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Consistent Male-biased Seabird Mortality in the Patagonian Toothfish Longline Fishery

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Seabird by-catch from longline fisheries is a global conservation concern. Many thousands of birds are killed each year when they seize bait from longlines and are drowned (Brothers 1991, Alexander et al. 1997). Most of these birds are procellariiforms, which are long-lived species with low reproductive rates and high susceptibility to even small changes in survival rate, especially in adults (Croxall et al. 1990). The estimated effect of the tuna longline fishery in the Southern Ocean during the last 30 years is sufficient to account for observed decreases in breeding numbers of many albatrosses and other procellariiforms (Weimerskirch and Jouventin 1987, Croxall et al. 1990, Gales 1993). More recently, longline fisheries have commenced in the Southern Ocean, notably for Patagonian toothfish (*Dissostichus eleginoides*), in waters to the south of the area exploited by the tuna fishery (Cherel et al. 1996, Moreno et al. 1996). Mortality from these fisheries is placing additional pressure on seabirds in the Southern Ocean (Alexander et al. 1997).

Procellariiforms are monogamous (Warham 1990). Consequently, the demographic implications of longline by-catch are exacerbated when mortality is sex biased. Female-biased mortality from longline fisheries has been reported for Wandering Albatrosses (*Diomedea exulans*; Weimerskirch and Jouventin 1987, Croxall and Prince 1990) and Grey Petrels (*Procellaria cinerea*; Bartle 1990, Murray et al. 1993). These biases have been attributed to differences between the sexes in foraging ranges, with females foraging farther north than males and thus spending more time in the waters where tuna longline vessels operate. Here, we report consistent male-biased mortality from the longline fishery for Patagonian toothfish that oper-

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TABLE 1. Proportion of male seabirds killed in the Prince Edward Islands longline fishery for Patagonian toothfish, October 1996 to June 1997.

Species	% Male	*n*	Significance[a]
White-chinned Petrel (*Procellaria aequinoctialis*)	83.3	233	$P < 0.001$
Grey-headed Mollymawk (*Thalassarche chrysostoma*)	85.6	111	$P < 0.001$
Yellow-nosed Mollymawk (*T. chlororhynchos*)	78.3	23	$P < 0.02$
Southern Giant-Petrel (*Macronectes giganteus*)	63.6	11	ns
Northern Giant-Petrel (*M. halli*)	71.4	7	ns
Wandering Albatross (*Diomedea exulans*)	0.0	1	—
Black-browed Mollymawk (*T. melanophris*)	100.0	1	—
Sooty Mollymawk (*Phoebetria fusca*)	100.0	1	—
Grey Petrel (*Procellaria cinerea*)	100.0	1	—
All giant-petrels[b]	61.9	21	ns

[a] *P*-values from Yates-corrected χ^2 test with 1 df; ns, $P > 0.05$.

[b] Three immature giant-petrels could not be identified with certainty due to postmortem loss of coloration and/or damage to bill tip.

ates around several subantarctic islands that are globally important breeding sites for seabirds.

Methods.—Fishing for Patagonian toothfish under permit commenced in October 1996 at the Prince Edward Islands (46°45′S, 37°50′E) in an attempt to control unregulated fishing (Ryan et al. 1997). Five permits were issued to South African companies to fish within the Exclusive Economic Zone (EEZ) that extended for 200 nautical miles around the islands. Permit holders in the Prince Edward Islands EEZ are required to have fishery observers on board. Observers record fishery statistics, note by-catch, and, in the case of vessels operating out of Cape Town, are asked to salvage dead birds for scientific examination.

Birds received in Cape Town were measured and dissected to determine sex, the state of their gonads, and stomach contents. Age and breeding status was inferred where possible using plumage or bill coloration, molt, extent of skull ossification, presence of a brood patch, etc. Birds were kept frozen prior to examination. Observers reported 923 birds killed during 10 fishing trips to the Prince Edward Islands EEZ between October 1996 and June 1997 (Ryan et al. 1997). Fishing effort was spread throughout the sample period (5 sets in October, 131 in November, 207 in December, 37 in January, 84 in February, 38 in March, 196 in April, 140 in May, 63 in June). Of the birds killed, 393 were brought to Cape Town for examination. We also examined nine birds killed by the *Koryo Maru II* near South Georgia Island from April to June 1997.

Deviations from an assumed 1:1 sex ratio were tested using χ^2 goodness-of fit-tests with Yates correction for continuity, or binomial tests for small sample sizes. Chi-square and log-likelihood tests (for small samples) were used to test whether the frequency of fishery discards in bird stomachs differed between males and females. We used one-tailed Mann-Whitney *U*-tests to evaluate whether males contained more bait items (fresh pieces of pilchard, maasbanker, or cut squid mantle) than females.

Results.—Males predominated among birds killed by the Patagonian toothfish fishery off the Prince Edward Islands (Table 1). A significant male bias existed for the three species for which sample sizes exceeded 20 birds: White-chinned Petrel (*Procellaria aequinoctialis*), Grey-headed Mollymawk (*Thalassarche chrysostoma*), and Yellow-nosed Mollymawk (*T. chlororhynchos*). These biases were maintained throughout the breeding season for the two most commonly killed species. Among White-chinned Petrels, males comprised 81% of the birds killed in November–December ($n = 51$; $\chi^2 = 17.65$, $P < 0.001$), 85% in January–February ($n = 163$; $\chi^2 = 79.73$, $P < 0.001$), and 77% in March–April ($n = 17$; $\chi^2 = 3.77$, $P < 0.05$). Most of the mortalities of Grey-headed Mollymawks occurred in late summer (March to May), when 85% of the birds killed were males ($n = 93$; $\chi^2 = 44.04$, $P < 0.001$). However, males also predominated (89%, $n = 18$; $\chi^2 = 9.39$, $P < 0.01$) during the earlier part of the breeding season (November to February).

Virtually all birds killed were breeding adults. All of the White-chinned Petrels killed during the incubation and brood phases (November to January) had well-developed incubation patches and enlarged gonads, indicating actively breeding birds. White-chinned Petrels caught later in the breeding season also appeared to be adults; the only mortality of a fledgling occurred in late April. Among albatrosses, only one Black-browed Mollymawk (*T. melanophris*) and one Grey-headed Mollymawk (<1% of the total) were in immature plumage. Most of the Grey-headed Mollymawks and Yellow-nosed Mollymawks exhibited signs of having bred during the 1996–1997 season (brood patches, enlarged gonads, no active molt). Giant-petrels (*Macronectes* spp.) caught during the summer breeding season (October to March) also appeared to be breeding adults, whereas most of those caught from April to June were subadults. Interestingly, all of the giant-petrels recovered during summer were males (six Southern Giant-Petrels [*Macronectes giganteus*] and two Northern Giant-Petrels [*M. halli*]; binomial test, $P = 0.016$). This bias disappeared after the breeding season (Table 1).

TABLE 2. Comparisons between male and female seabirds killed in the Prince Edward Islands longline fishery in proportion containing bait and other fishery discards (%, with n in parentheses) and the number of bait items per bird ($\bar{x} \pm$ SD).

Species	Males	Females	Significance
	Proportion with bait or discards		
White-chinned Petrel	65 (194)	59 (39)	$\chi^2 = 0.28$, $P > 0.05$
Grey-headed Mollymawk	87 (95)	75 (16)	$G = 0.76$, $P > 0.05$
Yellow-nosed Mollymawk	61 (18)	100 (5)	$G = 2.02$, $P > 0.05$
Southern Giant-Petrel	71 (7)	75 (4)	$G = 0.32$, $P > 0.05$
Northern Giant-Petrel	100 (5)	50 (2)	$G = 0.24$, $P > 0.05$
	Number of pieces of bait		
White-chinned Petrel	0.92 ± 1.15	0.59 ± 0.75	$U = 4{,}329$, $0.05 < P < 0.10$
Grey-headed Mollymawk	3.37 ± 3.37	1.94 ± 4.01	$U = 1{,}049$, $P < 0.01$
Yellow-nosed Mollymawk	1.89 ± 1.97	2.20 ± 1.79	$U = 53$, $P > 0.05$
Southern Giant-Petrel	0.14 ± 0.38	1.00 ± 1.15	$U = 20$, $P > 0.05$
Northern Giant-Petrel	1.20 ± 0.45	0.50 ± 0.71	$U = 8$, $P > 0.05$

The male bias in longline mortality was not restricted to the Prince Edward Islands fishery. All nine birds collected off South Georgia Island in April 1997 were males: eight White-chinned Petrels (binomial test, $P = 0.004$) and one Black-browed Mollymawk.

Discussion.—The reason for the marked sex bias in seabird mortality associated with the Patagonian toothfish fishery is unclear. Sex differences in foraging area are unlikely to account for the higher mortality of males, because the toothfish fishery operates close to the birds' breeding islands. At the Prince Edward Islands, more than 80% of fishing effort occurred within 200 km of the islands during 1996–97 (Ryan et al. 1997). Even if males and females tended to forage in different areas historically, neither sex would be likely to forego an easy meal close to the breeding colony, especially when they are provisioning large chicks whose food demands are highest. By-catch rates of birds from the toothfish fishery at the Prince Edward Islands peaked at the end of the chick-rearing period (Ryan et al. 1997).

Different reproductive roles by males and females also are unlikely to account for male-biased mortality, because albatrosses and petrels share incubation and chick-rearing duties equally (Warham 1990). Because these species are monogamous and long-lived, it is difficult to imagine a selective advantage in having a skewed sex ratio in the population. It could be argued that selective mortality of females in the past (e.g. from the tuna fishery; Weimerskirch and Jouventin 1987, Bartle 1990, Croxall and Prince 1990) has resulted in an excess of males. However, the three species killed most frequently in the toothfish fishery at the Prince Edward Islands are not known to be killed in large numbers by tuna fisheries (Brothers 1991, Alexander et al. 1997), nor is there any evidence of sex-biased mortality among these species in other longline fisheries (Murray et al. 1993, Barnes et al. 1997). We believe that these hypotheses fail to account for the consistent male bias among several species throughout their breeding seasons, suggesting that another factor is responsible for the greater susceptibility of males.

An alternative hypothesis is that females are competitively excluded from scavenging around fishing vessels. Bartle (1990) posited that the higher survival rate of male Westland Petrels (*Procellaria westlandica*) results from females being disadvantaged when competing with larger males for fishery discards around trawlers. Males average larger than females in procellariiforms (Warham 1990), and dominance hierarchies in feeding groups are based on size (Bartle 1974). Croxall and Prince (1990) used a similar argument to account for unexpectedly high mortality of adult female Wandering Albatrosses relative to juveniles.

If females are at a competitive disadvantage at fishing vessels, they should be less successful at scavenging bait and fishery discards. However, except for a larger mean number of bait items in male Grey-headed Mollymawks, significant differences between the sexes in the presence of bait and fishery discards in stomachs were absent (Table 2). Another possibility is that females generally avoid feeding around fishing vessels, even though they appear not to be greatly disadvantaged when they do feed there. At present, we have no data to test this hypothesis.

Irrespective of the reason for male-biased mortality, the bias exacerbates the effect of the Patagonian toothfish fishery on albatross and petrel populations breeding on subantarctic islands. The fishery kills substantial numbers of birds annually (Ryan et al. 1997), and sex-biased mortality of breeding adults increases the demographic effect (Weimerskirch and Jouventin 1987, Croxall et al. 1990). The problem is made even worse by the development of new longline fisheries elsewhere within the range of affected bird species (Barnes et al. 1997).

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