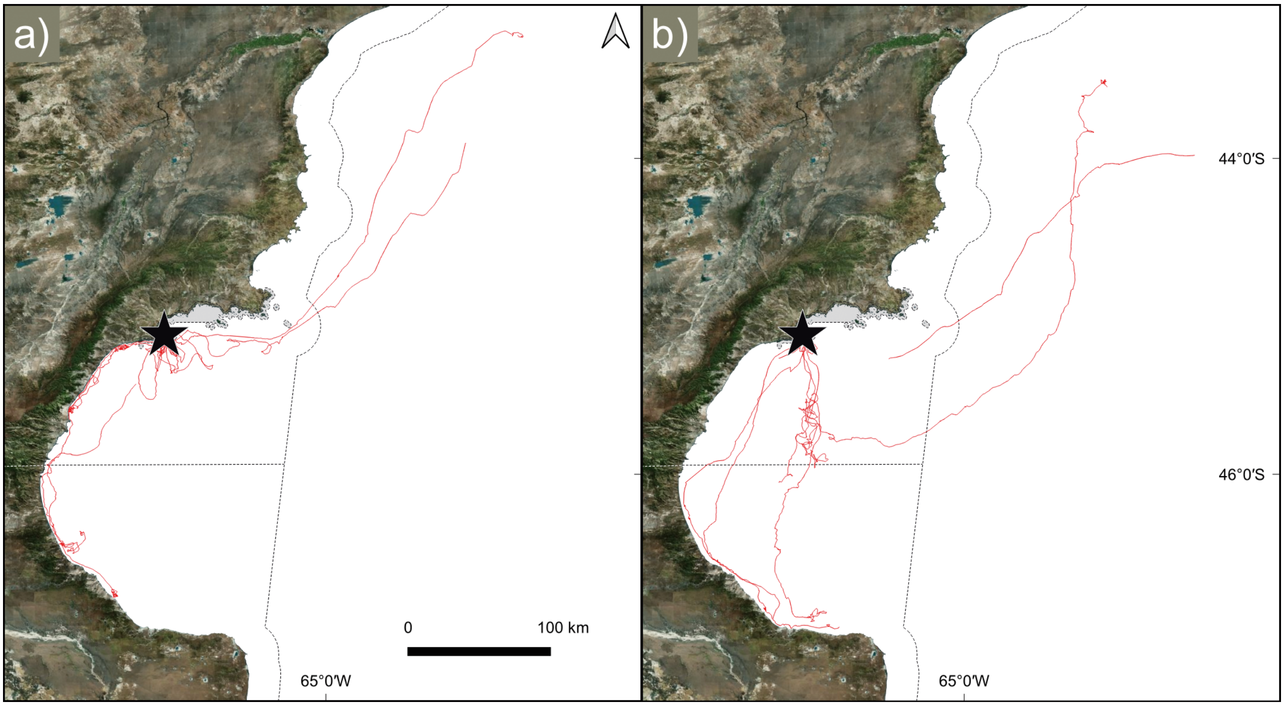

Fig. 2. Foraging tracks (red lines) of incubating Magellanic penguins equipped with GPS at Isla Vernaci Este (black star) in (a) 2015 and (b) 2016 (see Section 3.1 for details). Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

before batteries failed was 208.4 km for trips within the San Jorge Gulf and 329.3 km for trips in federal waters. Trips in federal waters extended between 110 and 140 km offshore in 2015 and between 110 and 180 km offshore in 2016 (Fig. 2). Trips performed by 3 individuals during the late incubation stage in early December 2015 were short (<46 km), ranging over the Chubut jurisdiction waters and close to the Patagonia Austral Marine Park.

During the early chick stage, Magellanic penguins breeding at Isla Vernaci Este, Isla Tovita and Isla Leones used areas located mostly south of their respective colonies, almost exclusively in provincial waters under the jurisdiction of Chubut within San Jorge Gulf (Figs. 3 & 4). Only 1 individual from Isla Vernaci Este in 2015 and 3 individuals from Isla Leones in 2017 travelled offshore reaching federal waters. Magellanic penguins breeding at Isla Vernaci Este tracked over 4 consecutive years used similar areas over time, overlapping 77, 72 and 65% of their area in 2015, 2016 and 2017, respectively, compared to 2014 (Fig. 3). By contrast, individuals tracked simultaneously from the 3 study colonies in 2017 used mutually exclusive areas (Fig. 4). Magellanic penguins breeding in Isla Vernaci Este and Isla Leones showed no overlap, while individuals from Isla Vernaci Este and Isla Tovita showed an overlap of only 1.0%, and individuals from Isla Tovita and Isla Leones an overlap of 18.0%. Magellanic penguin foraging range and trip length varied between individuals, colonies and years, with a maximum distance from the colony of 75.6 km and a maximum trip length of 202.0 km, and trip duration varied between 3 and 60 h (Table 2). Dive information was recovered from only 11 birds from Vernaci Este in 2016 and from 5 birds in 2017. These birds performed a total of 8676 dives in 14 trips in 2016 and 5747 dives in 8 trips in 2017. Most dives (~50–60%) were <10 m, but a small second peak of frequency appeared in the 50 to 60 m depth bins (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/m658p219_supp.pdf). Diving effort (VTD) was higher in 2016 (21.7 ± 12.7 km) compared to 2017 (16.8 ± 7.5 km, $t = -16.61$, $p < 0.001$), as were diving depths (22.5 ± 24.6 m in 2016 and 16.1 ± 19.6 m in 2017), although not significantly so ($t = -0.484$, $p = 0.636$). Diving rates and durations remained similar ($t = 0.147$, $p = 0.885$; $t = 0.400$, $p = 0.695$, respectively) (Table 2).

During the late chick stage, Magellanic penguin foraging areas were located exclusively south of the colony within San Jorge Gulf, mostly in waters of the Chubut province with only 2 individuals performing extended trips into waters of the Santa Cruz province (Fig. 5). Foraging range and trip length varied be-

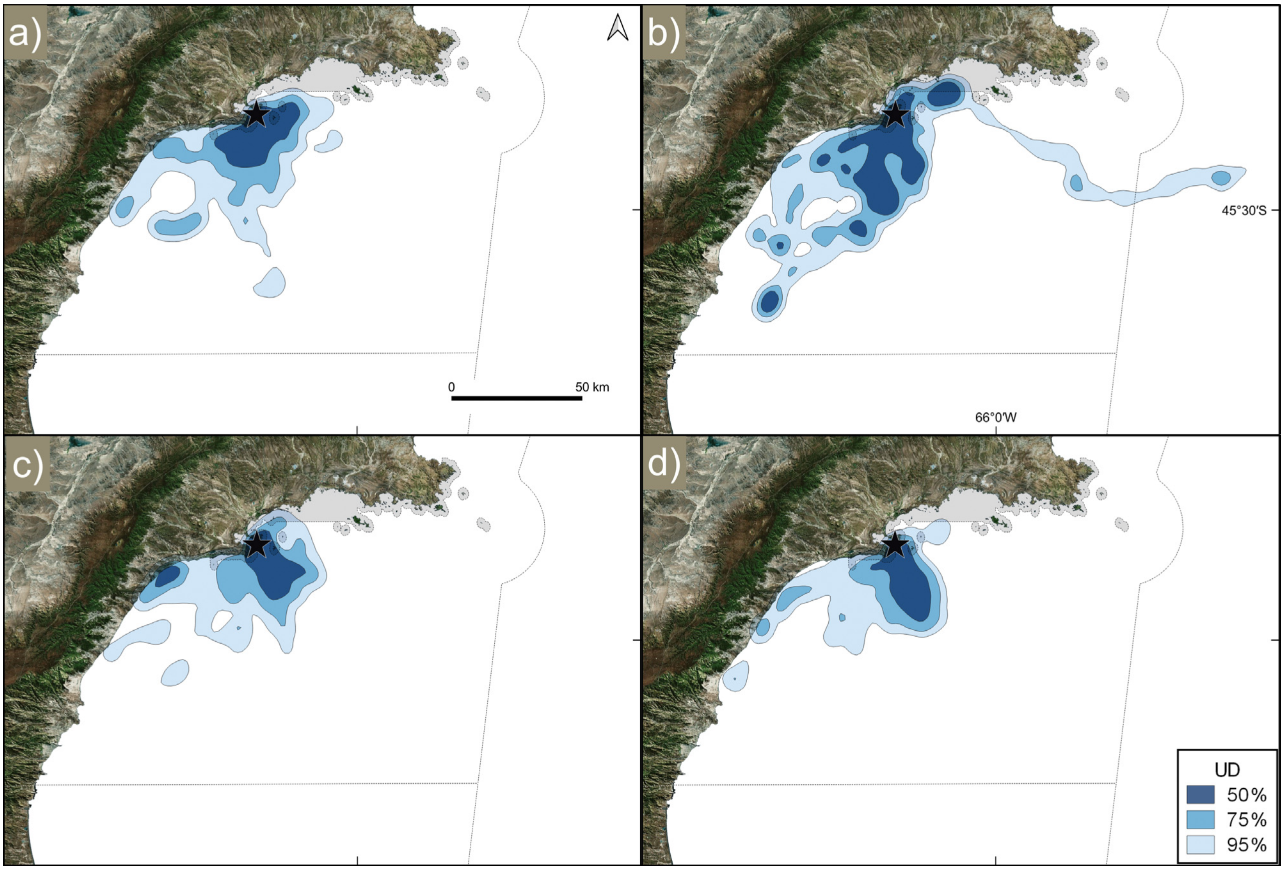

Fig. 3. At-sea distribution of Magellanic penguins equipped with GPS at Isla Vernaci Este during the early chick-rearing stage. Areas are shown as the 50, 75 and 95% kernel utilization distributions (UDs). (a) 2014, (b) 2015, (c) 2016, (d) 2017. Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

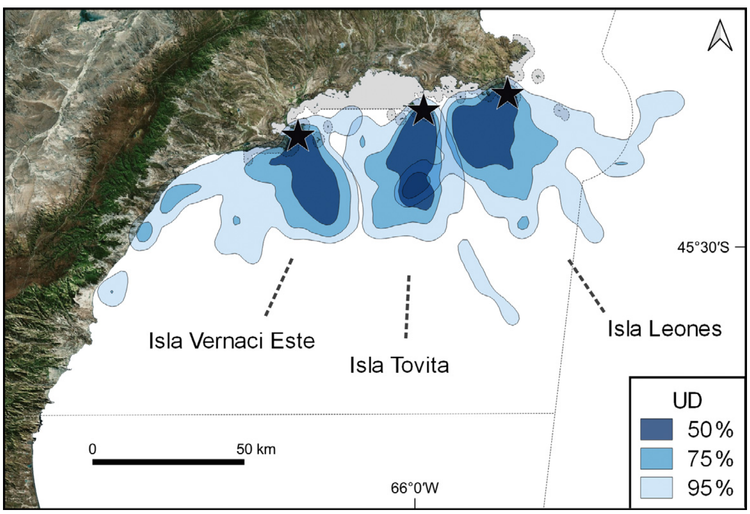

Fig. 4. At-sea distribution of Magellanic penguins equipped with GPS at Isla Vernaci Este, Isla Tovita and Isla Leones during the early chick-rearing stage of 2017. Areas are shown as the 50, 75 and 95% kernel utilization distributions (UDs). Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

tween individuals, with a maximum of 126.2 and 313.3 km, respectively (Table 2).

At Isla Vernaci Este during 2014, the best models describing the variation in maximum distance (MD) and trip length (TL) included the effect of the chick stage as the only explanatory variable (Table 3). Model parameters indicated that maximum distances and trip lengths were significantly shorter during the late chick stage (MD: LMMs, $\beta = -14.9$, $z = 16.0$, df = 1, $p < 0.0001$; TL: LMMs, $\beta = -41.8$, $z = 9.5$, df = 1, $p < 0.0001$) (Table 3). When comparing among years, the maximum foraging distances and trip lengths during the early chick stage at Isla Vernaci Este, the models with the best fit included the effect of the year (Table 3). In this case, model parameters indicated that maximum distances were shorter in 2016 and 2017 (LMMs, 2016: $\beta = -15.0$, $z = 8.3$, df = 1, p <

Table 2. Foraging patterns of Magellanic penguins breeding at San Jorge Gulf, Argentina, during the 2014–2017 breeding seasons (mean ± SD with range in parentheses). VE: Isla Vernaci Este; TO: Isla Tovita; LE: Isla Leones; n: number of trips. (–): no data available

Site, year (n)	Max distance from colony (km)	Trip length (km)	Trip duration (h)	Vertical travel distance (km)	Dive depth (m)	Dive rate (dives h^{-1})
Early chick rearing						
VE, 2014 (20)	34.3 ± 15.7 (12.4–68.5)	96.0 ± 39.7 (29.8–168.1)	–[a]	–	–	–
VE, 2015 (11)	30.2 ± 21.2 (3.4–71.2)	86.3 ± 60.4 (7.7–202.0)	26.1 ± 18.4 (2.6–59.3)	–	–	–
VE, 2016 (27)	28.0 ± 13.9 (7.9–71.5)	76.3 ± 33.1 (17.5–163.9)	21.4 ± 8.0 (4.9–38.1)	21.7 ± 12.7 (6.4–62.0)	22.5 ± 24.6 (1.5–92.6)	21.4 ± 6.7 (13.1–38.3)
VE, 2017 (31)	26.8 ± 11.2 (9.2–62.1)	74.1 ± 27.0 (32.8–157.6)	19.2 ± 6.5 (8.0–33.9)	16.8 ± 7.5 (5.6–33.7)	16.1 ± 19.6 (1.5–83.5)	21.9 ± 9.7 (9.6–39.6)
TO, 2017 (12)	34.3 ± 17.0 (8.7–75.6)	82.8 ± 36.5 (20.7–164.9)	20.0 ± 7.8 (4.6–28.5)	–	–	–
LE, 2017 (14)	33.5 ± 12.2 (22.3–55.9)	98.7 ± 30.5 (62.2–161.5)	24.2 ± 6.2 (16.8–37.0)	–	–	–
Late chick rearing						
VE, 2014 (30)	26.0 ± 34.8 (1.4–126.2)	65.5 ± 83.4 (2.9–313.4)	–[a]	–	–	–

[a]Data lost due to database corruption

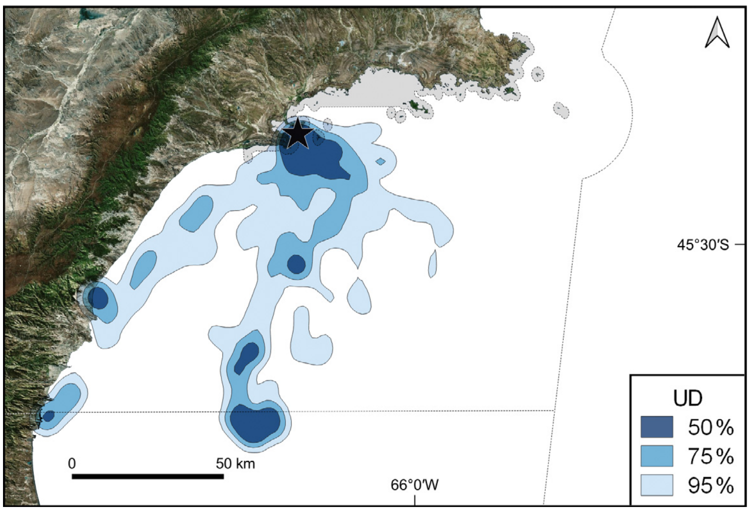

Fig. 5. At-sea distribution of Magellanic penguins equipped with GPS at Isla Vernaci Este during the late chick-rearing stage in 2014. Areas are shown as the 50, 75 and 95% kernel utilization distributions (UDs). Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

0.0001; 2017: β = −9.7, z = 5.6, df = 1, p < 0.0001), and trip lengths were shorter only in 2016 (LMMs: β = −28.9, z = 2.5, df = 1, p < 0.05) (Table 3). Finally, regarding the comparison among colonies during the early chick stage of 2017, the best fit models included the effect of colony, and model parameters indicated that maximum distances (LMMs, β = −8.0, z = 2.1, df = 1, p < 0.05) and trip lengths (LMMs, β = −27.7, z = 3.1, df = 1, p < 0.0001) were shorter at Isla Vernaci Este (Table 3).

3.2. Spatial overlap between breeding penguins and trawlers

During the 2005–2007 Magellanic penguin breeding seasons, freezer trawlers operated exclusively in waters under provincial jurisdiction within the San Jorge Gulf and throughout the 7 mo of the penguin breeding season, from October to April (Figs. S2a–S8a). This fishing pattern contrasted sharply with the pattern observed in 2014–2016, when no fishing activity by freezer trawlers was recorded in waters of San Jorge Gulf until March and April (Figs. S2d–S8d), also due to a fishing moratorium spanning December to mid-February. During October and November, they operated exclusively in federal waters east and north of the gulf (Figs. S2d & S3d).

During 2005–2007, high-sea ice trawlers operated exclusively within San Jorge Gulf, in provincial waters of both Chubut and Santa Cruz in October and November, but concentrating fishing effort in the

Table 3. Linear mixed-effects models explaining the variation in the maximum distance from the colony and trip lengths of foraging Magellanic penguins at (a) Isla Vernaci Este during the 2014 early and late chick stages, (b) Isla Vernaci Este during the early chick stage in 2014–2017 and (c) Isla Vernaci Este, Isla Tovita and Isla Leones during the early chick stage in 2017. AICc: Akaike's information criterion corrected for small sample size; ΔAIC: difference in AIC values compared to best model

Maximum distance					Trip length				
Explanatory variables	df	AIC_C	ΔAIC	w_i	Explanatory variables	df	AIC_C	ΔAIC	w_i
(a)									
Stage	18	401.0	0.0	0.83	Stage	18	514.4	0.0	0.89
Stage + Sex	19	404.2	3.2	0.17	Stage + Sex	19	518.5	4.2	0.11
Null	17	442.5	41.46	<0.001	Null	17	538.4	24.0	<0.001
(b)									
Year	43	781.2	0.0	0.84	Year	43	946.7	0.0	0.71
Null	40	784.8	3.7	0.13	Year + Sex	44	948.5	1.77	0.29
Year + Sex	44	788.5	7.3	0.02	Null	40	965.3	18.63	<0.001
(c)									
Colony	5	454.1	0.0	0.60	Colony	5	551.3	0.0	0.64
Null	3	456.1	1.9	0.22	Colony + Sex	6	552.8	1.5	0.30
Colony + Sex	6	456.5	2.4	0.18	Null	3	556.2	4.9	0.05

northern sector near the Patagonia Austral Marine Park in December and January (Figs. S2b–S5b). During 2014–2016, high-sea ice trawlers operated mostly in federal waters east and north of San Jorge Gulf during October and November, while they operated within and outside the gulf in December and January (Figs. S2e–S5e). When fishing within San Jorge Gulf, vessels operated in the northern sector in waters adjacent to the Patagonia Austral Marine Park, mainly east and south-west of Isla Vernaci Este.

In both study periods, coastal trawlers operated almost exclusively close to shore in provincial waters from October to April, except in October–November in 2014–2016, when they also used federal waters (Figs. S2c,f–S8c,f). Within San Jorge Gulf, coastal trawlers always operated in waters of the Chubut jurisdiction and in waters adjacent to the Patagonia Austral Marine Park in all months except October 2005–2007 and January–April 2014–2016 (Figs. S2c,f–S8c,f). In 2005–2007, coastal trawlers also used waters in the Santa Cruz jurisdiction.

Spatial overlap between foraging Magellanic penguins and fishing operations during 2014–2017 varied depending on the fishing fleet, breeding stage, year and colony, but was always less than 26.3% (Table 4; Figs. 6–8). No overlap was observed between freezer trawlers and Magellanic penguins during the chick-rearing period, as these vessels operated exclusively outside the San Jorge Gulf (see above). During both the early and late chick stages, most penguins travelled offshore, reaching areas beyond trawl fishing grounds (Figs. 6–8). Overlap with high-sea ice trawlers was higher than with coastal trawlers (Table 4). During 2017, overlap between Magellanic penguins and fishing operations differed among the 3 study colonies, with no overlap for penguins breeding at Isla Leones and a higher overlap at Isla Tovita than Isla Vernaci Este (Table 4). Overlap between foraging Magellanic penguins and trawl fisheries during early chick stages of 2006 and 2007 was close to 50% for freezer trawlers, 60% for high-sea ice trawlers and 12% for coastal trawlers (Table 4; Fig. S9).

Table 4. Percent of foraging areas of Magellanic penguins raising chicks at San Jorge Gulf, Argentina, which overlap with trawl fisheries during (a) 2014–2017 and (b) 2006–2007. Foraging and fishing areas are those represented by the 95% kernel utilization distributions (see Section 2.3 and Figs. 6–8). VE: Isla Vernaci Este; TO: Isla Tovita; LE: Isla Leones. (–): no data available

Colony, year	Freezer trawlers	High-sea ice trawlers	Coastal trawlers
(a)			
Early chick stage			
VE, 2014	–	16.5	13.9
VE, 2015	–	7.9	9.1
VE, 2016	–	18.1	17.5
VE, 2017	–	12.4	9.6
TO, 2017	–	26.3	18.1
LE, 2017	–	0.0	0.0
Late chick stage	–		
VE, 2014	–	22.9	1.1
(b)			
Early chick stage			
VE, 2006	48.4	59.6	12.3
VE, 2007	45.7	60.8	12.1

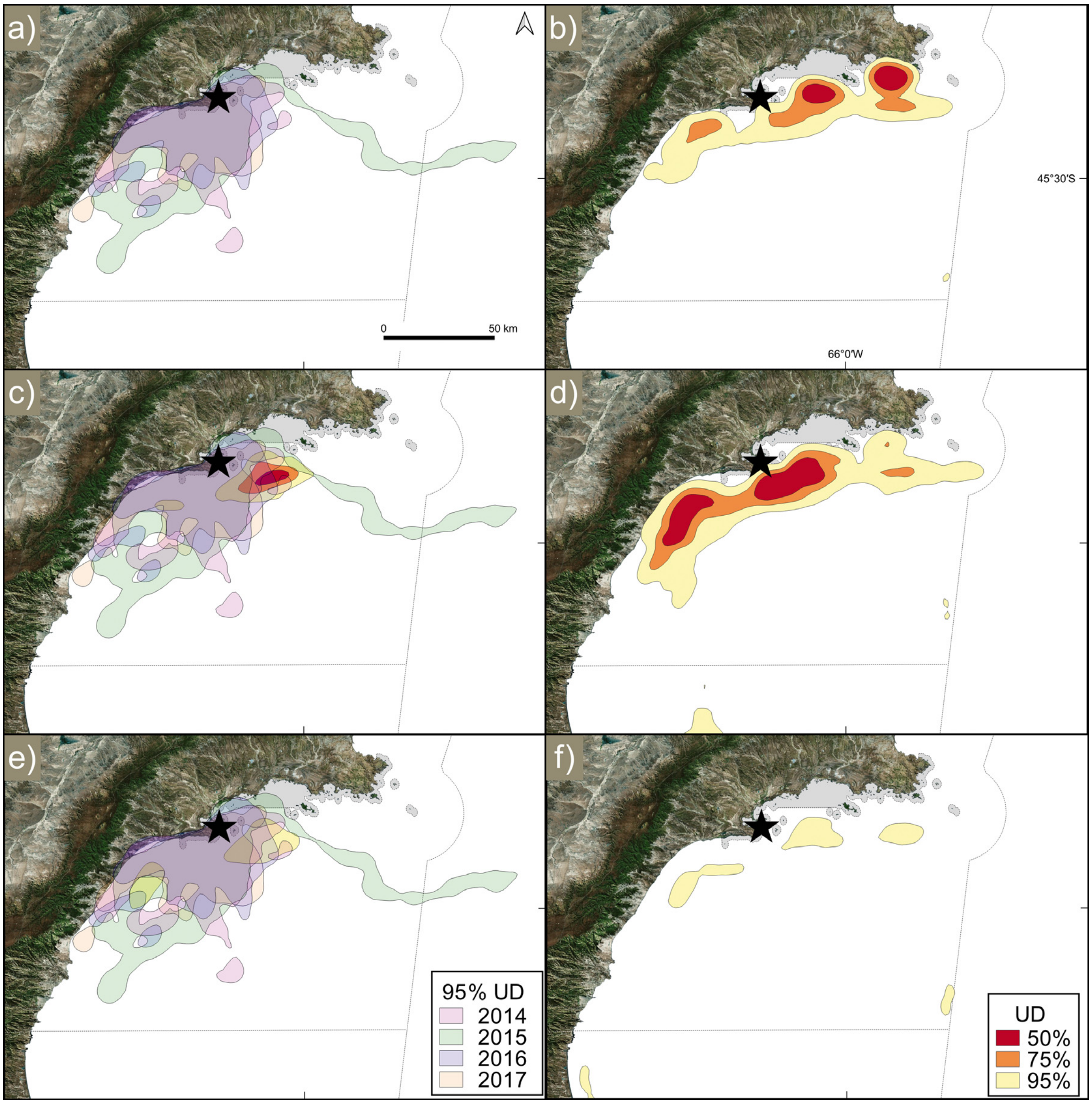

Fig. 6. At-sea distribution of foraging Magellanic penguins equipped with GPS at Isla Vernaci Este during the early chick stage of 2014–2017 (years represented by different colours) and spatial distribution of fishing effort for the period 2014–2016 (3 years pooled) made by (a) freezer trawlers, (c) high-sea ice trawlers and (e) coastal trawlers operating in the study area during December. Black star: breeding colony. Panels (b), (d) and (f) show the distribution of the fishing effort for the period 2005–2007 (3 years pooled) made by freezer, high-sea ice and coastal trawlers, respectively. Magellanic penguin foraging areas shown as the 95% kernel utilization distributions (UDs; see Section 2.2) and fishing areas as 50, 75 and 95% kernel UDs. Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

3.3. Magellanic penguin incidental mortality caused by freezer and high-sea ice trawlers

A total of 159 Magellanic penguins were incidentally killed in trawl nets during the 7 study years (2008–2014), with rates that varied between months and years (Table 5). Mortality rate ranged between 0.0 and 0.363 birds per haul in the high-sea ice trawlers and between 0.0 and 0.055 birds per haul in freezer trawlers (Table 5). In addition, during 2008, 3 penguins were caught alive and released in the high-sea ice trawl fishery and 1 in the freezer trawl fishery, although their condition and fate after being released are unknown. Incidental captures occurred only within San Jorge Gulf and only in the late Magellanic penguin breeding season, from January to April (Table 5). Seabird incidental captures occurred close to shore, at a mean distance of 6.3 ± 5.6 km

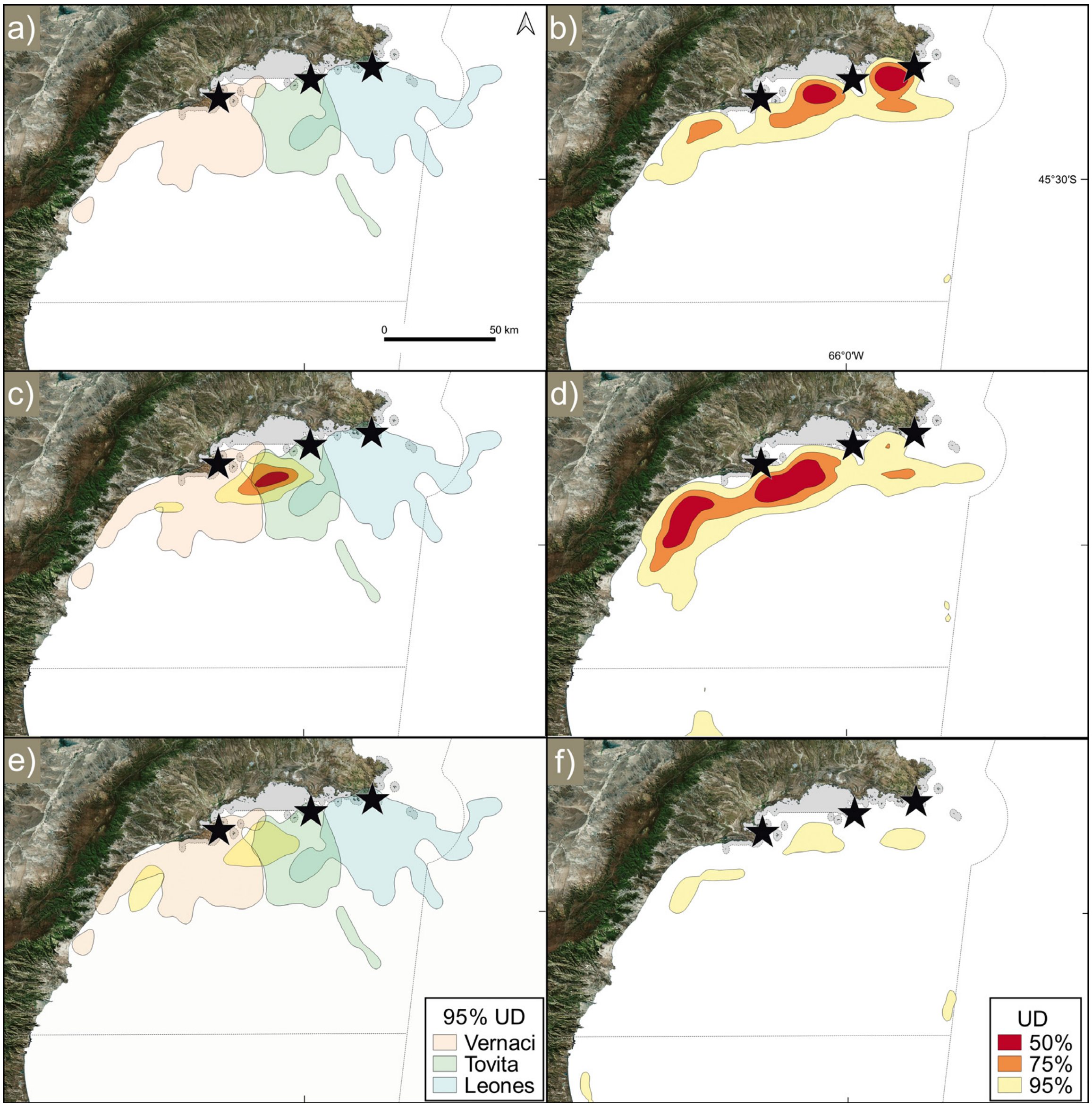

Fig. 7. At-sea distribution of foraging Magellanic penguins equipped with GPS at Isla Vernaci Este, Isla Tovita and Isla Leones during the early chick stage of 2017 and spatial distribution of fishing effort for the period 2014–2016 (3 years pooled) made by (a) freezer trawlers, (c) high-sea ice trawlers and (e) coastal trawlers operating in the study area during December. Black stars: breeding colonies. Panels (b), (d) and (f) show the distribution of the fishing effort for the period 2005–2007 (3 years pooled) made by freezer, high-sea ice and coastal trawlers, respectively. Magellanic penguin foraging areas shown as the 95% kernel utilization distributions (UDs; see Section 2.2) and fishing areas as 50, 75 and 95% kernel UDs. Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

(range: 0.8–35.5) for freezer trawlers and 12.7 ± 13.2 km (range: 3.5–64.3) for high-sea ice trawlers.

4. DISCUSSION

Our results show that Magellanic penguins breeding in San Jorge Gulf mainly used waters under provincial jurisdiction within the gulf, with some use of federal waters depending on the breeding season and colony location. The spatial overlap of breeding penguins with trawl fishing between 2014 and 2016 varied but was relatively low. Overlap was lower than previously reported as a result of recent spatial changes in fishing operations, which mainly operated in recent years in federal waters north of San Jorge Gulf (see below). Incidental mortality was also variable and relatively low, in part reflecting the ob-

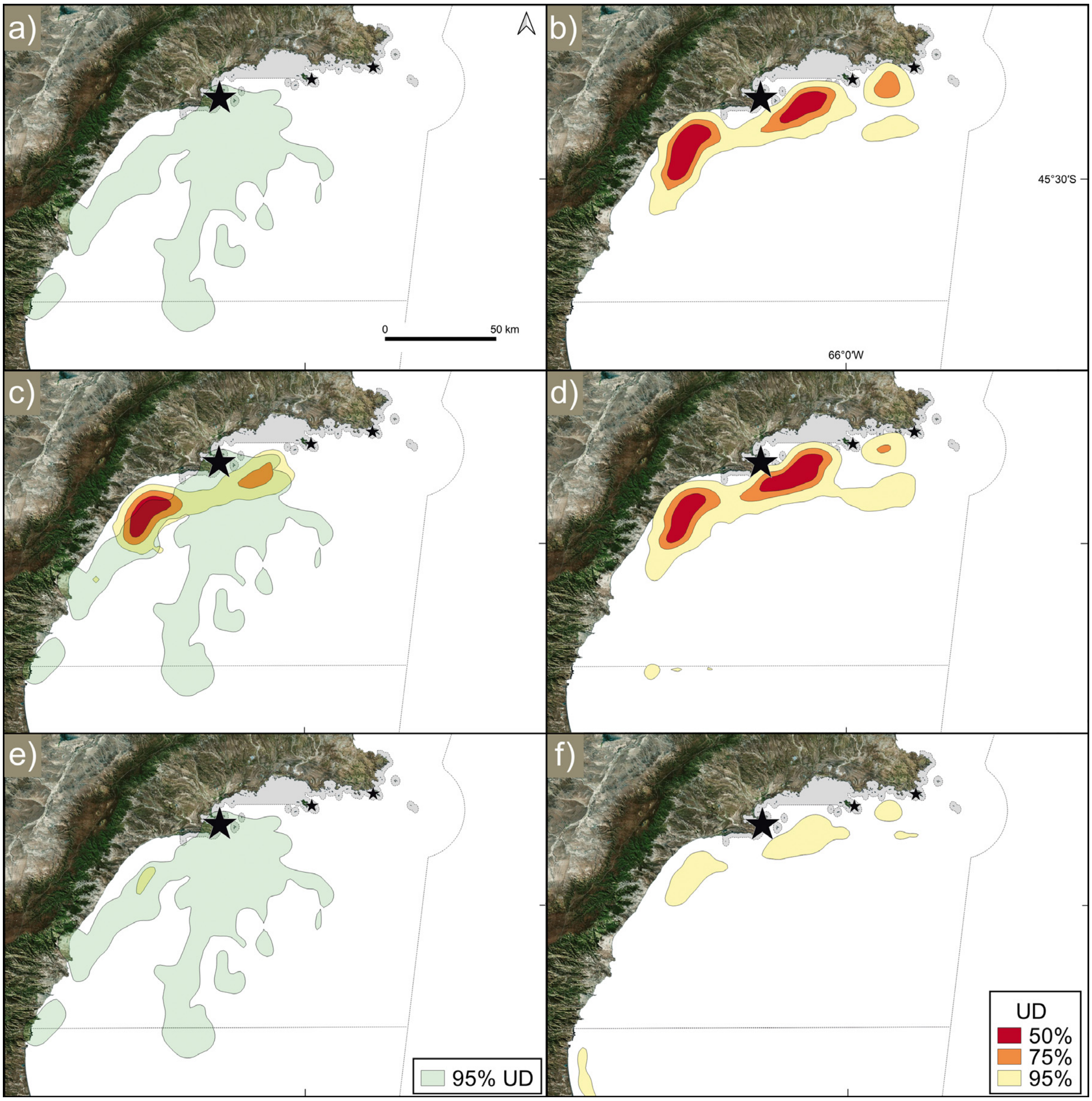

Fig. 8. At-sea distribution of foraging Magellanic penguins equipped with GPS at Isla Vernaci Este during the late chick stage of 2014 and spatial distribution of fishing effort for the period 2014–2016 (3 years pooled) made by (a) freezer trawlers, (c) high-sea ice trawlers and (e) coastal trawlers operating in the study area during January. Black star: breeding colony. Panels (b), (d) and (f) show the distribution of the fishing effort for the period 2005–2007 (3 years pooled) made by freezer, high-sea ice and coastal trawlers, respectively. Magellanic penguin foraging areas shown as the 95 % kernel utilization distributions (UDs; see Section 2.2) and fishing areas as 50, 75 and 95 % kernel UDs. Jurisdiction limits for the study area are shown by dotted lines (see Fig. 1)

served weak spatial interaction. Information on foraging patterns of Magellanic penguins breeding in the Patagonia Austral Marine Park in San Jorge Gulf, one of their main breeding grounds in coastal Argentina (Yorio et al. 1998), was only available for the early chick-rearing stage at the Isla Vernaci Este colony (Yorio et al. 2010, Sala et al. 2012). Based on 4 additional years, this study confirms the relevance of northern San Jorge Gulf for penguins raising small chicks at that colony. In addition, this study provides the first information on the use of the marine environment during the incubation and late chick stages by penguins breeding at Isla Vernaci Este, and during the early chick stage by breeders at 2 other colonies located in different sectors of the Marine Park. This information obtained at locations representing the 3 groups of colonies distributed along the Marine Park allows a better understanding of Magel-

Table 5. Number of Magellanic penguins killed, and mortality rate (in parentheses), in freezer and high-sea ice trawlers operating in the study area between 2008 and 2014. n: number of hauls; M: moratorium; (–): no data available. Data source: On-board Observer Program of Chubut Province, Argentina

Year	Trawler type	January	February	March	April	October	November	December
2008	Freezer	M	1 (0.010) n = 99	28 (0.040) n = 690	0 n = 429	0 n = 803	0 n = 343	0 n = 28
	High-sea ice	8 (0.363) n = 22	9 (0.090) n = 75	0 n = 41	0 n = 126	–	0 n = 5	0 n = 26
2009	Freezer	10 (0.011) n = 90	23 (0.032) n = 709	51 (0.042) n = 1195	2 (0.004) n = 452	0 n = 732	0 n = 312	2 (0.032) n = 247
	High-sea ice	–	–	0 n = 29	–	–	–	–
2010	Freezer	3 (0.055) n = 54	0 n = 90	2 (0.003) n = 664	1 (0.001) n = 1334	0 n = 311	0 n = 706	0 n = 194
	High-sea ice	0 n = 43	–	–	0 n = 15	–	–	–
2011	Freezer	M	M	6 (0.004) n = 1395	2 (0.003) n = 568	0 n = 386	0 n = 6	M
	High-sea ice	3 (0.068) n = 44	1 (0.036) n = 28	–	0 n = 9	–	–	–
2012	Freezer	M	M	0 n = 77	0 n = 515	–	0 n = 445	M
	High-sea ice	–	–	–	0 n = 15	–	–	–
2013	Freezer	M	M	2 (0.004) n = 440	3 (0.008) n = 368	–	–	M
	High-sea ice	–	–	–	0 n = 12	–	–	–
2014	Freezer	M	M	2 (0.003) n = 573	0 n = 368	0 n = 4	0 n = 10	M
	High-sea ice	–	–	–	0 n = 6	–	–	–

lanic penguin spatial needs and potential interactions with human activities, including interactions with fisheries when foraging beyond the boundaries of the marine protected area.

During the early chick stage (December), Magellanic penguins made relatively short trips, travelling almost exclusively in the northern sector of San Jorge Gulf within waters under the jurisdiction of Chubut Province and making only a few foraging trips to federal waters. Other studies reported larger mean foraging ranges of penguins raising small chicks (e.g. 47.8 km at the Isla Vernaci Este colony, Sala et al. 2012; or 61.0 to 169.0 km at other breeding locations in the Chubut Province, Boersma & Rebstock 2009, Gómez-Laich et al. 2015). But the relatively high overlap among areas used by Magellanic penguins from Isla Vernaci Este in 2014–2017 and in 2006–2007 (Sala et al. 2012) likely reflects the predictability of food resources relatively close to the breeding site. Even though foraging areas remained similar, diving strategies differed between 2016 and 2017, with birds diving at the same rate but shallower in 2017, which translated in shorter VTDs. This result confirms the foraging flexibility of Magellanic penguins previously demonstrated (e.g. Wilson et al. 2005, Sala et al. 2012).

Even though foraging ranges of Magellanic penguins breeding at Isla Leones and Isla Tovita were significantly longer than at Isla Vernaci Este, individuals of all colonies mostly foraged in Chubut waters. Interestingly, individuals from the 3 breeding sites used mostly mutually exclusive foraging areas, despite the potential for overlaps. Inter-colony segregation of foraging areas is a widespread phenomenon in seabirds, being the result of high intraspecific inter-colony competition for prey (see review by Bolton et al. 2019). Further studies are needed to determine the role of food availability in the observed inter-colony segregation of foraging areas in order to adequately understand the spatial relationship among colonies in San Jorge Gulf.

Several studies have shown that spatial requirements may change throughout the reproductive cycle of seabirds (Huin 2002, Suárez et al. 2012, Poupart et al. 2017), and Magellanic penguins are known to travel farther away from their colony during the late chick period than when chicks are small (Boersma & Rebstock 2009). In this study, however, foraging ranges during the late chick stage (January) at Isla Vernaci Este were significantly shorter than reported in other studies, despite a few birds that reached waters under the Santa Cruz jurisdiction in a few extended trips. These results highlight again the productivity and/or predictability of the foraging area for these birds. Foraging ranges of the few complete trips obtained during the incubation period (mostly October and November) were similar to those reported for other colonies in Patagonia (Wilson et al. 2005, Boersma et al. 2009) and considerably longer than those corresponding to other breeding stages. During incubation, the off-duty partner can spend over 2 wk at sea (Yorio & Boersma 1994), and thus several of our GPS devices stopped recording data due to battery failure before the birds returned to the colony. This and the low recovery rate of devices unfortunately resulted in a sample size too small to adequately assess the spatial use of the marine environment by incubating Magellanic penguins from the San Jorge Gulf. Nevertheless, the available information clearly showed that they can leave the gulf and travel north to federal waters. These birds may have been searching for food in the predictable and productive Peninsula Valdés tidal front (Acha et al. 2004), an area also used by Magellanic penguins breeding at Punta Tombo and Punta Lobería (Wilson et al. 2005, Boersma & Rebstock 2009). Some individuals also foraged within the San Jorge Gulf, particularly close to shore, sometimes reaching the southern sector in waters under the jurisdiction of the Santa Cruz Province. These trips to coastal areas may have been also associated with frontal areas located in southern San Jorge Gulf (Glembocki et al. 2015).

Understanding the patterns of overlap between seabirds and fisheries is particularly relevant during the birds' breeding season, when their movement patterns are constrained by central-place foraging. During the breeding season, the degree of overlap will be largely influenced not only by the species' foraging range, but also the distance from the colony to fishing grounds and the spatial extent of fishing operations. Our results showed a considerable change in the spatial distribution of fishing operations in recent years, particularly by the freezer trawl fishery. The distribution of the Argentine red shrimp has expanded north up to 41° S since 2014, which has resulted in the relocation of the fishing activity (de la Garza et al. 2017 and references therein). Freezer trawlers which fished mainly within San Jorge Gulf since the opening of the fishery in 1980 have been operating mainly in federal waters north of the gulf in the last few years. In addition, given the high market value of the Argentine red shrimp, most high-sea ice trawlers traditionally targeting Argentine hake in San Jorge Gulf switched to fishing shrimp mostly in federal waters. As a result, fishing effort declined in northern San Jorge Gulf, with no fishing activity by freezer trawlers and the operation of only 2–3 high-sea ice trawlers throughout the Magellanic penguin breeding season (Figs. S2–S8). This has resulted in a substantial change in penguin-fishery spatial interaction between 2005–2007 and 2014–2016.

A clear overlap was apparent between fisheries and Magellanic penguins raising small chicks in 2006–2007 (Yorio et al. 2010). The re-analysis of the same data indicates that the spatial overlap during the early chick stage of those years was close to 50% for freezer trawlers, 60% for high-sea ice trawlers and 12% for coastal trawlers. In contrast, our results for 2014–2016 show that due to the above-mentioned factors the overlap with fishing vessels during the early chick stage was relatively low (<20% for both high-sea ice and coastal trawlers and no overlap with freezer trawlers). This overlap remained low during the late chick stage. Spatial interactions with fisheries during the penguins' incubation period seem more complex in relation to jurisdictions and fishing fleets, as the activity of the 3 fleets in that period was concentrated mainly in federal waters north of the gulf while some activity by high-sea ice and coastal trawlers took place in its northern sector. Additional information during the early stages of the Magellanic penguins' breeding cycle, as well as from other colonies located along the Chubut coast north of San Jorge Gulf (Yorio et al. 1998) would be needed to adequately assess the differential exposure of penguins following the current observed spatial changes in fishing activity.

Indeed, the degree of overlap between penguins and fisheries differed among colonies in this study, with a slightly larger overlap and no overlap with vessels in the cases of Isla Tovita and Isla Leones, respectively, and thus a differential vulnerability to the potential impact of fishing activity among penguins breeding along the Marine Park. Similar differential vulnerability, though with a higher spatial overlap, should have occurred previous to the observed changes in fishing spatial patterns, and may occur again in the event the San Jorge Gulf is reopened to fishing activity (see below). Information on seabird foraging segregation is of applied relevance for marine planning and conservation (Bolton et al. 2019), and data obtained in this study may prove valuable in case the implementation of spatial and temporal closures of fishing operations is needed.

In this study, incidental capture of Magellanic penguins in freezer and high-sea ice trawlers operating in the study area was relatively low as a result of the relatively small spatial interaction. It varied from 0.001 to 0.363 birds per trawl depending on the month, year and fishing fleet. Previous estimates of Magellanic penguin incidental capture in nets in northern San Jorge Gulf were higher, ranging between 0.09 and 1.31 birds per haul in high-sea ice trawlers targeting hake (González-Zevallos & Yorio 2006, González-Zevallos et al. 2007) and between 0.005 and 0.17 birds per haul in freezer trawlers targeting shrimp (González-Zevallos et al. 2011). Estimates for coastal shrimp trawlers operating in the Isla Escondida fishing ground, in waters off central Chubut, ranged between 0.003 and 2.07 birds per haul (Marinao et al. 2014). Incidental mortality peaked between January and March during the chick-rearing stage, as observed in previous studies in northern San Jorge Gulf and Isla Escondida (González-Zevallos et al. 2011, Marinao et al. 2014). Incidental mortality occurred exclusively within San Jorge Gulf, as fishing operations from January until the end of the penguin breeding season during the study years were restricted to gulf waters. These events occurred mostly close to the shore, as reported for freezer trawlers in a previous study (González-Zevallos et al. 2011). This spatial pattern of incidental mortality may be reflecting both the higher fishing activity closer to the shore and the higher concentration of penguins near colonies as a result of central-place foraging. Our results suggest that there are greater risks of penguin mortality from trawlers close to shore and within the later part of the breeding season, and thus spatial and temporal closures may be a valuable tool to minimize the impact of fisheries on Magellanic penguin breeding populations. Regardless of the variability in recorded Magellanic penguin dive depths, most were shallower than trawl depths, which are normally over 40 m (Ruibal Nuñez 2020), suggesting a low vertical overlap if penguins were foraging during trawling activity. However, as Magellanic penguins usually get entangled when diving to take prey directly from the net during haulback, thus increasing their chances of becoming captured when near the surface (González-Zevallos & Yorio 2006, C. Marinao pers. obs.), it is likely that the incidental capture by high-sea ice and freezer trawlers is independent of diving depths.

Mortality rates were in general relatively low and may suggest a low impact at the population level given the large number of breeding birds in the study area (Schiavini et al. 2005, Pozzi et al. 2015). It should be noted, however, that there are some data limitations that possibly resulted in an underestimation of mortality rates. First, information on high-sea ice trawlers for most assessed periods is either lacking or incomplete due to partial coverage by the provincial On-board Observer Program. Previous studies have shown that Magellanic penguin mortality can be higher with high-sea ice trawlers than freezer trawlers in northern San Jorge Gulf (González-Zevallos & Yorio 2006, González-Zevallos et al. 2011). Second, coverage by the provincial On-board Observer Program was inadequate for October and November in the last years of the analysed period, when these fishing fleets operated almost exclusively in federal waters where some breeders from San Jorge Gulf and breeders from northern colonies regularly forage (see above). Therefore, coordination for the future quantification of incidental mortality and data management by the provincial and federal observer programmes is urgently needed to understand the true impact of commercial fishing on Magellanic penguins along the Chubut coast. In addition, an adequate assessment of the impact at the metapopulation level should consider not only the cumulative effects of all fisheries and fishing grounds during the breeding season but also along the winter distributional range. Incidental mortality of Magellanic penguins in their wintering grounds has been reported from waters in coastal Buenos Aires Province (Tamini et al. 2002, Seco Pon et al. 2013, Paz et al. 2018), Uruguay (Domingo et al. 2007) and Brazil (Cardoso et al. 2011, Fogliarini et al. 2019).

In summary, results indicate that Magellanic penguins breeding in the Patagonia Austral Marine Park forage outside protected area boundaries and can spatially overlap with and face potential threats from 3 different fishing fleets that operate in waters under provincial and/or federal jurisdiction. The intensity of this threat may vary between months and years, based on resource availability. This indicates the need for complementary management and conservation strategies to adequately protect Magellanic penguin populations, requiring the coordination and cooperation among agencies and administration levels, which in Argentina is often challenging (Esteves et al. 2000, Barragán Muñoz et al. 2003, Yorio 2009). This complex scenario is further complicated by changing fishery scenarios. The Argentine red shrimp stocks can show high inter-annual variability resulting in wide fluctuations in landings (Góngora et al. 2012). Thus, in future scenarios of reduced shrimp abundance, fishing effort may be directed again at Argentine hake, vessel activity may be relocated to traditional fishing grounds, and/or there may be growing interest in expanding operations to alternative target species such as the Argentine anchovy *Engraulis anchoita*, the main prey of Magellanic penguins in the study area (Yorio et al. 2017). The above mentioned results show how changes in resource distribution and in associated fishing patterns may modify the vulnerability of Magellanic penguin populations to commercial fishing activity in relatively short time periods, and may be likely the case for other seabird populations in the same region. For example, spatial changes in the operations of coastal fisheries may have important implications on the vulnerability to incidental mortality of coastal breeding species like the imperial cormorant *Phalacrocorax atriceps* or the provisioning of fishery discards to the opportunistic kelp gull *Larus dominicanus*, 2 widely distributed species that regularly interact with fisheries (González-Zevallos & Yorio 2006, Marinao & Yorio 2011). The modification in the distribution of fishing effort in response to changes in resource availability due to oceanographic variability, climate change or over-fishing in other regions worldwide may have similar implications for the differential effect of commercial fishing on seabird breeding aggregations. In coastal Patagonia, the dynamics of target resources, the relatively fast changes in fishing patterns and the increase in fishing effort in the recent past draw attention to the challenges in relation to the management and conservation of penguins and other seabirds. Sustained monitoring of interactions is needed under this potential scenario to allow the early detection of negative effects on seabird populations.

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