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Marine protection is needed for Magellanic penguins in Argentina based on long-term data

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ABSTRACT

Magellanic penguins (*Spheniscus magellanicus*) are listed as near threatened by the IUCN. At their largest colony, Punta Tombo, Chubut, Argentina, active nests declined >30% over 30 years. Reproductive success is low, many penguins forage far from the colony, and starvation, the major cause of chick death, kills 39% of chicks on average each year. A 210-ha provincial reserve protects part of the breeding colony but there is no marine protected area (MPA) around Punta Tombo. An MPA protecting the foraging area of adults with small chicks could reduce chick starvation, increase reproductive success, and reduce adult mortality. The Province of Chubut wants an MPA to protect penguins at Punta Tombo but when and where would an MPA be most effective? We used our long-term dataset to determine that most chicks starve within 20–30 days after hatching (November and December). We used satellite tags to track penguins foraging for chicks <20 days of age in 1997–2001 and 2006–2009. Core foraging areas for penguins whose chicks did not starve (successful) and those whose chicks starved (unsuccessful) partially overlapped. Unsuccessful penguins, however, foraged farther from the colony (59 ± 27 km, $N = 39$ penguins, 115 trips) and had a larger core foraging area (554 km^2) than successful penguins (46 ± 19 km, $N = 23$ penguins, 78 trips, $P = 0.002$; 375 km^2). Unsuccessful parents took longer to return to feed their chicks, increasing chick starvation. There is a limited window of opportunity to secure protection through adequate management of a critical foraging area for penguins and the rich assemblage of other marine species using the same area. Increases in chick growth and survival would demonstrate the effectiveness of the MPA.

1. Introduction

All seabirds lay their eggs and feed their young chicks on land but capture prey at sea, making them central place foragers (Orians and Pearson, 1979). Travel time to and from foraging areas is a major determinant of the rate of food delivered to the nest, and, consequently, of nestling condition and survival (Boersma and Rebstock, 2009b; Davoren and Montevecchi, 2003; Granadeiro et al., 1998). Starvation (death from lack of food) is often a major source of nestling mortality, especially when chicks are small and feeding frequency is constrained by the need of one adult to remain at the nest to brood and protect the young (Chivers et al., 2012; Hovinen et al., 2014). A marine protected area (MPA) may reduce travel time by increasing food available close to the colony, increasing reproductive success in species with high nestling starvation. However, knowledge of foraging areas and prey is essential for proper MPA siting (Camphuysen et al., 2012). Long-term seabird research can enhance the identification, delineation, and monitoring of MPAs (Ronconi et al., 2012).

Magellanic penguins (*Spheniscus magellanicus*) are classified as near threatened by the IUCN. The overall population trend is unknown and colonies in Argentina show mixed trends, with at least 12% of colonies decreasing (Boersma et al., 2013; Pozzi et al., 2014; Sala et al., 2012a). The largest colony, at Punta Tombo in Chubut Province, declined about 30% since 1987 (Boersma, 2008; Boersma unpubl. data). Climate change (Boersma and Rebstock, 2014), oil pollution (Boersma, 2012; Gandini et al., 1994; García-Borboroglu et al., 2006; Petry and Fonseca, 2002), mismanagement of tourism (Boersma, 2008; Fowler et al., 1994; Walker et al., 2005a; Yorio et al., 2001b), fisheries by-catch (Cardoso et al., 2011; Gandini et al., 1999; Petry and Fonseca,

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2002; Yorio et al., 2010), competition with fisheries for prey (Gandini et al., 1999; Skewgar et al., 2007), and harmful algal blooms (Shumway et al., 2003) all threaten the population. Mortality in fishing gear and fisheries competition are among the highest-impact threats to Magellanic penguin populations (Trathan et al., 2014).

A provincial reserve protects part of the Punta Tombo breeding colony on land, but there is no protection for the waters around the colony (García Borboroglu et al., 2006). Through an agreement with the Global Penguin Society we are working with Chubut provincial and Argentine national government agencies to design an MPA to protect penguins and other species around Punta Tombo. Enhancing food density in the most critical foraging area when adults are feeding small chicks is likely to augment nestling survival because starvation is the most important cause of nestling mortality, killing 39% of chicks on average each year ($N = 28$ years) (Boersma and Rebstock, 2014). Most nestlings that starve die within the first 30 days of hatching (Boersma and Rebstock, 2014; Boersma et al., 1990). In contrast, native predators such as gulls, skuas, armadillos, foxes, and skunks kill about 9% of chicks (Boersma and Rebstock, 2014). Magellanic penguins lay two eggs in a single clutch per season and replacement clutches are very rare (Boersma and Rebstock, 2014). When Magellanic penguins have to swim farther to find food for chicks, they are gone longer, feed chicks less frequently, and raise fewer chicks (Boersma and Rebstock, 2009b). Magellanic penguins' average reproductive success at Punta Tombo is 0.49 chicks per nest with eggs, which is lower than at many other colonies (Boersma et al., 2013, 2009; Van Buren, 2012; Yorio et al., 2001a). The low reproductive success is related to the local marine productivity and long distances penguins must travel for food at Punta Tombo (Boersma et al., 2009).

The decline at the largest colony of Magellanic penguins in the world potentially threatens its attractiveness to tourists and hence its economic value to Chubut Province and Argentina. How can this decline be stopped? Climate change cannot be altered or reversed in the near future (Solomon et al., 2009). Oil pollution has decreased along the Chubut coast (Boersma, 2008) but remains a problem in southern Brazil, Uruguay and northern Argentina (Boersma, 2012; García-Borboroglu et al., 2006) and is unlikely to be eliminated. Moreover, there is pressure to develop fisheries for Argentine anchovy (*Engraulis anchoita*) (Pastous Madureira et al., 2009; Skewgar et al., 2007), one of Magellanic penguins' main prey species at Punta Tombo. Another major prey species, Argentine hake (*Merluccius hubbsi*), is overfished in Argentina (Alemany et al., 2013; Vaz-dos-Santos et al., 2010). The political will in Argentina exists to create an MPA. For an MPA to be effective it should be based on science and highlight where and when protection would be most effective.

In addition to enhancing populations of prey, MPAs have other direct and indirect benefits. No-take or effectively-managed MPAs reduce incidental mortality in fishing gear. In parts of the southwest Atlantic Ocean by-catch of seabirds, marine mammals, and sea turtles is high (Lewison et al., 2014). Overfishing and intensive bottom trawling can change ecosystem productivity, carrying capacity, and food webs, reducing food for seabirds (Cury et al., 2011; Pikitch et al., 2012; Richardson et al., 2009; Utne-Palm et al., 2010). Marine ecosystems that are overfished and polluted have more harmful algal blooms than healthy ecosystems (Vasas et al., 2007) and overfishing large groundfish can shift phytoplankton-community dominance from diatoms to dinoflagellates (Katz et al., 2009).

When and where would an MPA at Punta Tombo be most effective? We used our long-term dataset on hatching dates and chick fates to determine the most critical time to protect penguin prey to increase chick survival. We used satellite-tracking data to show where successful and unsuccessful penguins breeding at Punta Tombo forage during this period.

2. Materials and methods

We visited nests in one study area daily or twice a day throughout each breeding season for 28 years. We recorded hatch dates, measured chicks every 10 days, and determined the cause of death for these known-aged chicks from 1983 through 2010 (Boersma and Rebstock, 2014). We followed 3496 chicks and calculated their ages at death or disappearance. The following factors indicated a chick starved: absence of external injuries and weight loss between measurements, weight below average for its age, or no changeover by adults at the nest for a few days when the chick was less than two weeks old. If we performed a necropsy lack of body fat and an empty stomach indicated starvation. When there were rainstorms or extreme heat events, chicks in nests with little cover more likely died from exposure than starvation (Boersma and Rebstock, 2014). We calculated reproductive success as the number of chicks that fledged per nest with eggs in the study area checked once or twice daily and in another study area about 350 m away where we followed chicks with less frequent visits. We counted chicks as fledged if they weighed at least 1800 g the last time they were seen after 10 January.

We defined "successful" penguins as those whose chicks did not starve and "unsuccessful" penguins as those who had at least one chick that starved. We followed chicks until they died or fledged and considered a penguin unsuccessful even if its chick starved after the tracking period ended. Chicks that did not starve may have fledged or died from other causes. A successful penguin may not have had either chick fledge if both died of causes other than starvation, and an unsuccessful penguin may have had one chick that starved and one that fledged or died from other causes, or two chicks that starved. Nevertheless, "successful" penguins fledged 0.7 chicks per breeding season on average compared to 0.4 chicks for "unsuccessful" penguins.

We tracked breeding Magellanic penguins' foraging trips (Table 1) using ST-10 and ST-20 Argos satellite-transmitter tags (PTTs, Telonics, Mesa, Arizona, USA, packaged in waterproof epoxy resin by Sirtrack Ltd., Havelock North, New Zealand). Tags weighed ~90 g with cross-sectional areas of 5.1 cm^2 for ST-20s and 7.8 cm^2 for ST-10s (Boersma et al., 2009). They were attached low on the penguins' backs to reduce drag (Boersma and Rebstock, 2009b; Boersma et al., 2009; Stokes and Boersma, 1999). In four years (1998–2001) we attached tags to adult penguins in mid- to late November to track penguins with young chicks (<20 days old) (Boersma and Rebstock, 2009b). In five other years, 1997 and 2006–2009, we tracked penguins during incubation, but left the tags on the penguins long enough to record one to five foraging trips after chicks hatched. In 1997–2001 we tracked male and female penguins. In 2006–2009, we tracked only male penguins. Females are smaller than males (Boersma et al., 2013) so carrying tags could be more costly to them. They are also less likely to return to their nests and will stay at sea if they are in poor condition. Males and females foraged at similar maximum distances from the colony (Boersma and Rebstock, 2009b) so we combined the data for both sexes. We tracked one penguin in each pair to minimize impacts on chicks, so where the mate foraged is unknown. We summarized the 1998–2001 data previously (Boersma and Rebstock, 2009b). We present a new analysis here and add the 1997 and 2006–2009 data.

We checked all nests with a tracked bird twice a day and measured chicks every 10 days. After removing tags, we checked nests every 10 days and continued to measure chicks until they died or

Table 1
Number of successful and unsuccessful Magellanic penguins foraging for young chicks (<20 days of age) tracked by year at Punta Tombo, Argentina, with the number of foraging trips tracked, and mean distance from the colony.

Year	Successful			Unsuccessful		
	Penguins	Trips (Mean ± SD)	Distance (km) (Mean ± SD)	Penguins	Trips (Mean ± SD)	Distance (km) (Mean ± SD)
1997	0			4	1.3 ± 0.5	70.5 ± 26.2
1998	3	4 ± 1	43.3 ± 13.7	11	4.3 ± 1.4	56.9 ± 20.8
1999	6	2.7 ± 1.9	42.9 ± 22.4	4	2 ± 1.4	64.0 ± 39.5
2000	0			9	2.4 ± 1.7	58.6 ± 37.6
2001	6	4.5 ± 1.2	49.5 ± 20.5	3	5 ± 0	65.6 ± 13.3
2006	4	2.3 ± 0.5	49.2 ± 10.4	3	1.7 ± 1.2	65.2 ± 49.2
2007	1	2	43.1 ± 25.9	3	2.3 ± 0.6	43.0 ± 16.1
2008	2	4 ± 1.4	30.7 ± 10.0	0		
2009	1	4	60.6 ± 11.8	2	3 ± 1.4	53.9 ± 25.2

fledged. Nests of successful and unsuccessful penguins were treated the same. Any effects of research disturbance were the same for all penguins. Similarly, carrying tags should not bias the comparison between successful and unsuccessful penguins because all penguins tracked within a year carried similar tags. Penguins carrying tags fledged chicks at similar rates to those without tags (Boersma, unpubl. data), but tended to take longer foraging trips although the difference was not significant (Boersma and Rebstock, 2009a). We did not control for each penguin's body condition because we weighed penguins only at the time of tag attachment and removal. When we attached tags during incubation, penguins had been fasting for several weeks and were in relatively poor condition. When we attached tags after chicks hatched, penguins were in better condition because they had replenished their reserves after their long incubation fasts. Month of attachment (October = incubation, November = young chicks) did not affect mean distance from colony or success.

We filtered penguins' at-sea positions with location classes 0 through 3 (at least 4 messages received by satellites) with two speed filters (Austin et al., 2003; McConnell et al., 1992). We prefiltered the data to remove locations closer together in time than 45 min, because small errors in location cause large errors in speed when the time interval is short. We also post-filtered the data to remove single locations that were far off the penguin's track but were not removed by the speed filters (Boersma and Rebstock, 2009b). All tags transmitted every 45 s 24 h per day.

We calculated the maximum distance that adults went from the colony for each foraging trip when feeding young chicks. We did not calculate the total distance traveled because the frequency of locations increased as the tags improved over the years and total distance calculated is related to the number of locations (Ryan et al., 2004). Maximum distance from the colony was correlated with the time penguins were away from the nest (Boersma and Rebstock, 2009b). We used maximum distance, which was measured more accurately than time away from the colony (Boersma et al., 2009) as a proxy for chick-feeding frequency and foraging effort. Maximum distance, not path length or trip duration, is the important variable for siting an MPA.

We compared maximum foraging distance between successful penguins ($N = 23$) and unsuccessful penguins ($N = 39$), using multiple regression. The response variable was maximum distance from the colony during each foraging trip. The predictor variables were a dummy variable indicating whether at least one chick starved, year (as a factor), and sequential trip number (1–5). To account for multiple trips by many penguins (median = 3 trips per penguin), we adjusted the degrees of freedom to the number of penguins rather than the number of trips and used robust standard errors (Long and Freese, 2006). We used only the first five foraging trips after the first chick hatched or all trips if there were $\leqslant 5$ for each penguin. Number of trips per penguin was independent of whether the penguin was successful or not ($\chi^2(4) = 3.6$, $P = 0.46$), meaning any bias due to differing numbers of trips per penguin is minimal. At least one live chick was in the nest at the start of each foraging trip. Chicks were 0 (hatch day) to 19 days of age at the start of a foraging trip. A graph of residuals on fitted values from the regression revealed a reasonable fit.

Magellanic penguins foraged primarily near the outer end of each foraging trip, whether the trip was long or short, based on time spent at various distances from the colony (Boersma et al., 2009). Mean daytime swimming speeds of penguins foraging for small chicks were more than 50% greater when penguins were swimming away from the colony and nearly two times greater when swimming back towards the colony than when they were at the outer edges of each trip (Boersma, unpubl. data). Although this study used low-accuracy Argos data without dive loggers, knowing the precise diving locations along the tracks is not crucial as long as all penguin locations are included in the MPA. We defined foraging locations for each trip as those locations with distance from the colony of at least 80% of the maximum distance for that trip (Boersma et al., 2009).

We estimated the densities of foraging locations using kernel analyses in ArcMap 10.0 (Esri, Redlands, California) separately for successful and unsuccessful penguins, using 398 locations for successful penguins and 615 for unsuccessful penguins. We used an output cell size of 1 km^2 and a search radius of 25 km. We mapped the 25%, 50%, and 75% equal-interval kernel contours for each group of penguins. The 75% contour encloses all areas (pixels) that had 75–100% of the maximum density value from the kernel analysis, or the highest density of penguin locations.

Statistical tests were run in Stata 9.1 (StataCorp LP, College Station, Texas). Maps were created in ArcMap 10.0.

3. Results

Of the 3496 chicks followed, 1372 starved when they were 0–112 days of age (Fig. 1). Half of the chicks (51%) starved when they were between 3 and 13 days old, with the highest number starving when they were 7 days old, probably because the yolk reserves were depleted. Of the chicks that starved 60% were dead by 20 days of age and 70% by 30 days of age.

Unsuccessful penguins foraged farther from the colony (59 ± 27 km, mean ± SD, $N = 39$ penguins, 115 trips) than successful penguins (46 ± 19 km, $N = 23$ penguins, 78 trips; Table 1 and Fig. 2). The 13-km mean difference was significant in the regression model ($t = 3.3$, $P = 0.002$). The maximum distance from the colony for successful penguins was 114 km. Only two of these 23 penguins (9%) went >100 km from the colony. For unsuccessful penguins, the maximum distance was 147 km and seven of these 39 penguins (18%) went >100 km.

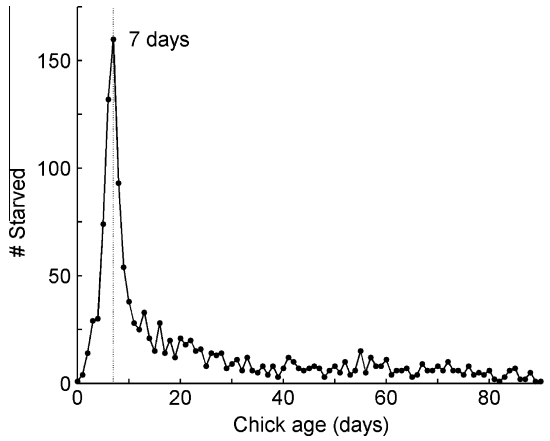

Fig. 1. Most Magellanic penguin chicks that starved at Punta Tombo, Argentina, from 1983 to 2010 were 3 to 13 days old when they died. $N = 1372$ chicks starved out of 3496 chicks studied.

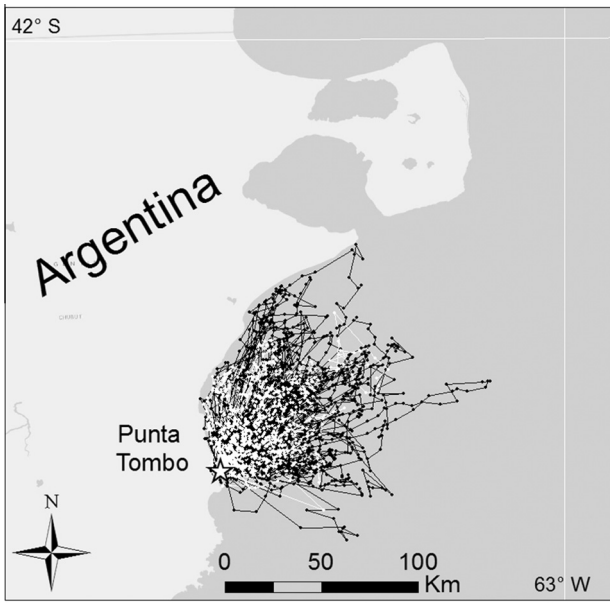

Fig. 2. Tracks of satellite-tagged Magellanic penguins foraging for young chicks (<20 days of age) at Punta Tombo, Argentina, 1997–2001 and 2006–2009. Positions and tracks of penguins whose chicks did not starve are white ($N = 23$ penguins, 78 foraging trips). Positions and tracks of penguins with at least one chick that starved are black ($N = 39$ penguins, 115 foraging trips). The Punta Tombo breeding colony is marked by a white star.

Maximum distance from the colony also varied with year ($t = 0.8–2.9$, $P = 0.44–0.006$) and increased with trip number ($t = 2.1$, $P = 0.04$) because as chicks age they need larger, less frequent meals. Penguins went farthest from the colony in 1997 (71 ± 26 km, $N = 5$ trips), 2000 (59 ± 38 km, $N = 22$ trips), and 2009 (57 ± 20 km, $N = 10$ trips), years when reproductive success was relatively low. In 1997 and 2000, all 13 penguins that we tracked had at least one chick that starved. Reproductive success was 0.43 chicks fledged per nest with eggs in 1997, 0.06 in 2000 (Boersma, 2008), and 0.32 in 2009 (this study). Penguins foraged closest to the colony in 2008 (31 ± 10 km, $N = 8$ trips) and 2007 (43 ± 17 km, $N = 9$ trips), years when reproductive success was higher, 0.76 in 2008 and 0.83 in 2007. Penguins did not forage in a semicircle around the colony (Fig. 2). Most penguins in all years went northeast of the colony.

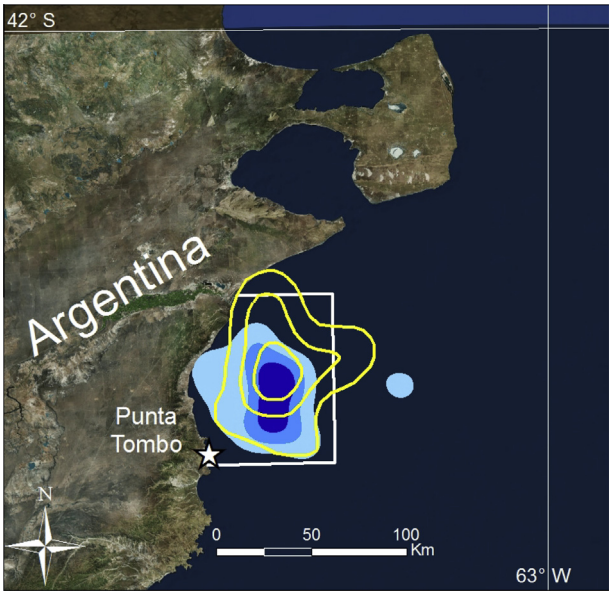

Fig. 3. Kernel density contours of at-sea locations of satellite-tracked Magellanic penguins foraging for young chicks (<20 days of age) at Punta Tombo, Argentina, 1997–2001 and 2006–2009. Penguins whose chicks did not starve are shown in filled blue contours ($N = 23$ penguins, 78 foraging trips). Light blue = 25% density contour (areas with 25–50% of the maximum density of locations from the kernel analysis), medium blue = 50% contour, dark blue = 75% contour. Penguins with at least one chick that starved are shown in yellow line contours ($N = 39$ penguins, 115 foraging trips). Outermost yellow line = 25% contour, middle yellow line = 50% contour, inner yellow line = 75% contour. The Punta Tombo breeding colony is marked by a white star. A possible marine protected area (latitude 43°18′S to 44°6′S, longitude 64°24′W to the coast; 5950 km^2) to reduce starvation of young chicks at Punta Tombo is indicated by the white box.

The core foraging areas (75% kernel density contours) used by successful and unsuccessful penguins partially overlap (Fig. 3). However, in addition to the area of overlap, successful penguins foraged closer to the colony and farther south, and unsuccessful penguins foraged farther from the colony and farther north. Unsuccessful penguins used larger foraging areas (75% contour = 554 km^2, 50% contour = 1989 km^2) than successful penguins (75% contour = 375 km^2, 50% contour = 1338 km^2).

4. Discussion

The provincial government of Chubut is committed to creating an MPA to protect penguins and other marine species near the largest breeding colony of Magellanic penguins, Punta Tombo. There is a window of opportunity to create an MPA to prevent the potential development of new fisheries (i.e., anchovy fisheries) or the expansion of current ones. The political will exists. Government has a rare opportunity to site an MPA based on science as a long-term study and satellite-tracking data are available for Magellanic penguins at Punta Tombo as we present in this paper. Five features of successful MPAs are no fishing allowed (no take), regulations well enforced, in existence for >10 years, large area (>100 km^2), and isolated (Edgar et al., 2014). An MPA should be realistic, easy to monitor and enforce, and based on sound, long-term data, and knowledge of the species (Lascelles et al., 2012). We used a combination of life-history and satellite-tracking data to determine when and where an MPA would be most effective.

The first 12 nautical miles (nm) from the coast is managed by the Province of Chubut (the province has jurisdiction up to 3 nm, but the 1999 Fishery Federal Law delegated the management, conservation, exploitation, and exploration of oil/gas and resources in the water column from 3 to 12 nm to the province). Waters off-

shore of 12 nm are under the jurisdiction of the national government so cooperation between the provincial and national governments is required for success. Some protection for the area under national and provincial jurisdiction already exists (Resolución CFP No. 90/2005) but fishing effort is heavy in some other areas managed by the province (Alemany et al., 2013).

Our long-term data from nest checks show that protecting the areas used by adult penguins foraging for small chicks has the potential to increase reproductive success of the colony because reproductive success is low at Punta Tombo, starvation is the major cause of chick mortality, and chicks are most likely to starve when they are less than 30 days old and still guarded by one parent, in November and December. In early to mid-November, before most chicks hatch, penguin adults make short foraging trips that are critical to hatchling survival (Boersma et al., 1990). If a parent does not return to the nest with food within the first two days after a chick hatches, the chick usually starves, even if it is fed later. Reproductive success and recruitment affect population trends, even in long-lived species such as seabirds (Jenouvrier et al., 2009; Sandvik et al., 2012), making protection of prey for chicks important.

Our tracking data show where successful and unsuccessful penguins forage during the critical period, November and December, and suggest the minimum size of an effective MPA at Punta Tombo is about 6000 km^2 (Fig. 3). Penguins' foraging locations vary among years (Boersma and Rebstock, 2009b) and colonies (Boersma et al., 2009) because of temporal and spatial variability in ocean productivity and prey availability and distribution. However, penguins forage northeast of the colony because frontal systems there enhance prey availability (Boersma et al., 2009).

Small pelagic fish undergo natural population fluctuations (Pikitch et al., 2012), and fishing effort is not static and can alter prey availability for seabirds (Anchundia et al., 2014; Bertrand et al., 2012; Cury et al., 2011; Jahncke et al., 2004). Hence multiple years of tracking data at each colony are needed to identify important foraging areas to protect. An MPA that reduces fishing effort can buffer penguin reproductive success in years of low prey availability. An MPA should encompass not only the core foraging areas for penguins feeding young chicks but also the routes between the colony and foraging area.

Unsuccessful penguins foraged about 13 km farther from the colony on average than successful penguins. Although 13 km is a small distance when a penguin can swim 173 km in 24 h (Boersma et al., 2009), the extra energy needed to travel longer distances, the longer time for digestion of prey in the adult's stomach, and the increase in waiting time for the chick can result in starvation of the chick. When penguins are feeding young chicks it takes almost 10 h more to swim an additional 13 km (26 km round trip) (Boersma and Rebstock, 2009b). For a recently-hatched chick waiting for a meal, 10 h can determine whether it starves or survives. Increases in wait time for food can weaken chicks, lower their ability to digest large meals (Yang et al., 2009), and, in cases of severe food deprivation, lower their corticosterone levels which may cause less vigorous begging (Walker et al., 2005b).

The foraging behavior and success of individual seabirds vary for a variety of reasons including age, experience, pair-bond duration, body condition, and other intrinsic factors (Harris et al., 2014a; Lewis et al., 2009; Nisbet and Dann, 2009). Individual seabirds are often consistent (Harris et al., 2014b), so some individuals contribute more to future generations in a population (Annett and Pierotti, 1999). Variation among individuals in foraging distance within a year determines reproductive success of Magellanic penguins (Boersma and Rebstock, 2009b). Protecting the closer foraging area of successful penguins will have a larger effect on reproductive output of the colony than protecting the most-distant foraging areas of unsuccessful penguins because the successful penguins produce more fledglings. However, an MPA is likely to improve breeding success of both successful and unsuccessful penguins by increasing prey availability close to the colony, reducing foraging distance, and increasing feeding frequency.

An MPA near Punta Tombo would also reduce adult mortality in fishing gear. Although incidental mortality of Magellanic penguins is currently low in some individual fisheries (Favero et al., 2013; Seco Pon et al., 2013), there are many fisheries in Argentina that kill Magellanic penguins and other seabirds (Gandini et al., 1999; Ministerio de Agricultura, 2010). Mortality of adults in fishing gear is highest near colonies (Marinao et al., 2014) because they transit that area twice on each foraging trip. Magellanic penguins are more likely to be killed in trawler nets and gill nets (Cardoso et al., 2011) than in long lines and jiggers (Favero et al., 2013) although this may be partly because the long line and jigger fleets generally fish farther offshore and overlap less with Magellanic penguins at sea. Most fishing for anchovy in Argentina uses trawlers and effort already focuses nearshore and in some years near penguin colonies including Punta Tombo (Prenski et al., 2011; pers. obs.).

Anchovy typically accounts for about 60–100% of prey in Magellanic penguin stomach contents, with hake accounting for up to 40%, and silversides (*Odontesthes* spp.) <10% (Frere et al., 1996; Gandini et al., 1999; Gosztonyi, 1984; Wilson et al., 2005). Squid (*Loligo* spp., *Illex argentinus*) is sometimes important in the diet as well, accounting for about 1–19% of prey in stomach contents (Gandini et al., 1999; Gosztonyi, 1984; Wilson et al., 2005). A stable-isotope study indicated that squid may be more important relative to fish than stomach samples indicate, accounting for 10–30% of the diet (Ramírez et al., 2014).

Argentine anchovy is considered an underexploited species (Pastous Madureira et al., 2009) but new or expanding fisheries are proposed in Argentina and Brazil and pressure to develop anchovy fisheries will likely increase (Carvalho and Castello, 2013; Pastous Madureira et al., 2009; Skewgar et al., 2007). Sizes of anchovy eaten by penguins (Gandini et al., 1999; Gosztonyi, 1984) overlap the sizes of fish taken by fisheries (Gandini et al., 1999; Hansen, 2004). Anchovy is a key prey item for commercially-valuable fish, and other seabirds and marine mammals, as well as penguins (Koen-Alonso and Yodzis, 2005).

Argentine hake is overexploited (Alemany et al., 2013; Vaz-dos-Santos et al., 2010). The Patagonian Closed Area was established in 1997 to protect hake stocks with year-round fishing closures. Closed areas vary from year to year and the boundary of the closed area is fished intensively in most years (Alemany et al., 2013). In spite of the closed area, fishing effort, landings, and by-catch of various species are high in the hake fishery (Favero et al., 2011; González-Zevallos et al., 2007; Marinao et al., 2014; Marinao and Yorio, 2011; Van Der Molen et al., 1998). Attempts to reduce catch and discard of juvenile hake have not been as successful as expected (Góngora et al., 2012; Romero et al., 2010). Penguins eat juvenile (Gandini et al., 1999) and adult hake (Gosztonyi, 1984) that sometimes overlap with fisheries catches. The fishery has targeted younger age classes, including juveniles, since the mid-1990s (Bezzi et al., 2004), increasing the potential competition between penguins and fisheries.

Silversides (pejerrey or cornalito) is only targeted in small artisanal fisheries in Argentina (Hansen et al., 2004). The Argentine shortfin squid (*Illex argentinus*) is the target of a large fishery on the mid- to outer shelf and shelf slope in Patagonia, but small coastal fisheries also operate, mainly in the austral winter (July–September) (Crespi-Abril et al., 2013).

Fisheries landings and discards reduce prey available to Magellanic penguins at Punta Tombo. Estimates of prey eaten by a Magellanic penguin range from 0.32 kg per day (Gandini et al., 1999) to 5.71 kg per day (Sala et al., 2012b). If Gandini's estimate is correct, 200,000 adult penguins (Boersma unpubl. data) foraging each day

in November and December would eat 1920 t per month. If penguins eat 5.5 kg per day (midway between Sala's estimates for colonies north and south of Punta Tombo), the colony consumption is 33,000 t per month. Landings of Argentine anchovy ranged from 326 t to 7422 t in November and from 0 t to 99 t in December 2009–2013. Landings of Argentine hake south of 41° S ranged from 17,800 t to 30,100 t per month in November and December over the same years. However, hake landings were as high as 88,600 t in December 1996 before the stock collapsed (http://www.minagri.gob.ar/site/pesca/pesca_maritima/02-desembarques/index.php). If penguin consumption is closer to the lower estimate, then fisheries take about 20 times more hake and anchovy than penguins at Punta Tombo eat. If the higher estimate is correct, fisheries take between 50% and 2.7 times the hake that penguins eat.

These fishery landings do not include bycatch of anchovy and hake, which is high in some fisheries (Bovcon et al., 2013; Gandini et al., 1999; Góngora et al., 2012; Marinao and Yorio, 2011). For example, each vessel in the shrimp (*Pleoticus muelleri*) fleet discarded approximately 1375 kg of anchovy and 24,475 kg of hake per day in the Golfo San Jorge in 1996 and 1997 (Gandini et al., 1999). Fishing for shrimp is allowed in the hake closure area.

The rapid decline of the African penguin (*Spheniscus demersus*) population was mainly caused by lack of forage fish (Crawford et al., 2014). An experimental no-take zone in South Africa resulted in immediate reduction of foraging effort in African penguins (Pichegru et al., 2010), but it was too small to reverse the decline in body condition of adults and chicks in the face of large industrial fisheries (Pichegru et al., 2012). The lack of prey for African penguin colonies, particularly in the western cape, results in high chick mortality and is of such concern that chicks are removed from their nests and bolstered for release to increase both adult and chick survival (Sherley et al., 2014).

Punta Tombo is a diverse seabird colony, with eight species breeding annually and three tern species breeding in some years (Yorio et al., 1998). An MPA there could benefit 54 species of coastal and marine birds and 32 species of marine mammals found in the area (Campagna et al., 2001; Coscarella et al., 2010; García Borboroglu et al., 2006; Reyes, 2006). Some of them, such as petrels and albatrosses (e.g., Copello and Quintana, 2009; Croxall and Wood, 2002; Huin, 2002) are of conservation concern due to bycatch in fisheries (Croxall et al., 2012).

Seabird reproductive success and ecosystem functioning depend on forage fish such as anchovy (Cury et al., 2011; Pikitch et al., 2014). Climate change will likely take an increasing toll on Magellanic penguin chicks as one storm can kill 50% of the chicks in a year (Boersma and Rebstock, 2014). An MPA would help keep the marine ecosystem healthy and resistant to climate change and other large-scale perturbations that are difficult to control (McClanahan et al., 2012).

An MPA could be more effective than the current system of regulation. The areas closed to fishing change from year to year, with no permanent protection. Some types of fishing are allowed in the protected zones. The closed area is subject to changes in regulations and developing fisheries. Part of the foraging area for penguins with small chicks at Punta Tombo overlaps with the heavily-fished boundary of the closed area (see Alemany et al., 2013; Marinao et al., 2014; Marinao and Yorio, 2011).

MPAs are often not effective for wide-ranging species because MPA size is limited (Boersma and Parrish, 1999). Magellanic penguins forage 400 km from the colony on average during incubation (Boersma and Rebstock, 2009b) and migrate across political boundaries when they swim as far as 3000 km during migration (Pütz et al., 2000, 2007; Stokes et al., 2014). Successful conservation of Magellanic penguins across their entire range and all year is a formidable task, requiring people to work together across international political boundaries because these penguins migrate or breed in Argentina, Brazil, Chile, Falkland/Malvinas Islands, and Uruguay. Reducing young chick starvation with an MPA at their largest breeding colony, however, has the potential for reversing the decline of Magellanic penguins at Punta Tombo because foraging areas are restricted when chicks are young and most vulnerable to starvation.

The scientific data needed to make an MPA for breeding Magellanic penguins at Punta Tombo are now available. The political challenge is to use the data and establish an effective MPA. Continued monitoring of chick growth, reproductive success, and foraging ranges is needed to test its effectiveness. The quality of life for penguins and the tourist industry may hang in the balance.

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