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INTERACTION BETWEEN MAGELLANIC PENGUINS AND SHRIMP FISHERIES IN PATAGONIA, ARGENTINA[1]

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Abstract. We analyzed the effect of the shrimp fishery on Magellanic Penguins (*Spheniscus magellanicus*) in two ways: (1) we determined whether penguins were incidentally killed and the magnitude of incidental take, and (2) estimated the overlap between penguin diet and fish by-catch of the shrimp fishery (total capture excluding shrimp and seabirds). We worked with the fishing fleet operating at Golfo San Jorge with onboard observers over 200 days in 1995–1997, sampling fishery by-catch and entangled birds. Penguins were affected during the austral summer. Estimations of mortality rates showed 0.33% of the breeding population at Golfo San Jorge is incidentally killed by the shrimp fishery every summer. By-catch in shrimp fishery nets was composed of species important as penguin prey (anchovy and hake) in higher proportions during summer. The daily by-catch of these species was higher than the total calculated daily intake for all penguins breeding in the Golfo San Jorge. This could have a significant effect on birds. We recommend that an observer program be implemented to monitor seabird mortality and that fishing gear should be improved to reduce the indirect effect of the fish by-catch on penguins.

Key words: by-catch, Golfo San Jorge, Magellanic Penguins, Patagonia, penguin diet, shrimp fishery, Spheniscus magellanicus.

INTRODUCTION

Many fisheries have attracted attention because of the large by-catch of nontarget species, including marine mammals, birds, turtles, and fish (Ryan and Cooper 1991, Julian and Beeson 1998). By-catch refers to part of the gross catch not used in any way but is thrown back into the water as whole organisms. Seabirds are a particularly conspicuous by-catch component and they drown in nets in different fisheries all over the world (Ainley et al. 1981, King 1984, Simeone et al., in press). Most seabirds are considered to be top predators in marine ecosystems, which makes them potential competitors with commercial fisheries (Furness 1984), a factor which tends to complicate the by-catch issue, both politically and biologically.

The growth of fisheries in Argentina in the 1980s caused considerable concern among conservationists with respect to their possible effect on marine predators, especially seabirds. Commercial fisheries in Patagonia, especially those for shrimp (*Pleoticus muelleri*) have been growing since 1984 (Csirke 1987, Anonymous 1994), and declines in populations of some seabirds in the south Atlantic have been linked to the growth of commercial fisheries in their feeding areas (Croxall et al. 1984, Boersma and Stokes 1995, Boersma 1997). However, there is no information about which species are entangled in commercial nets in Patagonia nor is there information on competition between fisheries and seabird populations.

In this paper we analyze the effect of the shrimp fishery on Magellanic Penguins (*Spheniscus magellanicus*) in two ways: (1) we determine the magnitude of the incidental take of the shrimp fishery and (2) estimate the overlap between penguin diet and fish by-catch of the

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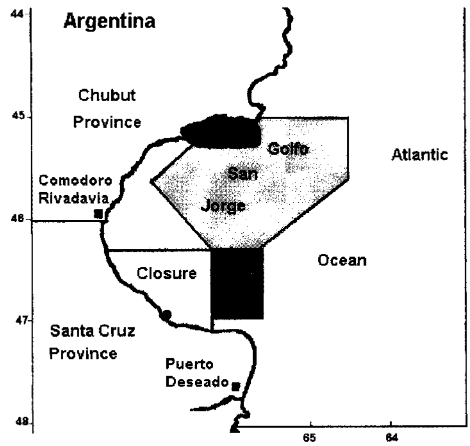

FIGURE 1. Map of the Golfo San Jorge area showing Magellanic Penguin colonies, main shrimp fishery areas, closure zone, and sites of seabird incidental mortality. The shaded areas show the fishing grounds of the trawlers. Dark gray corresponds to heavy effort areas and light gray to medium fishing effort areas. Dark circles indicate islands with Magellanic Penguin colonies, stars correspond to sites of entangled penguins, and squares show coastal cities.

shrimp fishery (total capture excluding shrimp and entangled seabirds).

METHODS

DATA COLLECTION

Double-beam trawlers are the only vessels authorized to fish for shrimp in the Golfo San Jorge, Argentina (Santa Cruz Fishing Agency, pers. comm.). Each vessel has two bottom nets, each 10–15 m long and 0.5–1.2 m high. Provincial regulations stipulate that trawling should only occur during the day and that the maximum number of vessels in the fishery should be no more than 60. The fleet fishes mainly in the southern section of the Golfo San Jorge during the summer, in both southern and northern areas in autumn, and in northern areas in the winter. During the spring, the vessels return to the south where there is a variable-limit protected area ("closure") to protect juvenile shrimp (Fig. 1).

Fishing effort was measured as "effective days of fishing," which we defined as one day of fishing by one vessel. We have official effort data for 34 vessels operating in the study area during summer. Total effective days of fishing were estimated for the whole fleet (60 vessels), based on the monthly rate of effective fishing days of the 34 known vessels divided by the total number of possible fishing days by month. Each monthly rate was then applied to the total fleet.

We worked with on-board observers who sampled the whole Golfo San Jorge region over 200 days. Sampling was subdivided into 120 days during summer and 80 days during fall in 1995, 1996, and 1997. Observers sampled 10 kg of by-catch from 29 tows chosen randomly during 1996 and 1997. Observer data were complemented by information from vessel logbooks which include daily catch by species and the geographic position of the vessel. After each tow, the two codends were emptied and all organisms were sorted by species. The weight in kg for each tow of shrimp were weighed by the crew, and total weight of by-catch by species was measured by the observer.

Seabirds caught and samples of by-catch were frozen on board (−20°C) and later analyzed in the laboratory. All sampled organisms were sorted by species weighed, and total body length was measured. Occasional species such as starfishes, urchins, scallops, polychaeta, etc. of each tow were discarded from the analysis.

ANALYSIS OF DIET SAMPLES

Each penguin was sexed during dissection and stomachs were weighed on an electronic balance to 0.01 g. Stomach contents were first weighed and then sorted into different components. The sorting method involved spreading stomach contents into large trays to be sorted into fragments of fish, squid, crustaceans, and nonfood items.

We identified different prey items using whole animals, skeletons, various distinct bones from the head, otoliths, scales, and cephalopod beaks. When fractions were not recognizable, we categorized them as "not identifiable."

Cephalopods were identified by examination of the lower beaks which vary in the morphology according to Order, Family, and Genus (Clarke 1986, Pineda et al. 1996). Beaks from Octopoda and Sepioidea were recognized by their pigmentation (Pineda et al. 1996), and we distinguished the two families of commercially-exploited Ommastrephidae and Loliginidae following Clarke (1986). Size of the squid was assessed from the lower beak by measuring rostral length and using the relationship between rostral length and the mantle length to estimate the original prey size (Pineda et al. 1996). We identified crustaceans by comparison with specimens from our own collection.

We identified fish by comparison with dissected specimens from our own collection, following identification guides (Menni et al. 1984), or by otolith or bone morphology (Torno 1976, Gosztonyi and Kuba 1996). For estimation of prey size of hake (*Merluccius hubbsi*) and anchovy (*Engraulis anchoita*), we used the regression provided by Koen et al. (1998).

The importance by mass of each prey species was calculated as the percent mass of the prey item in the total sample mass. We also estimated the frequency of occurrence as the percentage of samples in which the prey item was found. To differentiate between recently consumed and accumulated fractions, the following criteria were used: any crustacean remains were considered to have been ingested during the last meal. For cephalopods, only whole animals or tentacles were included in the last meal and loose beaks were considered as accumulated items. For small fishes, the estimation was made by counting whole animals or entire skeletons. Otoliths or heads were considered as having been ingested within the last 24 hr (Wilson et al. 1985). For big fishes, we considered only whole animals as having been ingested in the last meal.

The degree of diet overlap "α" was measured using the formulae of MacArthur and Levins (1967), $\alpha_{ij} = \Sigma p_i p_j / \Sigma p_i^2$ and $\alpha_{ji} = \Sigma p_i p_j / \Sigma p_j^2$, where α_{ij} is the overlap of penguin diet (j) with by-catch (i), α_{ji} is the overlap of by-catch (i) on penguin diet (j), and p_i is the unweighted use of a particular resource category by species i relative to its use of the other categories of that resource. Values of α varies from 0 (no overlap) to 1 (complete overlap) and may exceed 1 if niche widths are unequal (Hespenheide 1982). We also compared total body length of species shared in penguin diet and fishery by-catch.

We estimated the mean mass of stomach contents and compared the sexes. To estimate meal size, we used stomachs with more than 50 g of content.

Values presented are means ± SD; *P*-values < 0.05 are considered significant. We compared mean mass of the stomach contents between males and females and body sizes of penguin prey items and by-catch using Mann-Whitney *U*-tests. Other statistical tests are identified as they appear.

RESULTS

BY-CATCH COMPOSITION

Four species of fish (hake, kingclip [*Genypterus blacodes*], rock cod [*Notothenia* sp.], and anchovy [*Engraulis anchoita*]), three crustaceans (Patagonian prawn [*Peisos petrunkevitchi*], lobster krill [*Munida* sp.], and mantis shrimp [Stomatopoda]), Patagonian squid (*Loligo gahi*), and crabs (Brachyura) were included in the by-catch (Table 1). Hake was the most important species by frequency and weight, being present in almost all tows (Table 1). Cnidaria, starfish, sea urchins, scallops, polychaeta, skates, and sharks appeared infrequently, representing less than 3% of total by-catch biomass. By-catch was more diverse than the seabird diet, which did not include benthic groups such as Brachyura.

We divided the hake by-catch into groups corresponding to commercial and noncommercial sizes. The mean body length of noncommercial hake (n = 211) was 25.3 ± 7.6 cm, weighing 167.6 ± 235.9 g, and 41.27 ± 3.29 cm, weighing 581.7 ± 347.6 g for commercial individuals (n = 80). Pooling all data (n = 291), mean body length was 29.69 ± 9.78 cm. The mean body length for anchovy was 14.9 ± 1.7 cm with a maximum length of 27.4 cm and a minimum of 12.4 cm (n = 153).

Tow median by-catch biomass was 5,500 ± 3,740 kg, which means that 27,500 ± 18,700 kg is discarded daily per vessel, given that each vessel makes on average five tows (4.7 ± 1.3; n = 44). If 5% of by-catch biomass is comprised of anchovy (Table 1), each vessel catches approximately 1,375 kg of anchovy per day. For hake, the proportion of by-catch biomass is 89% (Table 1), resulting in 24,475 kg discarded by each vessel per day. Taking into account those sizes of hake preyed upon by penguins (< 35 cm, Fig. 2), the daily discarded biomass resulted in 15,175 kg vessel^{-1} day^{-1} of potential penguin food.

PENGUIN DIET

The mean mass of penguin stomach contents was 229.25 ± 171.47 g (range 11.84–779 g). The mean mass for males was 264.12 ± 260.78 g (range 30–779 g, n = 12), and for females 180.59 ± 132.90 g (range 11.84–362.47 g, n = 9); there was no difference between sexes (Mann-Whitney U-test, U = 34, $P > 0.5$).

Anchovy was the most frequently encoun-

TABLE 1. Percent frequency of occurrence (n) and contribution by mass of each prey species of Magellanic Penguin diet and fisheries by-catch at Golfo San Jorge.

Prey item		Penguins		By-catch	
		% occurrence	% biomass	% occurrence	% biomass
Fish					
anchovy	*Engraulis anchoita*	67 (14)	55	14 (4)	5
hake	*Merluccius hubbsi*	43 (9)	32	93 (27)	89
rock cods	*Nototheniidae*			26 (8)	1
kingclip	*Genypterus blacodes*			34 (10)	2
Mollusca					
octopus	*Octopus* sp.	24 (1)	<1		
Patagonian squid	*Loligo gahi*	19 (4)	8	28 (8)	<1
Argentine squid	*Illex* sp.	5 (1)			<1
Crustaceans					
lobster krill	*Munida* sp.	5 (1)	2	14 (4)	<1
Patagonian prawn	*P. petrunkevitchi*	24 (5)		24 (7)	<1
Mantis shrimp	Stomatopoda			45 (13)	<1
crabs	Brachyura			52 (15)	2
Unidentified		9 (2)	3		

tered prey, followed by hake. Crustaceans were found at low frequencies (lobster krill and Patagonian prawn), as were Patagonian squid, Argentine shortfin squid (*Illex argentinus*), and octopus (*Octopus* sp.) (Table 1). Anchovy also was the most important prey by weight, followed by hake, squid, and crustaceans (Table 1). The squid fraction of the diet was more important by frequency than by weight (Table 1).

The mean body length for predated anchovy was 14.46 ± 2.02 cm (range 18.64–7.42 cm, n = 187). The mean body length for predated hake was estimated to be 16.13 ± 3.70 cm with a maximum of 33.04 cm and a minimum of 8.92 cm (n = 122). All hake correspond to juveniles belonging to noncommercial sizes (length < 37.35 cm) (Simonazzi y Otero 1986). The anchovies taken by penguins and those in the by-catch did not differ in body length (Mann-Whitney U-test, $U = 13{,}497$, $P > 0.5$, Fig. 3). Length of predated hake in by-catch were significantly larger than those taken by penguins (Mann-Whitney U-test, $U = 3{,}679$, $P < 0.001$).

The estimated dorsal mantle length from 17 Patagonian squid beaks was 22.7 ± 6.2 cm. Most crustaceans in the samples were Patagonian prawn (n = 5), but in one case we found lobster krill (Table 1), a new prey species for Magellanic Penguins. The crustacean fraction was not very major in the overall penguin diet (Table 1), but in some cases the whole stomach content corresponded to this prey.

The mean meal size was estimated as 318.9

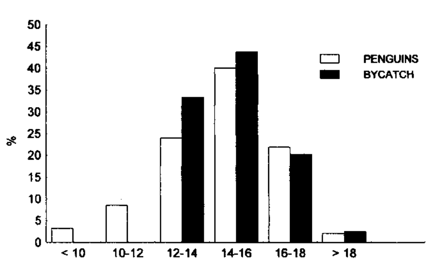

FIGURE 2. Length-frequency distribution of hake (*Merluccius hubbsi*), eaten by Magellanic Penguins, and the fishery by-catch.

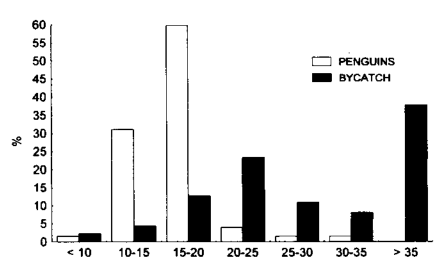

FIGURE 3. Length-frequency distribution of Argentine anchovy (*Engraulis anchoita*), eaten by Magellanic Penguins, and the fishery by-catch.

± 210.5 g (n = 17) with a maximum of 779 g and a minimum of 58 g.

INCIDENTAL SEABIRD MORTALITY AND OVERLAP WITH THE FISHERY

The species with highest mortality in the commercial fishery was the Magellanic Penguin, followed by Sooty Shearwater (*Puffinus griseus*), Imperial Shag (*Phalacrocorax atriceps*), and Black-browed Albatross (*Diomedea melanophris*). During the 120 days sampled during summer, 26 Magellanic Penguins were incidentally killed during operations of fishing vessels at Golfo San Jorge. In 80 days sampled during fall, two Sooty Shearwater, one Imperial Shag, one Black-browed Albatross, and no penguins were killed. Locations of seabird mortality from observer records indicate that mortality was concentrated in areas of heavy fishing effort (Fig. 1).

Effort of the fleet (60 vessels), measured as effective days of fishing during summer, was 8,889 days for the study period (1995–1997). Assuming incidental mortality did not vary among years, we estimated that every summer 642 ± 225 penguins died entangled in nets, a total of at least 11 penguins vessel^{-1}. Twenty-one individuals were recovered and frozen, and five were lost. All the entangled penguins were adults, being 12 males and 9 females (χ^2_1 = 0.43, $P > 0.85$).

Overlap between penguin diet and fishery by-catch was α = 74.25 and between fishery by-catch and penguin diet was α = 2.94.

DISCUSSION

PENGUIN DIET

Diet of Magellanic Penguins incidentally killed consisted mainly of small fish. Anchovy was the most important component of the diet by both weight and number. This result was similar to the findings of Gosztonyi (1984), Scolaro and Badano (1986), Frere et al. (1996b), and Scolaro et al. (in press), for birds at breeding colonies located at latitudes close to those where our birds were killed. Crustaceans belonging to Sergestidae were found as part of the Magellanic Penguin diet and this is a new prey species, although other crustaceans, such as lobster krill, have been previously reported for the southern part of the species breeding range in the Falkland Islands (Thompson 1993). Our meal size estimation (0.32 kg) is smaller than that reported by Gosztonyi (1984) (0.62 kg) in stomach contents taken from penguins returning to a breeding colony. We may underestimate meal size because entangled penguins have not completed their feeding.

INTERACTION BETWEEN SEABIRDS AND FISHERIES

Penguin diet data indicate little competition with the commercial shrimp fishery. The target species of the fishery is not exploited by the penguins. Hake, however, is a resource exploited by both penguins and the fishing industry, although penguins take fish sizes below the commercially exploitable limit and in low proportions in comparison with the shrimp fishery by-catch. However, it appears that the converse may not be true because the fishery incidentally killed substantial numbers of penguins in their nets and overlap between penguin diet and fishery is high.

Diving species, especially inshore foraging flightless seabirds, such as penguins, rely on the presence of abundant and predictable fish stocks (Ainley 1977). The shrimp fishery is focused at Golfo San Jorge, an important foraging area for Magellanic Penguins. In addition, the fishery operates adjacent to penguin breeding colonies. Magellanic Penguins are most likely to be affected by this fishery during austral summer (December–February) when chicks are being reared (Boersma et al. 1990, Frere et al. 1996a) and when all breeding adults are consequently investing much time in foraging. The fact that seabirds died in the area of the most intense fishing effort area suggests that it would be detrimental to the penguins were there to be an increase in total effort of this fishery at Golfo San Jorge. There are 11 penguin colonies located in this area, totaling approximately 116,000 breeding pairs (Gandini et al. 1996, Yorio et al., in press). If we consider that a penguin has a foraging range of 60 km (Wilson et al. 1995), all the colonies located in Golfo San Jorge would be affected, meaning that our estimate of 642 penguins incidentally killed every summer represents 0.33% of the breeding population. Penguins stay between six and seven months in this area, so the annual mortality rate would be less than 1%. At present, this does not seem to be of particular significance to the penguins, but this result reflects the effect of only one particular fishery for a portion of the whole penguin population. Other authors report higher mortality rates for Magellanic Penguins during migration (Boersma et al. 1990, Frere et al. 1996a), emphasizing the necessity of continuing to monitor this problem.

Although we have no direct evidence of competition, indirect effects of the fishery on penguins seem to be significant. Fishery by-catch overlap with penguins is high when the two main prey species of penguins (hake and anchovy) correspond to the principal species of the fish by-catch. Alpha values suggest that the potential effect of the fishery on penguins is higher than that of penguins on the fishery.

If we assume that 0.32 kg represents the penguin daily meal size, with prey proportions being 0.1 kg for hake, 0.18 kg for anchovy, and 0.04 kg for other prey, then each fishing vessel discards every day the equivalent of the daily food requirement of hake needed to support 150,000 penguins and enough anchovies to support 7,640 penguins. The total biomass discarded daily by all the fleet would feed 9 million penguins on hake for a day and 458,000 penguins on anchovy. If we assume that penguins eat 0.62 kg day^{-1}, as estimated by Gosztonyi (1984), then the number of birds that could be supported would be about half this. Whatever the case, it is clear that the daily by-catch by the shrimp fishery of anchovies and juvenile hake is higher than the daily food intake of all penguins breeding at Golfo San Jorge.

The interaction between penguins and shrimp fisheries in this region could be intense in the light of the magnitude of the fish by-catch. An observer program should be implemented to monitor seabird mortality. Also, the fishing gear should be improved to reduce the indirect effect of the fish by-catch on penguins. The consequences of the by-catch on the reproductive success of the seabirds remain to be evaluated, but such an analysis is urgently needed.

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