Fisheries bycatch mortalities of sooty shearwaters (*Puffinus griseus*) and short-tailed shearwaters (*P. tenuirostris*)

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CONTENTS

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ABSTRACT

The magnitude of the incidental 'bycatch' of two petrels, sooty shearwater (*Puffinus griseus*) and short-tailed shearwater (*P. tenuirostris*) in Pacific and Atlantic Ocean fisheries was estimated from a review of 46 published and unpublished documents. Though abundant, both species are harvested for food, and high levels of bycatch could affect the sustainable management of harvested populations. Bycatch of *P. griseus* and *P. tenuirostris* was evidenced from 14 net fisheries (21 reports), 5 longline fisheries (13 reports) and a trawl fishery (3 reports). In the past, these species were frequently captured by driftnets of fisheries in the central North Pacific, with sooty shearwaters especially in nets of the Japanese squid fishery from 1978 to 1991 and short-tailed shearwaters in the Japanese mothership salmon driftnet fishery from 1952 to 1988. These and several other ocean fisheries are now closed, and mortalities in present fisheries are much reduced. However, many fisheries have no observers, and available information may often be inaccurate, so that estimating total magnitude of bycatch within robust statistical limits is difficult.

Keywords: *Puffinus griseus*, *P. tenuirostris*, sooty shearwaters, muttonbirds, fisheries bycatch, seabirds, sustainable management, Pacific Ocean, Atlantic Ocean.

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1. Introduction

Incidental and accidental capture of seabirds in fishing gear (e.g. longlines, gill- and trawl nets) is a well-known and widespread problem that may threaten populations of rare albatrosses and petrels (Gales 1998). Sooty shearwaters (*Puffinus griseus*, 'tītī') and short-tailed shearwaters (*Puffinus tenuirostris*, 'yolla'), the most abundant procellariiforms in the South Pacific Ocean, migrate across the equator from their breeding colonies in the South Pacific to regions of the North Pacific and Atlantic during the austral winter and are therefore vulnerable to incidental capture over a vast range (Uhlmann 2001).

Like many other procellariiform petrels, sooty shearwaters and short-tailed shearwaters are long-lived, reproduce slowly and mature late in life (Warham 1990; Skira 1991). As cumulative source of adult mortality, fisheries bycatch could cause a population to decline if mortalities exceed the relative rate of population growth (Caswell et al. 1998). This could have major implications on the sustainable management of harvest regimes of these two species, because their chicks are annually harvested from their breeding grounds in Australia and New Zealand (Skira 1990; Lyver & Moller 1999). Any changes in abundance may also have profound effects on the ecology of their breeding islands. sooty shearwaters and short-tailed shearwaters are 'keystone species' because of their impact on soil aeration, nutrification and plant regeneration (Moller et al. 2000).

The impact of fisheries bycatch on seabird populations has been primarily focused on rare species, e.g. the wandering albatross (*Diomedea exulans*) (Weimerskirch & Jouventin 1987; De la Mare & Kerry 1994; Tuck & Polacheck 1995; Weimerskirch et al. 1997; Weimerskirch 1998). The extent and effects of fisheries bycatch on sooty shearwaters and short-tailed shearwaters populations are unknown (King 1984) or poorly understood (Warham & Wilson 1982; Ogi 1984; INPFC 1991; DeGange et al. 1993; Ogi et al. 1993). For far-ranging seabird species such as sooty shearwaters and short-tailed shearwaters, the total magnitude of bycatch can only be assessed by summing mortalities from as many fisheries as possible.

1.1 OBJECTIVES

This report reviews published and unpublished bycatch records to:

- characterise the main types of fisheries (longline, gill- and trawl-net, among others) that potentially pose most risk to sooty shearwaters and short-tailed shearwaters;
- assess whether at-sea abundance corresponds to observed bycatch rates; and
- describe trends and general patterns in the reporting and presentation of bycatch data by critically evaluating the results presented in the reviewed source materials.

This research forms a building block in the long-term research project '*Kia Mau Te Tītī Mo Ake Tōnu Atu*' ('Keep the tītī forever'), University of Otago, Dunedin, New Zealand to understand long-term threats to harvests and ecology of sooty shearwaters on their breeding islands.

2. Bycatch in gillnet fishing

2.1 GILLNET FISHING: AN OVERVIEW

Fishing with gillnets is a centuries-old technique. A gillnet typically consists of a headline and a weighted footline, with netting stretched between them (Hubert 1983; Herrick & Hanan 1988). A popular form of gillnet fishing is 'driftnetting' (Fig. 1). Driftnets consist of a single layer of net. Nowadays mostly durable monofilament nylon nets are used, which drift, fixed by buoys, like curtains several metres deep within the water column. Net and mesh size characteristics vary depending on the type of fisheries and their target species (Table 1).

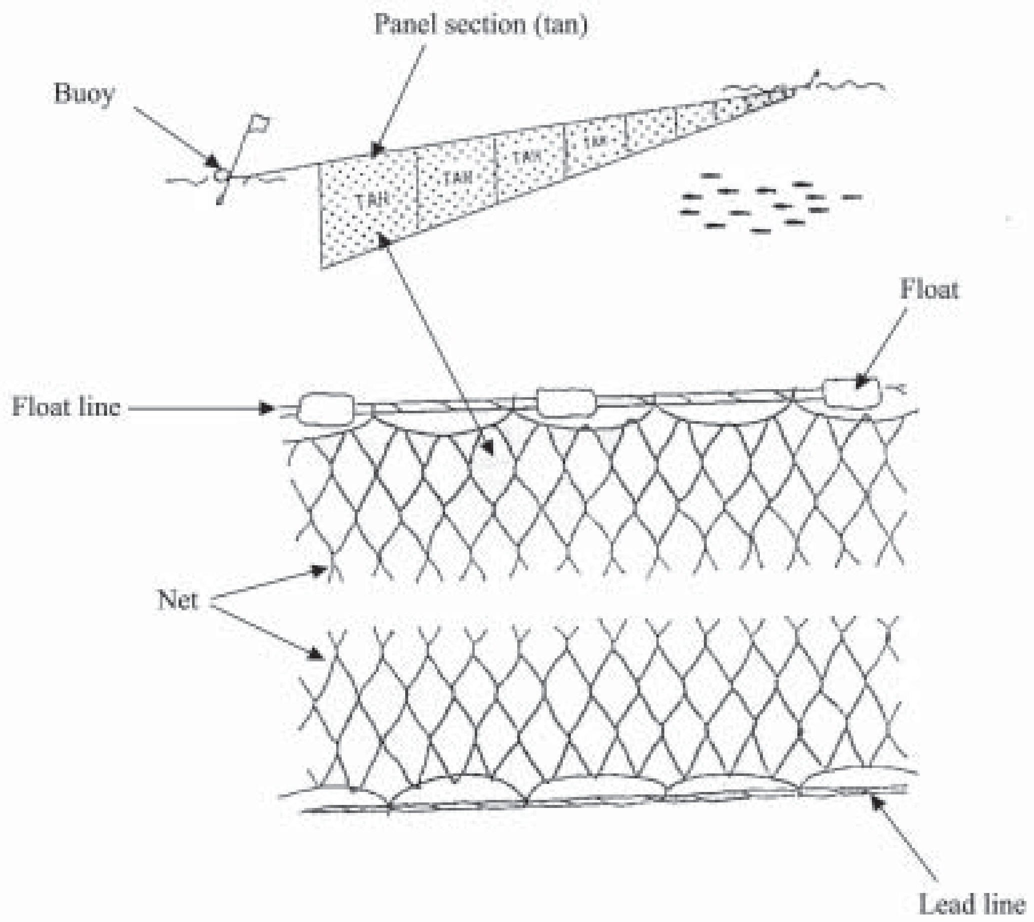


Figure 1. General type of driftnet as used in squid and salmon fisheries in the North Pacific since the late 1970s (from Nakano et al. 1993, fig. 3, p. 31).

TABLE 1. GENERAL LOCATIONS, FISHING SEASONS AND GEAR DIMENSIONS OF MAJOR NORTH PACIFIC DRIFTNET FISHERIES.

Ref.*	Fishery†	Period actively fishing	Fishing area	Fishing season	Length of net panel (m)	Setting depth (m)	Mesh size (mm)	No. of panels/ section	Section length (km)	No. of sections /set	Total length (km)
1, 3	JLAMFD	1970?–91	10°–46°N,145°E–145°W	Jan–May, year-round	32–54	6–13	151–210	96–167	3–5	8–10	30–50
2, 6	JLBSFD	1952–88	38°–44°N, 155°E–174°E	May–July	30, 37.5, 47.5	8	110–115				13–15
4, 6	JMOSFD	1952–88	46°–58°N, 155°E–175°E	Mid-May–late July	50	8	121,130	330			15-17
8	JSFDR	1991–pres.	40°–60°N, 150°E–170°E	Mid-May–late July	50	8	124–130		< 4	< 8	< 32
3, 4, 7	JSQFD	1978–91	20°–46°N, 170°E–155°W	May–Dec	30–52	6–12	105–135	100–180	< 6	8–10	20–62
3, 4, 5	KSQFD	1979–91	36°–46°N, 141°E–170°W	Apr–Dec	50	8–12	76–115	150–200	< 10	5–6	38–88
3	TLAMFD	1980?–91	32°–44°N, 156°E–166°W	Jan–May year-round	30–40	7–21	190–210	118–360	< 11	3–4	33–45
3, 4	TSQFD	1980–91	38°–44°N, 156°E–166°W	May–Dec	15–40	9–20	76–110	250–667	< 10	3-4	12–41

* 1 Nakano et al. (1993); 2 DeGange & Day (1993); 3 Fitzgerald et al. (1993); 4 Jones & DeGange (1988); 5 Gong et al. (1993); 6 DeGange et al. (1985); 7 Yatsu et al. (1993a); 8 Artyukhin & Burkanov (2000).

† See Table 2 for fisheries codes.

If the gear is deployed near the water surface, pursuit diving seabirds such as shearwaters, which seize fish and other prey species gilled in the nets by active diving (propelled underwater by moving wings and legs) (Weimerskirch & Sagar 1996) are particularly vulnerable to accidental entanglement (DeGange & Newby 1980; Ogi et al. 1993). Mortalities of seabirds from this type of fishing can be massive. For example, at least 10 million seabirds were estimated to be caught by a single fishery, the Japanese 'mothership' driftnet fishery for salmon, between 1952 and 1974 (Ainley et al. 1981).

Concern about high bycatch rates of non-target species including fish, turtles, marine mammals and seabirds in driftnets mounted in the early 1990s (King 1984; Jones & DeGange 1988; Northridge 1991; FAO 1999), when opposition to the use of such resource-wasting fishing gear was raised. Japan, Korea, Taiwan, the USA, and Canada initiated co-operative scientific observer programmes to assess the extent of incidental capture of non-target species in pelagic, sub-surface squid driftnets (operated by Asian fishing nations) for the 1989, 1990 and 1991 fishing seasons (INPFC 1991; Fitzgerald et al. 1993). These observer programmes revealed that thousands of 'dark shearwaters' (many observers do not separate sooty shearwaters and short-tailed shearwaters because they are not easy to distinguish) drowned each year in driftnets from various high seas North Pacific fisheries (DeGange et al. 1993; Johnson et al. 1993; Ogi et al. 1993; Yatsu et al. 1993a). For example, the annual incidental catch of sooty shearwaters and short-tailed shearwaters for all driftnet fleets combined was estimated to be 356 000 and 40 000 respectively for the 1990 season (Ogi et al. 1993). Worst-case scenarios estimated 1.2 million sooty shearwater captures by driftnet fisheries per year (DeGange et al. 1993).

Observer data spurred international discussions that resulted in UN resolutions 45/225, and 46/215, which banned all driftnet activities on the high seas by

TABLE 2. LIST OF ALL FISHERIES FROM WHICH RELEVANT BYCATCH INFORMATION WAS GATHERED.

CODE	NET FISHERY	REFERENCE*
BCSFD	British Columbia salmon gillnet	12, 29
BCSQE	British Columbia experimental squid	17
CAGF	Californian gillnet	26, 41
JLAMFD	Japanese large-mesh driftnet	18, 24, 31, 35
JLBSFD	Japanese land-based salmon driftnet	15, 17, 25, 27, 35
JMOSFD	Japanese mothership salmon driftnet	17, 35, 25, 27, 16, 33, 34
JSFDR	Japanese salmon driftnet in Russia	3
JSQFD	Japanese squid driftnet	17, 18, 24, 25, 28, 33, 35, 45, 46
KSQFD	Korean squid driftnet	18, 22, 24, 25, 33, 35
NSOG	Newfoundland salmon and cod gillnet	13
NZSF	New Zealand setnet	40
PWSFD	Prince William Sound salmon driftnet	42, 43, 44
PWSFS	Prince William Sound setnet	43
TLAMFD	Taiwanese large-mesh driftnet	18, 35
TSQFD	Taiwan squid driftnet	18, 24, 25, 33, 35
USECG	Unites States east-coast inshore gillnet	19
UPSFD	Unimak Pass salmon driftnet in Alaska	4, 25
CODE	**LONGLINE AND OTHER FISHERIES**	**REFERENCE***
ALOUS	Gulf of Alaska/Bering Sea groundfish longline	39, 42
ARDL	Argentinean demersal longline	37
AUDTL	Australian domestic tuna longline	7, 11, 21
AUJTL	Australian Japanese tuna longline	7, 9, 10, 11, 20
BRDL	Brazil demersal and mid-water longline	32
BSAIGP	Gulf of Alaska/Bering Sea groundfish pot and trawl	42
SADL	South African demersal and pelagic longline	5, 36
NZDTL	New Zealand domestic tuna longline	2, 23
NZJTL	New Zealand Japanese tuna longline	2, 4, 7, 30
NZJSQ	New Zealand Japanese squid jig	8
NZSQT	New Zealand squid trawl fishery	6
UADL	Uruguay demersal and mid-water longline fishery	38

* 1 Ainley et al. (1981); 2 Alexander et al. (1997); 3 Artyukhin & Burkanov (2000); 4 Baird (1994); 5 Barnes et al. (1997); 6 Bartle (1991); 7 Bergin (1997); 8 Blezard & Burgess (1999); 9 Brothers et al. (1998); 10 Brothers et al. (1999a); 11 Brothers et al. (1999c); 12 Carter & Sealy (1984); 13 Chardine (1998); 14 Cousins et al.(2000); 15 DeGange & Day (1991); 16 DeGange et al. (1985); 17 DeGange et al. (1993); 18 Fitzgerald et al. (1993); 19 Forsell (1999); 20 Gales (1998); 21 Gales et al. (1999); 22 Gong et al.(1993); 23 Imber (1994); 24 Johnson et al. (1993); 25 Jones & DeGange (1988); 26 King (1984); 27 King et al. (1979); 28 McKinnell & Waddell (1993); 29 Mitchell (1997); 30 Murray et al. (1993); 31 Nakano et al. (1993); 32 Neves & Olmos (1998); 33 Northridge (1991); 34 Ogi (1984); 35 Ogi et al. (1993); 36 Ryan & Boix-Hinzen (1998); 37 Schiavini et al. (1998); 38 Stagi et al. (1998); 39 Stehn et al. (2001); 40 Taylor (1992); 41 US Department of Fish and Game (1987); 42 Wohl et al. (1998); 43 Wynne et al. (1991); 44 Wynne et al. (1992); 45 Yatsu et al. (1993a); 46 Yatsu et al. (1993b).

1 January 1993 (Nagao et al. 1993). However, large-scale driftnet fishing for salmon still persists in Russian and Mediterranean waters that are not included in the UN resolution (Northridge 1991; Artyukhin & Burkanov 2000).

Despite raised political concern and much-reduced bycatch from gillnet fisheries since 1993, there are still many gaps in our knowledge of whether a significant threat to sooty shearwaters and short-tailed shearwaters remains. Much of the bycatch occurs unobserved, and robust statistical estimates of bycatch totals are largely absent.

Eight major driftnet fisheries are reviewed here: Japanese, Korean and Taiwanese squid driftnet fisheries (JSQFD, KSQFD, and TSQFD, respectively), including Japanese and Taiwanese large-mesh components (JLAMFD and TLAMFD), Japanese mothership salmon driftnet fishery (JMOSFD), Japanese land-based salmon driftnet fishery (JLBSFD), and Japanese salmon driftnet fishery in Russia (JSFDR) (Table 2).

2.2 SALMON DRIFTNETS OF THE NORTH PACIFIC

Driftnetting for salmon (*Oncorhynchus* spp.) in the North Pacific evolved by 1952 into a large-scale offshore operation involving fleets from Japan, Korea and Taiwan (Fredin et al. 1977; King et al. 1979; Ainley et al. 1981; King 1984; DeGange et al. 1993). Fredin et al. (1977) provide most detail on history, fishing gear and strategy of the North Pacific salmon driftnet fishery.

Two distinct Japanese fleets fished for salmon: the mothership fishery in pelagic waters of the western Pacific (north of 46°N) and the land-based fishery in waters of the eastern Pacific, west of Japan (INPFC 1991). Seabird interactions were studied in both the mothership fishery (Ainley et al. 1981; King 1984; DeGange et al. 1985; Jones & DeGange 1988; Northridge 1991; DeGange et al. 1993; Ogi et al. 1993) and the land-based ones (King et al. 1979; Ainley et al. 1981; King 1984; Jones & DeGange 1988; DeGange & Day 1991; DeGange et al. 1993; Ogi et al. 1993).

The Japanese mothership salmon driftnet fishery traditionally fished to the north and south of the Aleutian Islands, between 46°N and 58°N and west of 175°E (Fig. 2). The fishery expanded to fish east of 175°E after 1956. These fishing grounds decreased significantly in size with the adoption of the 200 nautical mile exclusive economic zone (EEZ) regulations by USA and USSR in 1978. Fishing then became concentrated within the US EEZ, the southern Fisheries Convention Zone (FCZ), and south of the Aleutians (DeGange et al. 1985; Northridge 1991). The effort and size of the mothership fishery decreased gradually before ceasing altogether in 1991 (Ogi et al. 1993)

This fishery operated from mid-May/early June until late July (King et al. 1979; Jones & DeGange 1988), which was when migratory abundance of short-tailed shearwaters peaked in the fishing area (Uhlmann 2001). Catcher vessels typically set 15 km of gillnets per operation (defined hereafter as the deployment and retrieval of one gillnet unless described otherwise). Each gillnet consisted of a maximum of 330 panel sections, called tans, which were typically 50 m long and 8 m deep (DeGange et al. 1985; Jones & DeGange 1988; Northridge 1991) (Table 1). Nets were set at dusk and hauled at dawn, soaking for about 9 hours (DeGange et al. 1985).

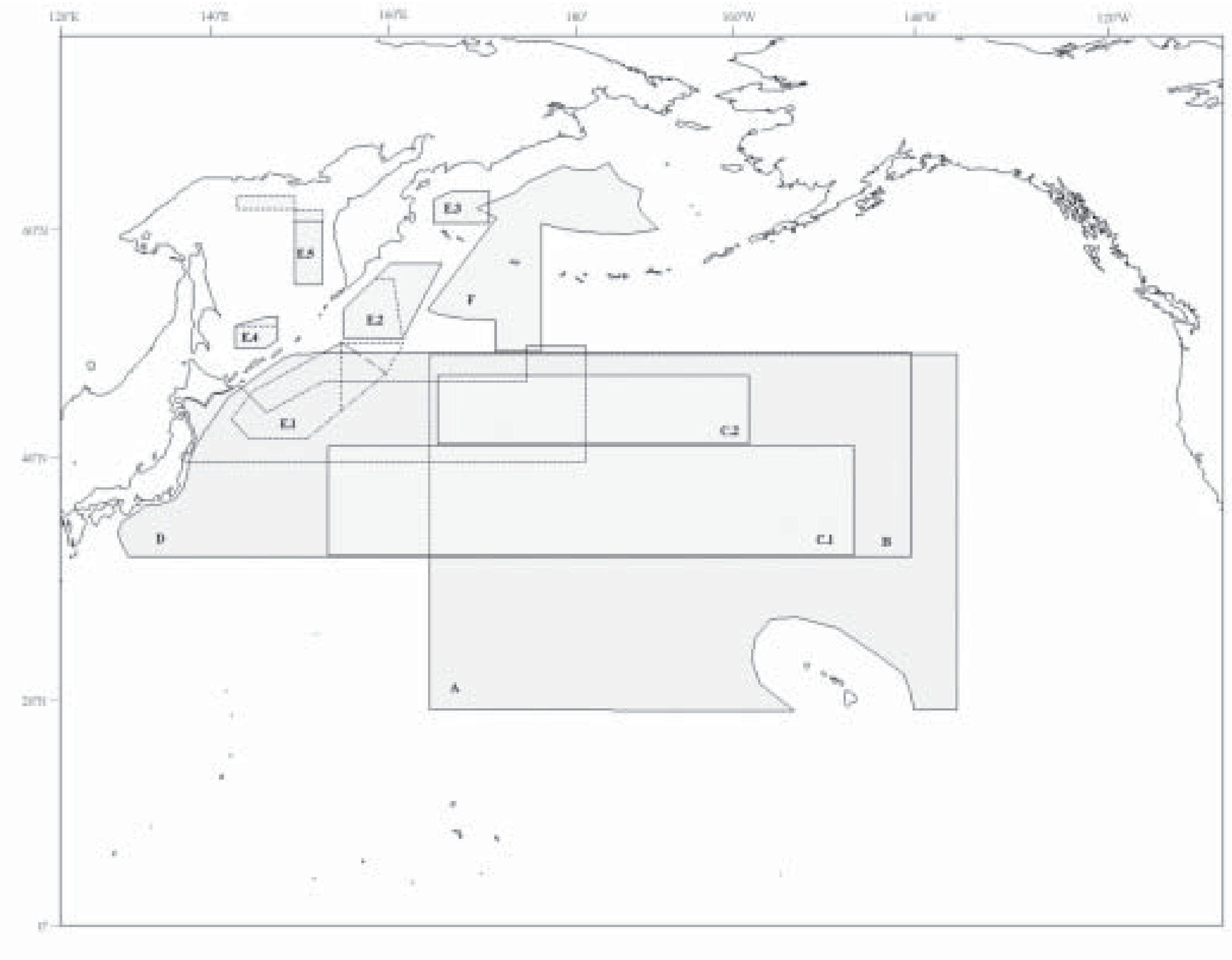


Figure 2. Fishing areas of major North Pacific Japanese driftnet fisheries: (A) Japanese squid, (B) Korean squid, (C.1) Taiwanese large-mesh, (C.2) Taiwanese squid, (D) Japanese salmon land-based, (E) Japanese salmon in Russia, (F) Japanese salmon mothership.

Mothership vessels were monitored in the US EEZ from 1977 until their ban from the area in 1988 (Wohl et al. 1998). US scientific observers systematically collected data on seabird bycatch from 1981 onwards (DeGange et al. 1985; Jones & DeGange 1988). Observers covered approx. 6% of the net retrievals between 1981 and 1987 (Jones & DeGange 1988; DeGange et al. 1993). Bird bycatch rates were temporally and spatially highly variable: between 0 and 457 seabirds were taken per operation (DeGange et al. 1985, DeGange et al. 1993).

The earliest records of shearwater mortalities from the Japanese mothership salmon driftnet fishery were obtained during the 1971 season, when 369 vessels were fishing north of 46°N and west of 175°W (King et al. 1979). King (1984) and King et al. (1979) estimated that between 150 and 450 thousand (60%) of the seabirds caught in the mothership fishery were sooty shearwaters or short-tailed shearwaters. These calculations were based on bycatch data gained onboard of US research vessels in the area of the commercial Japanese mothership salmon driftnet fishery in 1973, 1974, 1977/78, and 1981.

Two Japanese research vessels set 1 664 300 tans (here net sections were 50 m long and 6 m deep) of driftnet for salmon in the area of the commercial Japanese mothership salmon driftnet fishery between 48°N and 170°E in June/July of 1978 and 1979 (Ainley et al. 1981). The research vessels deployed varying numbers of tans with mesh-sizes ranging between 37 and 233 mm. Catch rates of 0.001 short-tailed shearwaters/tan and 0.004 sooty shearwaters/tan were observed, with the most birds taken in nets of commercial net size ranges (112 to 130 mm) (Ainley et al. 1981). This indicates that the commercial mothership fleet caught about 19 949 short-tailed shearwaters and 5894 sooty shearwaters in 1978. However, no confidence intervals are presented and temporal and spatial variability is likely to have been high (DeGange et al. 1985). In addition, extrapolations of bycatch from research observations for commercial fisheries need to take differences in mesh sizes between research and commercial nets into account (Ainley et al. 1981). There are also observations that up to 50% of entangled birds dropped out of the net before they were hauled on board, so total bycatch rates may have been much higher (Ainley et al. 1981). Nevertheless, if the mean values are reliable, 6 million dark shearwaters could have been caught between 1952 and 1974 (Ainley et al. 1981). It is not clear whether these estimates include extrapolations of total fishing effort outside the US EEZ.

Ogi (1984) estimated annual takes of 89 160 (SE ±13 698) short-tailed shearwaters and 2118 (SE ±1718) sooty shearwaters in driftnets of the Japanese mothership salmon driftnet fishery between 1977 and 1981 from data collected on research vessels. In order to calculate this estimate the average number of dead seabirds per unit of research gillnets was multiplied by the total number of commercially deployed gillnet tans. This assumes that bycatch rates in research nets were comparable with those from commercial nets, but fishing gear (especially mesh size), strategy, time and areas fished differed markedly between them (Ainley et al. 1981; DeGange et al. 1985), so this particular method of estimating total mortality is prone to error. To account for the higher catch rates of nets with commercial net sizes Ainley et al. (1981) suggested to generally increase estimates from research nets by at least 30%.

DeGange et al. (1985) precisely summarised observations from Japanese mothership salmon driftnet fishery vessels in the FCZ, north and south of the Aleutians, between 1981 and 1984 (Table 3). Catch rates of short-tailed shearwaters (as the observed number of birds taken per observed number of sets) were high, especially in 1983, and similar to estimates from the Japanese land-based fishery (DeGange & Day 1991, Ogi et al. 1993). Mean annual mortalities of short-tailed shearwaters ranged between 8910 (± 4611, 95% confidence interval) and 60 332 (± 16 443) between 1981 and 1984. In contrast, total mortality estimates for sooty shearwaters were much lower, at 62 (± 62) and 563 (± 500).

In a more recent study, Ogi et al. (1993) incorporated data of bird samples and bycatch records from 1982 to 1987 with observations of commercial operations of the 1990 season to estimate an incidental take of 550 (SE ± 1.3) sooty shearwaters and 3431 (SE ± 7.7) short-tailed shearwaters, but how these estimates were calculated and whether the standard errors given were realistic are unclear.

TABLE 3. NUMBERS OF SOOTY SHEARWATERS (SOSH), SHORT-TAILED SHEARWATERS (STSH) AND DARK SHEARWATERS (DASH) OBSERVED AS BYCATCH, AND TOTAL AND OBSERVED DRIFTNET FISHING OF THE JAPANESE SALMON MOTHERSHIP FISHERY NORTH AND SOUTH OF THE ALEUTIAN ISLANDS, 1981–84.[1]

Year	No. of sets (total)	No. of tans[2] (total)	No. of sets (observed)	No. of tans[2] (observed)	No. of SOSH (observed)	No. of STSH (observed)	No. of DASH (observed)
1981	8811	2 907 630	262	86 460	3	374	2063
1982	8906	2 938 980	277	91 410	24	2616	97
1983	9138	3 015 540	266	87 780	16	6567	67
1984	8403	2 772 990	344	113 520	19	2529	0

1 From DeGange et al. 1985, tables 1, 5.

2 The number of tans was approximated by assuming that 330 tans of 50 m length were deployed per set (DeGange et al. 1985).

The Japanese land-based salmon driftnet fishery operated between May and July in the North Pacific region (Fig. 2) from 38°N to 44°N and 155°E to 174°E from 1952 until 1988 (DeGange & Day 1991; Ogi et al. 1993) (Table 1). This overlapped with favourable habitat of sooty shearwaters and short-tailed shearwaters during their northward migration (Uhlmann 2001). Fishing effort during the seasons between 1986 and 1988 was typically highest in early/mid-June and concentrated along the northern boundary (between 42° and 44°N) in 1988 (Northridge 1991). Small-sized vessels (< 7 gross tons) fished further inshore than large vessels (7–90 gross tons). The large vessel component of the fleet peaked, both in fleet size and fishing effort, in the mid-1960s, when 374 vessels set more than 295 thousand km of gear, compared with 156 vessels setting 39 thousand km in 1989 (DeGange et al. 1993). The offshore land-based fishery used gillnets with mesh of 110 or 115 mm and panel sizes of 30–47.5 m long and 8 m deep, laced together to form 13–15 km long nets (DeGange & Day 1991) (Table 1). Nets were typically set during the late afternoon and retrieved in the early mornings (DeGange & Day 1991).

As was done with the Japanese mothership salmon driftnet fishery, most of the seabird bycatch estimates for Japanese land-based salmon driftnet fishery were generated from data obtained during research fishing and therefore may not be representative of the commercial fleet. DeGange & Day (1991) summarised data on the incidental take of seabirds from 413 gillnet operations made by Japanese research vessels on fishing grounds of the commercial land-based fishery between 1977 and 1987. The sample size of 413 observed sets is relatively small and spread across many years, especially considering that approx. 3480 operations were made on average annually between 1980 and 1985 (Jones & DeGange 1988). In these 413 operations, 2204 seabird deaths were observed, which comprised 5%, 33% and 18% sooty shearwaters, short-tailed shearwaters and dark shearwaters, respectively (DeGange & Day 1991). DeGange & Day (1991) scaled these observations against total commercial effort for the 1977 and 1987 seasons, when 146 265 km and 1 156 224 tans of gillnet were fished, respectively, and estimated that 1843 sooty shearwaters, 45 883 short-tailed shearwaters and 32 646 dark shearwaters were killed during the 1977 season, and 2197 sooty shearwaters, 16 418 short-tailed shearwaters and 8903 dark shearwaters in 1987.

Ogi et al. (1993) estimated seabird mortalities for the 1990 season. Their estimates extrapolated bycatch data obtained during research cruises of both medium- and small-sized vessels between 1974 and 1987. Ogi et al. (1993) estimated (without variance), based on observation from 878 operations of medium-sized vessels deploying 281 554 tans of gillnet, that 18 592 sooty shearwaters and 18 008 short-tailed shearwaters were caught; and that, including observations from 255 120 tans deployed by small-sized vessels, 46 162 sooty shearwaters and 5600 short-tailed shearwaters were killed in total. Proportion of sooty shearwaters in estimates by Ogi et al. (1993) differed considerably from data of DeGange & Day (1991), with sooty shearwaters being the dominant species taken. This may derive from differences between the two research fisheries, or natural year-to-year variability of bycatch events or both. However, the scale of these observations cannot be clarified unless more detail about the actual data (e.g. gear characteristics, sampling design and procedures) and estimation procedures is provided.

The Japanese salmon driftnet fishery in Russia developed rapidly when Japanese fleets increasingly shifted into Russian waters in the early 1990s following the ban from international pelagic waters and the North American EEZ (Artyukhin & Burkanov 2000). This fishery is the last remaining large-scale commercial driftnet fishery for salmon that is still active. Driftnetting for sockeye (*Oncorhynchus nerka*) and other salmon species takes place from mid-May to late July in five different management zones in the Sea of Okhotsk and in the vicinity of the Kamchatka Peninsula (Fig. 2), both areas potentially overlapping with the distribution of short-tailed shearwaters during the boreal summer (Uhlmann 2001). Between 1993 and 1997, about 503 796 km of driftnet (10 075 920 tans) were deployed by an unknown number of vessels in the Russian EEZ. One Russian observer has been placed on each mid-size tonnage vessel during all of the fishery's operations since 1993. In total, 3251 driftnets (length of 93 704 km) were monitored between 1993 and 1997, and 32 929 seabirds were caught in this observed sample, translating to approx. 827 181 seabird captures in all salmon driftnets in Russian waters between 1993 and 1997. An estimated 512 sooty shearwaters, 78 395 short-tailed shearwaters and 258 680 unidentified shearwaters were included in this bycatch (Table 4).

TABLE 4. TOTAL NUMBERS OF SOOTY SHEARWATERS (SOSH), SHORT-TAILED SHEARWATERS (STSH), AND DARK SHEARWATERS (DASH) BYCATCH, AND OBSERVED AND TOTAL FISHING EFFORT (km OF DRIFTNET) IN JAPANESE SALMON DRIFTNET FISHERIES IN RUSSIA, WHERE AVAILABLE, SINCE 1990.

Year	Observed km of driftnet	Total km of driftnet	No. of SOSH	No. of STSH	No. of DASH
1990–92	?	?	?	?	?
1993	42 157	148 000	0	0	142 111
1994	19 706	54 000	0	0	26576
1995	21 144	90 000	13	33 076	27 532
1996	4 684	75 000	48	13 954	14 011
1997	6 012	130 000	451	31 365	48 450
1998–present	?	?	?	?	?

From Artyukhin & Burkanov 2000, table 4, p. 111, except data for total km of driftnet, which are from Artyukhin & Burkanov (unpubl. data).

Interpretation of the data presented by Artyukhin & Burkanov (2000) is difficult because: there is no measure of variance given with the annual bycatch estimates of each species; and no details are given for the sampling design, e.g. what proportion of sets was observed per year and area in relation to total fishing effort.

Fishing area and fleet size of Asian salmon fisheries declined when the USA and Russia introduced 200 mile EEZs. Alternative fisheries developed, and Japan, Korea and Taiwan commenced using driftnets to catch 'neon flying squid', *Ommastrephes bartrami*, in the pelagic waters of the northwestern Pacific in 1978, 1979 and 1980 (Yatsu et al. 1993a). Fishing gear, season and strategy was very similar between these three fleets (Table 1). Fishing followed a seasonal cycle in adaptation to the seasonal movements of squid between sub-arctic and sub-tropical waters (Gong et al. 1993), which are believed also to have influenced sooty shearwaters migratory patterns (Uhlmann 2001).

2.3 SQUID DRIFTNETS OF THE NORTH PACIFIC

Driftnet fishing for squid in the North Pacific by Japanese, Korean and Taiwanese fleets was intense in the 1980s (Jones & DeGange 1988; INPFC 1991; Northridge 1991; DeGange et al. 1993; Fitzgerald et al. 1993; Gong et al. 1993; Johnson et al. 1993; McKinnell & Waddell 1993; Yatsu et al. 1993a). A large-scale, co-operative observer programme was developed between the USA, Japan, Korea, Taiwan for these fisheries for the 1989, 1990, and 1991 seasons (Fitzgerald et al. 1993). A preliminary observer programme in 1989 (Gjernes et al. 1990) served as a trial for the subsequent years to help to eliminate errors and uncertainties in observer identification, coverage levels and programme logistics (INPFC 1991). Detailed information on the 1991 observer programme is not available.

The Korean squid driftnet fishery fished the Central North Pacific, between 36°N and 46°N and 141°E and 170°W, between April and December, 1979–91 (Fig. 2). Gong et al. (1993) present a summary of the fishery (Table 5). Gillnets with mesh sizes ranging from 76 to 115 mm were used (Table 1). A set of one gillnet typically consisted of 5–7 sections, composed of 200–250 panels, with each panel ('pok', equivalent to Japanese 'tans') 50 m long and 8–11 m deep. Nets were usually deployed in surface or sub-surface sets (set 1–2 m below the surface) during the late afternoon, soaked for 6–8 hours and then retrieved at night (Gong et al. 1993). Fishing operations of the Korean squid driftnet fleet were systematically monitored during the 1990 season (Fitzgerald et al. 1993; Gong et al. 1993; Johnson et al. 1993; Ogi et al. 1993), but information on seabird mortalities from previous fishing years is sparse (Jones & DeGange 1988; Northridge 1991; Gong et al. 1993). In 1990, US and Korean observers monitored an unspecified sub-sample of net sections per haul, and all birds (dead or alive) that were decked or dropped out during net retrieval were recorded (Fitzgerald et al. 1993). Altogether 669 662 of 26.6 million tans were observed (2.5% coverage) (Gong et al. 1993). Korean observers were not confident with seabird identification, so their data were deemed too inaccurate to use (Johnson et al. 1993). Based on valid observations during 440 operations

TABLE 5. FISHING EFFORT OF THE KOREAN SQUID DRIFTNET FISHERY, 1979–90.

YEAR	NO. OF PANELS	CATCH (t)	NO. OF VESSELS
1979	?	?	3
1980	3 826 469	4 694	14
1981	7 124 523	22 899	34
1982	7 124 161	22 897	60
1983	5 634 961	37 732	99
1984	12 506 039	49 441	111
1985	13 943 441	70 762	97
1986	17 587 232	59 024	117
1987	19 781 364	84 470	140
1988	24 594 370	100 898	150
1989	24 780 316	134 120	157
1990	24 590 505	123 786	142
1991	Fishing ceased with adoption of UN resolution		

From Gong et al. 1993, table 1, p.47; table 3, p.51.

(1.5% of all operations made during the 1990 season) by 11 vessels, Johnson et al. (1993) estimated that 40 388 (SE ± 4452) dark shearwaters, 29 790 (SE ± 3705) sooty shearwaters, and 573 (SE ± 133) short-tailed shearwaters were caught in Korean squid driftnets in 1990. However, Ogi et al. (1993) report 10 709 dark shearwaters, 31 201 sooty shearwaters and 560 short-tailed shearwaters were killed in Korean squid driftnets in 1990. It is unclear whether the estimates by Ogi et al. (1993) are based on the same data that Johnson et al. (1993) used.

The Japanese squid driftnet fishery was by far the largest driftnet fishery in the North Pacific throughout its active period between 1978 and 1991 (Ogi et al. 1993; Yatsu et al. 1993a). Yatsu et al. (1993a) present a detailed description of this fishery, its history and fishing effort. The Japanese squid driftnet fleet grew rapidly in size and effort from its commencement in 1978 to its peak in 1986, when the greatest number of tans was deployed (Table 6). Fishing grounds were off eastern Hokkaido and Honshu in 1978 and gradually moved into pelagic waters of the Central North Pacific (Fig. 2). After 1981 the Japanese driftnetters targeted neon-flying squid usually between May and December in waters west of Japan at 20°–46°N and 170°E–155°W (Yatsu et al. 1993a). The northern boundary of the fishing area shifted north throughout the season to avoid the increased bycatch of salmonids (Yatsu et al. 1993a). Fishing effort was generally highest in August, with the most tans deployed along the northern boundary of the fishing ground at 46°N (Yatsu et al. 1993a).

Nylon monofilament driftnets were used, typically with mesh sizes between 105 and 120 mm and net panel dimensions of 30–52 m length and 7–11 m depth (Table 1). They were deployed in 50 to 62 km long nets during daylight hours, before retrieval at night (after approx. 10 hours in the water) (Fitzgerald et al. 1993).

Seabird interactions with some Japanese driftnets were recorded for the fishing seasons in 1984 (Jones & DeGange 1988), 1986 (Jones & DeGange 1988), 1988

TABLE 6. FISHING EFFORT OF THE JAPANESE SQUID DRIFTNET FISHERY, 1978–90.

YEAR	NO. OF PANELS (TANS)	CATCH (t)	NO. OF VESSELS
1978	7 490 242 [1]	46 308	> 800
1979	11 099 874 [1]	47 652	?
1980	14 709 505 [1]	119 000	?
1981	18 319 137 [1]	104 000	534
1982	21 928 768	158 722	529
1983	25 224 746	215 778	515
1984	29 251 829	123 719	505
1985	34 023 355	197 715	502
1986	36 367 294	152 226	492
1987	32 017 130	208 319	478
1988	36 055 567	157 773	463
1989	34 385 032	171 014	460
1990	22 769 857 [2]	187 660	457
1991	Fishing ceased with adoption of UN resolution		

From Yatsu et al. 1993a, table 1, p. 7.

[1] Extrapolation assuming steady increase from beginning of fishery.
[2] Includes research fishing in May.

(Northridge 1991; McKinnell & Waddell 1993), 1989 (Northridge 1991; McKinnell & Waddell 1993; Yatsu et al. 1993a), and 1990 (Fitzgerald et al. 1993; Johnson et al. 1993; McKinnell & Waddell 1993; Ogi et al. 1993; Yatsu et al. 1993a). Despite the number of authors that had access both to fishing effort and observer data, complete and coherent reporting of essential information is lacking (Table 7).

Yatsu et al. (1993a) estimated mortalities within 95% confidence intervals of 51 603–347 107 and 198 778–340 795 dark shearwaters in the 1989 and 1990 fishing seasons, respectively. Estimates for proportions ofsooty shearwaters and short-tailed shearwaters are not available.

In 1988, 11 Japanese observers monitored the catch and bycatch in 533 618 tans of 10 Japanese squid driftnet vessels and recorded the capture of 1796 dark shearwaters (Northridge 1991). Observations from 1 427 225 tans during the 1989 season from June to December revealed bycatch of 8438 dark shearwaters (Gjernes et al. 1990) (Table 8). All records of sooty shearwaters and short-tailed shearwaters were lumped as dark shearwaters, and probably also contained records of Buller's shearwaters (*Puffinus bulleri*) and pale-footed shearwaters (*Puffinus carneipes*), which some observers mistakenly grouped within the dark shearwaters category (Gjernes et al. 1990).

The most complete history is available for the 1990 season, when Japanese and US observers boarded 74 out of 457 active vessels and monitored 13% of the operations (3010 out of 23 656) (Fitzgerald et al. 1993; Johnson et al. 1993). Observers sampled on average 80% of each haul, or 2 132 651 tans of the 22 769 857 tans set (coverage of 9%). Johnson et al. (1993) estimated that 302 495 dark shearwaters (SE ± 13 824), 203 447 sooty shearwaters (SE

TABLE 7. TOTAL NUMBERS OF SOOTY SHEARWATERS (SOSH), SHORT-TAILED SHEARWATERS (STSH) AND DARK SHEARWATERS (DASH) OBSERVED AS BYCATCH, AND TOTAL AND OBSERVED DRIFTNET FISHING OF THE JAPANESE SQUID DRIFTNET FISHERY. (STANDARD ERRORS IN PARENTHESES.)

Source[1]	Study period	No. of operations observed	No. of vessels observed	No. of tans observed	Total no. of operations	Total no. of vessels	Total no. of tans	Total no. of DASH	Total no. of SOSH	Total no. of STSH
46	1984–89			11 118						
25	1984				50 000	504	28 846 153		21 [3]	73 [3]
25	1986	30						36	1	
28	1988	464	10							
33	1988					463	36 055 576			
25	1989	1402	28							
33	1989	1402		1 427 225				8438 [3]	355 000 [4]	
45	1989	27 [2]				460	34 385 032	199 355 (73 876)		
18	1990		74			457				
24	1990	3010	74	2 132 651	23 656		22 769 857	302 495 (13 824)	203 447 (9717)	10 239 (1333)
28	1990	2864	74							
35	1990							269 786 (35 323)	c. 258 000[5]	c. 12 000[5]
45	1990	75 [2]				364		269 786 (35 504)		
46	1990	2991						26 183 [3]		
18	1991		61							

[1] See Table 2 for source codes. [2] Unit of fishing effort is vessel trip. [3] Numbers were observed not estimated. [4] Estimate in relation of fishing effort of all other driftnet fisheries combined. [5] Approximated split of DASH estimate (Ogi et al. 1993).

TABLE 8. OBSERVED NUMBERS OF DARK SHEARWATER (DASH) BYCATCH, AND FISHING EFFORT OF THE 1989 CO-OPERATIVE OBSERVER PROGRAMME OF THE JAPANESE SQUID DRIFTNET FISHERY.

Month	No. of sets (observed)	No. of tans (observed)	Total no.tans (obs. + not obs.)	No. of DASH (observed)
Jun	337	350 860	5 600 000	1068
Jul	489	479 248	9 500 000	3245
Aug	424	440 031	8 800 000	3542
Sep	140	144 519	4 200 000	542
Oct	12	12 567	3 800 000	41
Nov	0	0	2 200 000	0
Dec	0	0	600 000	0
Total	1402	1 427 225	34 100 000	8438

Mostly from Gjernes et al. 1990, table 3; Total no. of tans from Yatsu et al. 1993a, fig. 6, p. 11.

± 9717), and 10 239 short-tailed shearwaters (SE ± 1333) were caught in Japanese squid driftnets during the 1990 season. Although an extension of the co-operative observer programme was planned for the 1991 season (Fitzgerald et al. 1993), results have yet been disclosed.

Northridge (1991) reviewed some data from Japanese non-commercial, squid research cruises made between 1986 and 1989. Eighteen 'shearwaters' were caught in 2900 tans of driftnets in 1989. In another survey 3300 tans were deployed which entangled 1 unidentified shearwater in 1989. Because net sizes were of ranging sizes, interpretation of these records in relation to commercial efforts are difficult to make (Northridge 1991).

The Taiwan squid driftnet fishery fished for both squid and tuna, switching gear depending on the target species, fishing the Central North Pacific between 38° and 44°N and 156°E and 166°W for squid and between 32° and 44°N and 156°E and 155°W for tuna (Ogi et al. 1993) (Fig. 2). The season for squid fishing was between May and December (Jones & DeGange 1988) coinciding with the migratory abundance of sooty shearwaters and short-tailed shearwaters in that area (Uhlmann 2001). Accurate estimates of total fishing effort are not available. Mesh sizes of 76–110 mm were used for squid and 190–210 mm for tuna (Table 1). Nets were typically deployed in daylight and hauled before sunrise.

The extent of seabird interactions with Taiwanese driftnets is largely unknown. However, two sooty shearwaters and short-tailed shearwaters bycatch estimates are available for the 1990 season (Johnson et al. 1993; Ogi et al. 1993). In 1990, 138 vessels made 11 266 operations of which 331 (3%) were observed from 14 vessels (Johnson et al. 1993). Johnson et al. (1993) estimated that 4559 (SE ± 2575) dark shearwaters, 793 (SE ± 418) sooty shearwaters and 75 (SE ± 52) short-tailed shearwaters were accidentally taken. The variance for these estimates was high, primarily because of inconsistencies within the data (Johnson et al. 1993). Ogi et al. (1993) estimated 2043 dark shearwaters, 438 sooty shearwaters and 29 short-tailed shearwaters were taken in the same year. Their estimates are about half those of Johnson et al. (1993), although the proportion of each category is similar. The source and associated error limits of the estimates of Ogi et al. (1993) are not revealed.

2.4 OTHER GILLNET FISHERIES OF THE NORTH PACIFIC

The Japanese large-mesh driftnet fishery dates back to the 1840s (Nakano et al. 1993). In the early years of modern commercial fishing (early 1970s), these fleets were targeting large fish species such as striped marlin (*Tetrapterus audax*), broadbill swordfish (*Xiphias gladius*) in the coastal waters of Japan. They then expanded to primarily fish for albacore tuna (*Thunnus alalunga*) in the pelagic waters of the North Pacific (10°–46°N; 145°E–145°W) from the mid-1970s (Nakano et al. 1993). Fishing effort was high until 1980 after which it declined gradually until 1988 (Table 9). The implementation of time and area closures by the Japanese government finally suspended fishing in 1991 (Nakano et al. 1993). Large-mesh fishing continued year-round with peaks in effort between February and May (Nakano et al. 1993). More than 90% of active vessels ceased fishing for tuna by the end of May and switched gear to catch squid between June and December (Nakano et al. 1993). The vessels commonly used mono- or multi-filament nylon nets with mesh sizes of 170–180 mm for tuna fishing. Individual panels were 32–54 m long and 6–7 m deep. Nets were

TABLE 9. FISHING EFFORT OF THE JAPANESE LARGE-MESH DRIFTNET FISHERIES, 1973–88.

YEAR	NO. OF VESSELS	CATCH (t)
Before 1973	?	?
1973	501	8 483
1974	380	8 057
1975	351	15 394
1976	396	16 807
1977	314	18 723
1978	292	25 501
1979	394	24 071
1980	457	33 149
1981	559	33 536
1982	717	44 505
1983	620	37 887
1984	547	33 750
1985	470	31 640
1986	474	36 469
1987	460	25 070
1988	459	40 083
1989 –91	Fishing ceased	

From Northridge 1991, table 20, p. 49; and Nakano et al. 1993, table 1, p. 26.

deployed during daylight hours (usually in the early afternoon) and hauled at night (Nakano et al. 1993).

Information on seabird bycatch was made available from the co-operative observer programme during the 1990/91 fishing seasons (DeGange et al. 1993; Fitzgerald et al. 1993; Johnson et al. 1993; Nakano et al. 1993; Ogi et al. 1993). In total 829 operations were observed in the 1990/91 season (Nakano et al. 1993). The bycatch estimates by Johnson et al. (1993) of 1849 (SE ± 133) dark shearwaters, 1643 (SE ± 130) sooty shearwaters and 0 short-tailed shearwaters were based on observations of 205 144 tans (total: 4 682 630) in a subset of 475 operations (total: 3485) on board 14 vessels (total: 67). According to 'preliminary data' presented by Ogi et al. (1993), some short-tailed shearwaters were caught as well.

Other countries operating large-mesh driftnet fleets in the Pacific are Taiwan and the USA (Northridge 1991), but no bycatch data for these fisheries could be located.

Japanese coastal gillnet fisheries are considerable in fleet size and fishing effort but unmonitored and unregulated (DeGange et al. 1993). Northridge (1991) cites that almost 38 thousand vessels are permitted to catch various demersal and pelagic species (e.g. shark, mackerel, skipjack, saury, flatfish, cod, etc.) in coastal and offshore waters of Japan. Annual landings are approx. 270 thousand tonnes. Potential consequences and interactions of these versatile fisheries with migrating shearwaters and other seabirds are not known, but impacts are likely because shearwaters overwinter in coastal Japanese waters (Uhlmann 2001).

Set, trammel or driftnet fishing along the Pacific North American coastline is also popular. For example, fishing for halibut (*Paralichtys californicus*), starry flounder (*Platichthys stellatus*), and white croaker (*Genyonemus lineatus*) operated between 1970 and 1980 in Monterey Bay, California (Fig. 3). The season for halibut was from May to October, for flounder from March to April, and white croaker were targeted year-round (Herrick & Hanan 1988). Sooty shearwaters are a dominant seabird species during the boreal summer month (May to July) in inshore waters of the Californian current (Briggs & Chu 1987; Veit et al. 1997) and could have been killed by this fishery (King 1984). The halibut–flounder fishery used large mesh of 200–250 mm width in shallow waters; the white croaker fishery used smaller mesh of 51–76 mm in 18–91 m deep waters; and the rockfish fishery used 114 mm mesh in waters up to 230 m deep (Haugen 1984). Observations of all three fisheries were made between 1980 and 1985. Bycatch of sooty shearwaters was only observed in the halibut fishery (US Department of Fish and Game 1987). In total, 420 (6%) halibut sets were observed out of 7500 sets made in Monterey Bay between 1980 and 1987, from which 352 dead sooty shearwaters were recovered (US Department of Fish and Game 1987) (Table 10). These observations lead to much lower values than King's (1984) initial estimate that 4000 sooty shearwaters were killed between July and September each year. The reason for this discrepancy is unclear

Figure 3. Fishing areas of (a) the South Unimak Pass (SUP) salmon driftnet, (b) the Prince William Sound (PWS) drift- and set gillnet, (c) experimental Canadian–Japanese squid (BCESQ), (d) British Columbia salmon gillnet (BCSFD) and (e) Californian gillnet (CAGF) fisheries.

TABLE 10 OBSERVED NUMBERS OF SOOTY SHEARWATERS (SOSH) TAKEN IN OBSERVED GILLNETS OF COASTAL HALIBUT FISHERIES IN MONTEREY BAY, CALIFORNIA, 1980–87.

Year	No. of nets (observed)	No. of nets (total)	No. of SOSH (observed)
1980	25	1339	56
1981	29	969	91
1982	15	609	0
1983	14	377	0
1984	148	1286	205
1985	76	1611	0
1986	44	897	0
1987	34	412	0

K. Forney, unpubl. data.

because King (1984) did not present the necessary detail explaining how her estimates were derived. Severe mortalities of sooty shearwaters have not been observed since the early 1990s (K. Forney, pers. comm.), partly because sooty shearwater abundance decreased in Californian waters during the summer months of the following years (Veit et al. 1997) and partly because fishing effort declined and eventually ceased due to regulative pressure in the late 1990s. The waters of Monterey Bay are now closed to commercial gillnet fishing (G. Martin, *San Francisco Chronicle*, 13 Sep 2000).

Coastal gillnetting in the Baja California, Mexico, may have presented a risk to sooty shearwaters similar to that of the Californian gillnet fisheries, but data are not available (DeGange et al. 1993).

Alaskan near-shore, coastal salmon gillnet fisheries are widespread, but largely unobserved (Wohl et al. 1998; Fadely 2000). Wynne et al. (1991, 1992) reports sooty shearwaters mortalities in coastal drift and set gillnets for sockeye salmon in Prince William Sound (PWS) and South Unimak Pass (SUP) (Fig. 3). There were 611 vessels registered in the PWS driftnet fishery in 1991, primarily fishing in near-shore waters of river deltas in eastern and western parts of the Sound between May–June and August–September (Wynne et al. 1991). In 5875 observed net retrievals (5% of 116 674), two sooty shearwaters were observed within 10 m of active fishing, one became entangled and an estimated 20 sooty shearwaters were killed in total (Wynne et al. 1992). In 387 observed operations on the Copper River delta between 1988 and 1989 no bird entanglements were observed (Wynne et al. 1991). Observers monitored 4% (373 out of 9054) of sets made by the salmon gillnet fishery off South Unimak between June and August 1990, and recorded mortalities of one sooty shearwater and one short-tailed shearwater (Wynne et al. 1991).

Coastal gillnet activities of around 4000 (small, non-commercial) vessels in Puget Sound, Washington (Northridge 1991) caused concern because of relatively high bycatch mortalities of marbled murrelets (*Brachyramphus marmoratus*), an endangered alcid species (Carter & Sealy 1984; Wolf et al.

1995). Information on both the scale of this fishery and the potential number of sooty shearwaters entanglements was not found.

A Canadian gillnet test fishery for salmon off the west coast of Vancouver Island, Canada, caught six sooty shearwaters in a total of 865 net sets during 16 days of fishing in September and October 1997 (Mitchell 1997; Morgan et al. 1999) (Fig. 3). Similar effort was fished in 1996 and 1995, when 1349 and 855 gillnet sets were made during 19 and 16 days of fishing, respectively, but no observations of sooty shearwaters captures are available. Other gillnet fisheries for salmon operate with unknown effort in the Strait of Georgia, particularly at the mouth of the Fraser River, the northern end and western side of the Strait of Juan de Fuca, and in the Fitz Hugh Sound along the northern-central coast of British Columbia (DeGange et al. 1993). There is no information available on seabird mortalities from these fisheries, and thus the potential risk for shearwater species cannot be estimated.

An experimental Canadian–Japanese squid fishery (Fig. 3) was trialled off British Columbia in 1979, 1980, 1983 and between 1985 and 1987 (DeGange et al. 1993). The Canadian Department of Fisheries and Ocean conducted six trials between 1979 and 1988 (Northridge 1991). An unknown area was fished mostly from June/July until August/September in these years. Northridge (1991) records that 1437, 2475, 4308 and 4417 km of net were set in 1983, 1985, 1986 and 1987, respectively. Bycatch records are available from 1985 to 1987 (DeGange et al. 1993). Altogether 652 sooty shearwaters and 33 short-tailed shearwaters were taken in 11 200 km of gillnet sets (Table 11). There was a 2.6-fold increase in sooty shearwaters take between 1986 and 1987 although fishing effort remained almost constant. However, DeGange et al. (1993) did not state whether these records stem from an observer programme with 100% coverage or are estimates based on a sub-sampled proportion, so more sooty shearwaters and short-tailed shearwaters may have been caught. Other Canadian research driftnet operations were conducted between 1986 and 1989 to study the interception of salmonids with squid fisheries (Northridge 1991). Between 50 and 618 tans were deployed in each of these years, but any further detail on seabird bycatch was not available.

The Bering, Chukchi and Okhotsk Seas are traditionally fished for salmon by native people using set nets (Bakken & Falk 1998). However, the scale of fishing and magnitude of interactions with seabirds has not yet been documented.

TABLE 11. NUMBERS OF SOOTY (SOSH) AND SHORT-TAILED (STSH) SHEARWATERS TAKEN BY EXPERIMENTAL SQUID FISHING OFF BRITISH COLUMBIA, CALIFORNIA IN 1983, 1985–87.

Year	Net deployed (km)	No. of SOSH	No. of STSH
1983	1474	?	?
1985	2475	12	29
1886	4308	176	3
1987	4417	464	1

1983 data from DeGange et al. 1993, table 3, p. 207; others from Northridge 1991, table 15, p. 40.

2.5 GILLNET FISHERIES OF THE NORTH ATLANTIC

Some sooty shearwaters also frequent the North Atlantic during the austral winter (Peterson et al. 1954; Cramp et al. 1977; Brown et al. 1981). There has been relatively little research done to investigate seabird bycatch in US commercial fisheries in the northwest Atlantic. However, the few data available suggest that seabirds are primarily caught in gillnet fisheries (Lanza & Griffin 1997; Forsell 1999). There are anecdotal records of sooty shearwaters and unidentified shearwater bycatch in commercial sink gillnet fisheries off New England and Maine (Lanza & Griffin 1997), but because of the paucity of information, the scale of the bycatch cannot be estimated.

Documentation on seabird bycatch in Canadian Pacific and Atlantic gillnet fisheries is sparse and mostly anecdotal (Chardine 1998). The three fisheries—offshore gillnet fishery around the Grand Banks; lumpfish, herring, flounder and capelin gillnet fishery in Newfoundland; and inshore salmon fishery off the south-central coast of Labrador (North Atlantic)—are all thought to interact with seabirds (Chardine 1998). However, little information is available on effort and magnitude of each fishery to evaluate potential risk for migrating sooty shearwaters and short-tailed shearwaters overwintering in the North Atlantic. Only one study systematically measured the interactions of the inshore summer fishery of southeast Newfoundland with seabirds (Piatt et al. 1984). Bycatch of sooty shearwaters was reported primarily for salmon and cod gillnets, with very little extra mortality in cod traps or flounder gillnets (Chardine 1998). Exact bycatch numbers and fishing effort are not presented, so no confident assumptions about the magnitude of the bycatch in these fisheries can be made.

2.6 GILLNET AND DRIFTNET FISHERIES OF THE SOUTH PACIFIC

South Pacific gillnet and driftnet fisheries may pose risks to short-tailed shearwaters and sooty shearwaters, because fishing takes place in close proximity to major breeding and feeding grounds (Uhlmann 2001). Commercial and non-commercial gillnet fishing in coastal South America, New Zealand, and Australia probably catch sooty shearwaters and short-tailed shearwaters, but little evidence exists to prove this assumption. There is some indication of incidental short-tailed shearwaters bycatch in net fisheries in Victoria, Australia (Norman 1999). In New Zealand, surveys suggest that more than 60 thousand recreational fishers used set gillnets in 1987 (Taylor 1992). Based on data from surveys in 1996, an estimated 350 thousand recreational fishers are eligible to fish using various techniques including set gillnets (Bradford 1999). Fishing is largely unobserved and the reporting of bycatch is not compulsory. Systematic investigations of seabird bycatch are recent and focused on interactions with penguins (Darby & Dawson 2000) or dolphins (Baird & Bradford 2000). Bycatch of sooty shearwaters has been officially documented only once, when 600 sooty shearwaters were taken in two separate gillnet operations in Te Wae Wae Bay, Southland, New Zealand, in early February 1973 (Taylor 1992).

The waters off Tasmania and New Zealand were previously major fishing grounds for Japanese, Taiwanese and Korean large-mesh gillnet fishing fleets (Lawson 1995). For example, Japanese vessels regularly fished there for albacore tuna (*Thunnus alalunga*) during the austral summer (November–March) between 1983 and 1989 (Northridge 1991, Nakano et al. 1993). Information on seabird bycatch in these fisheries was not available. However, mesh sizes of 150–210 mm (Table 1) were probably too large to entangle shearwater-sized seabirds, so the threat was likely to be minor. Large-mesh driftnet fisheries in the South Pacific phased out by 1989/90 with the adoption of the Wellington Convention (Northridge 1991).

Large-mesh driftnet fisheries persisted in Central and South American waters, but little information on effort, catch and bycatch was available. For example, swordfish (*Xiphias gladius*) is targeted in Chilean waters (15–200 miles offshore) from May to August/September using 1.5 km long nets with mesh sizes of 200–220 mm (Northridge 1991). Interaction with migrating sooty shearwaters from both South American and New Zealand breeding populations is unlikely, given the large mesh size.

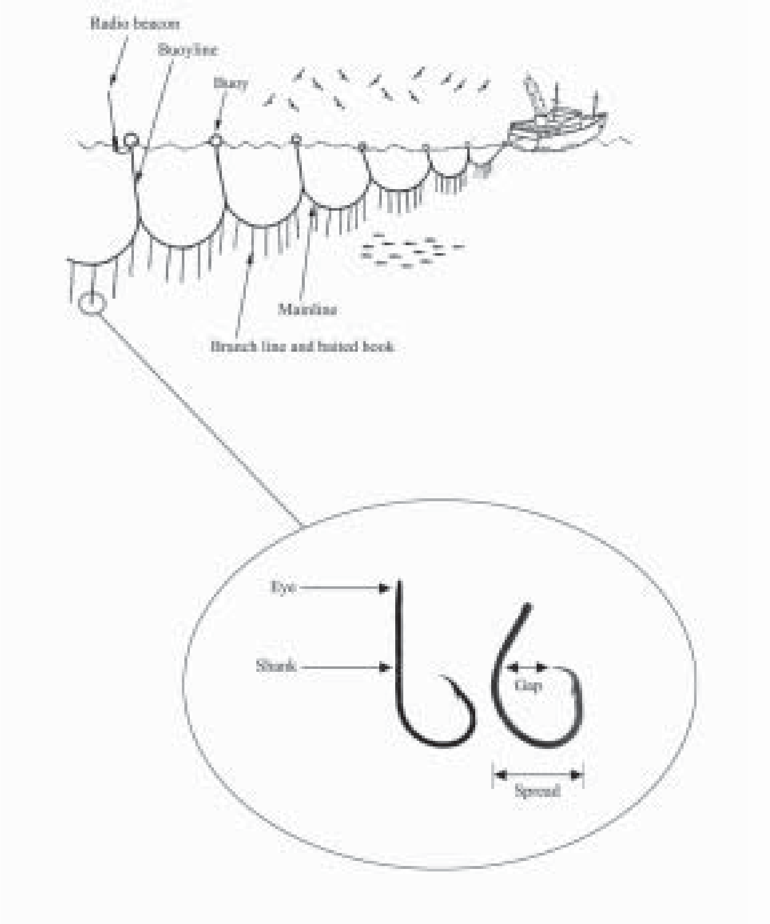
3. Bycatch in longline fishing

3.1 LONGLINE FISHING: AN OVERVIEW

Longline fishing is a versatile fishing strategy that typically deploys a single 'main line' with numerous 'branch lines' (snoods) to which hooks are attached (Bjordal 1989) (Fig. 4). Line length, number and length of branch lines and size/shape of the hooks vary with the area fished, species targeted and the size of fishing vessel. The line can be set at bottom, mid-water or surface levels depending on the species being targeted. If lines are set on the bottom of the seabed, it is commonly called 'demersal longlining'. This usually takes place in continental shelf waters. If lines are set near the water surface, it is termed 'pelagic longlining'. This occurs mainly in deep waters off continental shelf breaks (Brothers et al. 1999a). Longlining has been thoroughly reviewed by the Fisheries Working Group of the United Nations Food and Agriculture Organization (FAO) (Brothers et al. 1999a).

Potential lethal interactions between seabirds and fisheries occur both when mainlines are set and hauled. Birds are more likely to be hooked during line setting (Brothers 1991; Imber 1994; Ashford et al. 1995; Klaer & Polacheck 1997) because lines sink relatively slowly, leaving birds with enough time to attack the baited hooks. In contrast, during line hauling the birds cannot attack the hooks so easily, because hooks are retrieved fast and at a steep angle (Imber 1994). Sink speeds of baited hooks are therefore important in determining availability and exposure to seabirds (Brothers 1991). Baited hooks sink faster when the snood lines are weighted and when the bait is thawed. If whole fish are used as bait their swim bladders can be removed to make them sink faster (Brothers et al. 1995).

Figure 4. 'Japanese style' longline and two common hook shapes: 'E-Z' baiter (left); mustad tuna (right). (From Robertson 1998, fig. 1, p. 213; hooks modified from Dyrkorn, Produkt-katalog 2000, p. 11.)



Almost every bird hooked during line setting will be dragged under water, drowned and hauled aboard dead (Brothers 1991), although a few captured birds may come off the hook during the hauling process by dropping off the line, being cut off the line alive by crew members, or by being eaten by sharks or other predators.

Longline baits are easy prey that remain accessible to sooty shearwaters and short-tailed shearwaters for longer than for surface feeding or scavenging seabirds because these birdss are proficient divers (Brown et al. 1978), with sooty shearwaters foraging prey to depths of up to 68 m (Weimerskirch & Sagar 1996). Often during line setting it is smaller diving petrel species, such as sooty shearwaters and short-tailed shearwaters, that bring the baited hooks back to the surface where larger dominant species can kleptoparasitise them (Bartle 1974; Imber 1994; Bergin 1997). Although shearwater species are usually not capable of swallowing longline baits as a whole (Bartle 1990; Imber 1994; Barnes & Walshe 1997; Gales et al. 1999), they do occasionally become hooked (Brothers et al. 1998a, b; 1999a). Mortalities do occur therefore, but are in much lower numbers than, for example, in gillnet fisheries (Murray et al. 1993) even though both shearwaters attend some longline vessels in great numbers (B. Lee, pers. comm.). This shows that the species composition of seabird bycatch is not necessarily correlated with the composition and abundance of birds attending the vessel. The size and foraging strategy of each particular species may be more important indicators of risk (Ashford et al. 1995; Gales et al. 1999).

3.2 PELAGIC AND DEMERSAL LONGLINES IN THE NORTH PACIFIC

There is a large demersal longline fishery operating in the US EEZ of the Gulf of Alaska (GOA) and the Bering Sea (BSAI) region. This fishery is under US management and targets Pacific halibut (*Hippoglossus stenolepis*) and 'groundfish' (such as walleye pollock, *Theragra chalcogramma*; pacific cod, *Gadus macrocephalus*; sablefish, *Anoplopoma fimbria*; greenland turbot, *Psetta maximus*; and rockfish, *Sebastes* and *Sebastolobus* spp.) (Brothers et al. 1999a; Stehn et al. 2001).

The Pacific halibut fishery uses mostly conventional longline gear with main and branch lines and circle-shaped hooks, which are typically deployed and retrieved during daylight hours (Gilroy et al. 2000). The season for both Pacific halibut and sablefish is from mid-March until mid-November (Gilroy et al. 2000). The Pacific cod fishery operates from January to May and September to December.

There is some published evidence of incidental mortalities of seabirds for some Alaskan groundfish longline fisheries (Wohl et al. 1998; Brothers et al. 1999a; Bayle 2001; Stehn et al. 2001). Observer coverage is required for the groundfish, but not the halibut fleets (Cooper et al. 2000). Observer coverage levels in the groundfish fisheries are determined by the length of the vessel. Vessels less than 18 m operate without observers, vessels between 18 m and 38 m are required to have an observer on board for at least 30% of the fishing, and vessels longer than 38 m are required to carry an observer for 100% of the fishing (Stehn et al. 2001). There were 916 groundfish longline vessels registered for the 1998 season, and they set approx. 190 million hooks (Cooper et al. 2000). In 1997, 1802 licensed vessels set 25 million hooks for halibut and 171 million were set for groundfish (Bayle 2001).

On average, 8700 seabirds were estimated to be caught annually in groundfish longline gear in the Gulf of Alaska and the Bering Sea region between 1989 and 1993, with less than 10% consisting of shearwater species (Bakken & Falk 1998; Brothers et al. 1999a). Of these, 530 were reported from the Bering Sea region, compared with 74 from the Gulf of Alaska.

Based on observations of 51 643 hauls in the Alaskan groundfish longline fisheries between 1993 and 1997, Stehn et al. (2001) reported total estimated mortalities of 14 thousand seabirds annually. An estimated total of 3322 shearwaters may have been caught in the Bering Sea/Aleutian Islands region over this period, in contrast to 391 from the Gulf of Alaska region. In all years fishing effort was lowest between June and August, which may have decreased the risk for sooty shearwaters and short-tailed shearwaters being caught, as this is when migratory abundance is low in the Gulf of Alaska (Uhlmann 2001). However, risk assessments for sooty shearwaters and short-tailed shearwaters are impaired, because shearwaters were not accurately defined to species level.

Canadian demersal longline fisheries operate in waters off British Columbia, targeting Pacific halibut, sablefish, dogfish (*Squalus acanthias*) and rockfish species. The halibut fishery is large, setting approx. 5–6 million hooks annually, compared with 500 thousand hooks in the sablefish fishery (Cooper et al. 2000). The rockfish fishery is active year-round with about 160 vessels, while the halibut fishery typically operates from mid-March until mid-November. The halibut fishery had 10% and the rockfish fishery 5% observer coverage for the 1998 and 1999 seasons (Fargo & Yamanaka 2000). However, there were no reliable records of seabird mortalities available for these Canadian longline fisheries. Judging from the similarity to US equivalent fisheries, mortalities of sooty shearwaters and short-tailed shearwaters are likely to occur.

Demersal longline fisheries in northwestern Pacific waters are largely unobserved, and information on seabird mortalities is lacking (Brothers et al. 1999a). Japanese and Russian fleets fish for walleye pollock, Pacific cod and Pacific halibut in the coastal and pelagic waters of their EEZ.

Pelagic longline fishing in the northeast Pacific target primarily tuna and swordfish species in the waters between the equator and sub-Arctic. Effort, catch magnitude and economic value of the pelagic longline industry are much higher than for demersal longlining. Major participating nations are Japan, Taiwan, Korea, China and the USA, with fishing effort being most intense between 20° and 40°N (Brothers et al. 1999a). Despite the size of these fisheries, information on seabird mortalities is scarce (Credle et al. 1994), because only a few investigations have been completed (Cousins & Cooper 1998; Cousins et al. 2000; Boggs et al. 2001). The catch of swordfish and tuna by the Hawaiian longline fleet made up 10% of the annual landings of the combined North Pacific longline fleets (Cousins et al. 2000). The Hawaiian-based US pelagic longline fleet was monitored by observers of the National Marine Fisheries Service (NMFS) between 1994 and 1998 (Cousins et al. 2000) and currently receives about 5% coverage. Altogether 73.5 million hooks were set in total with an annual average of 14.7 million (SE ± 2 million) between 1994 and 1998. Shearwaters have been sighted on fishing trips of Hawaiian domestic longliners (B. McNamara, pers. comm.), and deaths of two unidentified shearwaters were recorded for the US domestic Hawaiian longline fishery during 1994–98 (Brothers et al. 1999a). This is likely to be an underestimate, because observations were biased towards incidental mortality of albatrosses (Brothers et al. 1999a).

3.3 PELAGIC AND DEMERSAL LONGLINES IN THE SOUTHWEST ATLANTIC

Demersal and pelagic, mid-water longline fisheries of Argentina, Brazil and Uruguay target mainly kingclip (*Genypterus blacodes)*, and Patagonian toothfish (*Dissostichus eleginoides*), in the southwest Atlantic, off Chile, Argentina and Uruguay (Neves & Olmos 1998; Stagi et al. 1998; Schiavini et al. 1998). Schiavini et al. (1998) examined fishing effort of 12 demersal Argentinean longline vessels (10 manual set vessels, two autoliners) between 1993 and 1995. Altogether 3972 fishing operations were made and about 25 million hooks deployed during the 18 months of fishing in areas between 43°–50°S and 53°–57°S. Information on seabird bycatch is only anecdotal and the authors derived crude estimates by applying minimum and maximum catch rates from longline fleets fishing outside of the EEZ. Records of sooty shearwaters and short-tailed shearwaters bycatch were not presented.

Mid-water and demersal longlining for tuna (*Thunnus* spp.) and hake (*Merluccius hubbsii*) in Uruguayan waters poses most risk to seabirds, especially albatrosses (Stagi et al. 1998; Stagi 2001). Fishing effort of the demersal fleet is considerable, with 350 thousand hooks set per fishing trip. Investigations of incidental bycatch are only recent, and therefore reliable bycatch estimates are not available. However, mortalities of seabirds (especially albatrosses) are frequently observed, but bycatch of shearwaters has not yet been reported (A. Stagi, pers. comm.).

Fourteen mid-water tuna longline and one demersal longline vessel were surveyed in a study carried out in Brazilian waters between 1994 and 1995 (Neves & Olmos 1998). No entanglements of sooty shearwaters with longline gear were observed, although birds were sighted in the vicinity of the vessels (T. Neves, F. Olmos, pers. comm.).

3.4 PELAGIC AND DEMERSAL LONGLINES IN THE SOUTHEAST ATLANTIC

There are three main longline fisheries off southern Africa: demersal longline fishery for hake; demersal longline fishery for Patagonian toothfish; and pelagic longline fishery for tuna (Ryan & Boix-Hinzen 1998). There are some estimates of seabird mortalities in the South African tuna fishery and the hake fishery (Barnes et al. 1997; Ryan & Boix-Hinzen 1998). Ninety Taiwanese and 30 Japanese vessels were licensed to target southern bluefin (*Thunnus maccoyii*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in the EEZ of South Africa, between 35° and 50°S and 0° and 40°W in 1997 (Ryan & Boix-Hinzen 1998). Interactions with sooty shearwaters and short-tailed shearwaters were not reported in the pelagic tuna fishery, because there was no observer programme (Ryan & Boix-Hinzen 1998).

Observers collected bycatch information onboard of two demersal longliners exploratory fishing for hake in coastal waters near Cape Town between October and December 1994 (Barnes et al. 1997). Longline gear with baited hooks was usually set after midnight and hauled 12 hours later. The three vessels participating in the experimental hake fishery set 1.8 million hooks, of which 94 thousand were observed (coverage level of 5.5%). Approx. 763 birds were killed, most of which were white-chinned petrels (*Procellaria aequinoctalis*). Some sooty shearwaters may have been caught, because they are regularly sighted in the vicinity of the boats, especially during daytime (Barnes et al.1997), but the report presents no detail regarding the catch composition of other species.

3.5 PELAGIC AND DEMERSAL LONGLINES IN THE SOUTHEAST PACIFIC

Demersal longline fisheries in the mid- and southeastern Pacific are mainly operated from Mexico, Venezuela, Chile and Peru. There is very little descriptive or quantitative information available on any of these fisheries

(Brothers et al. 1999a) and observer programmes are largely absent (Baird 2001a). However, a survey of Peruvian fishers was conducted in 1999, which revealed that bycatch of dark shearwaters 'may be common' (A. Guillén, pers.comm.). Numbers are too vague to allow for any extrapolation.

3.6 PELAGIC AND DEMERSAL LONGLINES IN THE SOUTHWEST PACIFIC

Australian pelagic and demersal longline fleets typically operate between March and September in the Australian Fishing Zone (AFZ). Demersal fishing effort is much lower than that by the pelagic fleets. Interactions with seabirds were considered a minor problem in the demersal fisheries, so most observer effort was dedicated to the pelagic fisheries (Brothers et al. 1999a). Pelagic fishing is shared by two distinct fisheries using different strategies and gear: the foreign licensed Japanese fleet and the Australian domestic fleet. Japanese vessels are larger (40–50 m long), operate further offshore, and set more hooks per line set (approx. 3 thousand) than domestic vessels (15–30 m long), which set 0.5–2 thousand hooks per set in waters further inshore (Brothers et al. 1999b).

Japanese pelagic longline vessels started to fish primarily for southern bluefin tuna in the AFZ in 1979 and were joined by a growing domestic industry in the late 1980s (Brothers et al. 1998a). After a peak in 1988, effort by the Japanese fleet declined gradually, before ceasing in 1998. Effort of the domestic fleet expanded rapidly, from 1.4 million hooks in 1989 to 7.8 million in 1997 (Brothers et al. 1999b; Gales et al. 1999). The Tasmanian Parks and Wildlife Service established an ongoing observer programme for the Japanese fishery in 1988 to systematically collect data on bycatch species (Gales et al. 1999). Funding constraints prevented allocation of observers to a stratified scheme to cover each area, fishery and season, so data stem from a few areas, are temporally patchy, and focus mostly on Japanese fleets.

Bycatch of sooty shearwaters and short-tailed shearwaters on longline hooks of both domestic and Japanese vessels was rarely noticed by scientific observers (Klaer & Polacheck 1997). Sooty shearwater captures were first recorded in the Japanese fisheries in 1996, but only occasionally in the domestic fleet. Observers retained two sooty shearwater carcasses from Japanese vessels between 1988 and 1996 (Brothers et al. 1998a, b). A domestic tuna vessel off Tasmania caught one short-tailed shearwater during the 1994/95 season (Brothers & Foster 1997; Brothers et al. 1999b). The paucity of observations from domestic longline fleets makes the reliability of these estimates uncertain, but the general inference is that very few sooty shearwaters and short-tailed shearwaters are caught by longliners in Australia.

New Zealand pelagic longline fishing commenced with foreign vessels, primarily licensed in Japan, in the EEZ of New Zealand in the late 1950s (Duckworth 1998; Keith 2000). Longliners fishing in the north and east of New Zealand are known to have targeted albacore (*Thunnus alalunga*), yellowfin (*Thunnus albacares*) and bigeye tuna and swordfish (*Xiphias gladius*) since 1968 (Slack 1972). Off southern parts of the South Island, longliners primarily target southern bluefin tuna (Murray et al. 1993; Baird 1994). The southern fishery begins in March in waters around 50°S, moving northeastward to 47°S as boats follow the migration of southern bluefin tuna. The vessels leave the EEZ of New Zealand by September each year. The Japanese tuna longline fishery ceased fishing in New Zealand EEZ by 1994. The domestic fishery took over the northern component of the fishery from the early 1990s (Keith 2000) and increased in size from 21 vessels in 1992 to 52 in 1995 (Baird 1994) and 130 in 2002 (J. Molloy pers. comm.). Fleet size and gear characteristics are somewhat different between the foreign licensed and the domestic fisheries. Japanese tuna vessels use kuralon nylon mainlines (7 mm diameter), approx. 130 km in length, which are deployed into the water from buoylines at intervals of 225–300 m. Attached to the mainline are the baited branchlines, typically 35 m in length. Lines are usually set at night, and soak for 4–5 hours.

The New Zealand Ministry of Fisheries (MFish, formerly known as MAF) have placed scientific observers on some tuna longliners since 1987. Initial coverage was very low and not evenly distributed across fleets, fishing areas and times. For example, 94% of all observer trips made between 1987 and 1995 were carried out on board foreign licensed and chartered vessels, while the growing domestic fleet was hardly monitored (Baird 1996). Observers were permitted to retain all seabird specimens that were hauled on deck and to return to the mainland since 1989. These were sent to the Museum of New Zealand Te Papa Tongarewa where detailed identification and autopsies were carried out (Murray et al. 1993; Bartle 2000a, b; Robertson 2000; Robertson & Bell 2002a, b).

Of all observed longline operations (for both foreign and domestic vessels), only three identified sooty shearwaters were killed in 4 million observed hooks set (38 million hooks set altogether) in New Zealand waters between 1990 and 1996 (Manly et al. 2002). There were two sooty shearwaters returned from observed tuna longliners during the 1998/99 fishing season (Baird 2001b). Earlier records also showed very low numbers of sooty shearwaters caught (Murray et al. 1993; Baird 1996). According to data published in Brothers et al. (1999a), three sooty shearwaters were observed taken by chartered Japanese vessels in New Zealand between 1988 and 1996.

A survey of the majority of the domestic tuna fleet revealed that most of vessels caught ‘a few’ sooty shearwaters each year and that most of the birds were caught during the haul and were released alive (Keith 2000). This contrasts with observation on foreign vessels where no sooty shearwaters bycatch was seen and where observations were usually made during the line-setting process (Imber 1994).

There are a few demersal longline vessels in New Zealand waters, setting about 20 million hooks for ling (*Genypterus blacodes*) annually (especially between August and December) (Hufflett 2001). So far, no bycatch records of shearwaters have been reported from these fleets in previous years and there were none caught during observations in 1998/99 (Baird 2001b).

Commercial exploitation of fish resources by longline fisheries in Antarctic waters south of 55°S began in 1988/89, and Soviet vessels took lanternfish (*Electrona carlsbergi*) and Patagonian toothfish in 1986/87 in waters around South Georgia (50°–55°S, 30°–50°W) (Kock 1992). Fishing has developed rapidly since then and required regulative measures by the Commission for the

Conservation of Antarctic Marine Living Resources (CCAMLR). Sooty shearwaters and short-tailed shearwaters frequent regions south of 55°S (CCAMLR 1999; E. Woehler, unpubl. data) and therefore could potentially interact with some of the prevalent fisheries.

Demersal longline fishery in Antarctic waters for Patagonian toothfish commenced in the late 1980s. Prior to 1993, the toothfish fishery was open year-round, but it was subsequently restricted to 15 December–15 September (Croxall & Prince 1996). Fishing effort around the Kerguelen Shelf (at about 48°S and 68°E) was moderate, with three Soviet longline vessels catching 109, 701, 92 and 959 tonnes of toothfish in the 1990/91, 1991/92, 1992/93 and 1993/94 fishing seasons, respectively (Cherel & Duhamel 1996). Each set involved between 240 and 360 baited hooks attached to 2800–4200 m longlines (Cherel & Duhamel 1996). The gear was set during both night and day. Observations of seabird bycatch were made during 13 days of fishing in February 1994, when 174 thousand hooks were observed (Cherel & Duhamel 1996). No sooty shearwaters or short-tailed shearwaters were present in the vicinity of the vessel and no mortalities of these two species were recorded during this study (Cherel & Duhamel 1996).

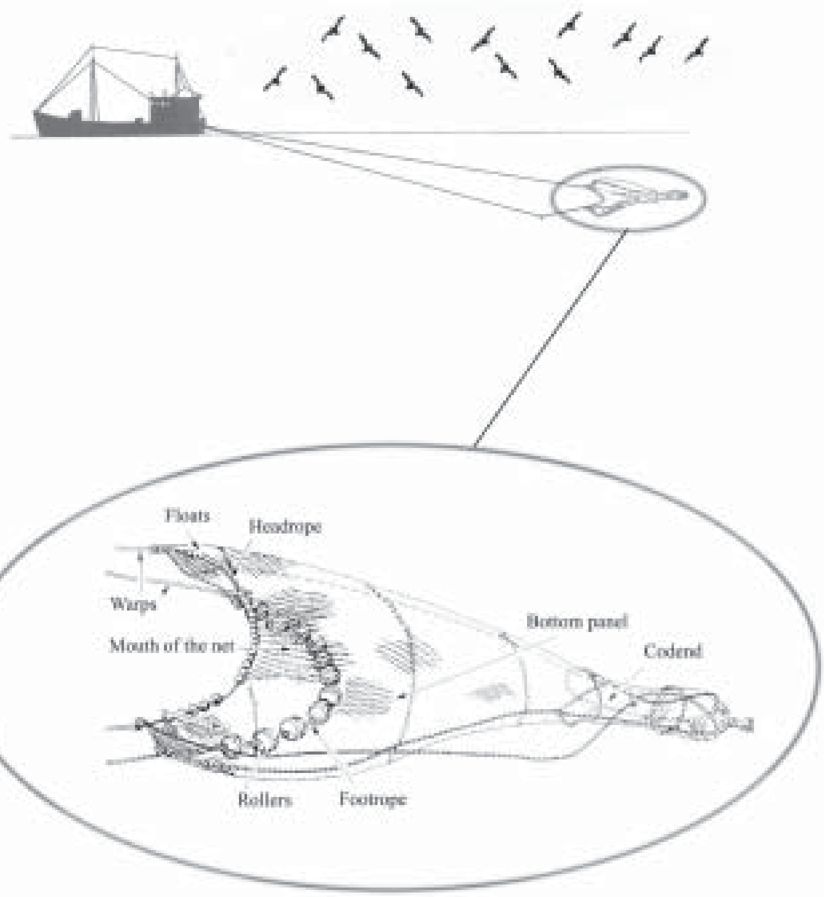
Longlining for toothfish around South Georgia was monitored on board one Chilean longliner between April and May 1994 (Ashford et al. 1995). In 20 line sets (day and night), totalling 200 thousand hooks, 98 seabirds were killed, with a maximum number of 34 birds per set (Ashford et al. 1995). Shearwaters were not caught during any of the observations.

Toothfish fishing operations of Chilean and Argentinean longliners in regions around South Georgia received almost 100% observer coverage in 1995 (Moreno et al. 1996). In 3.1 million hooks set by the six Chilean vessels between 1 March and 16 May 1995, 1178 seabird kills were observed (Moreno et al. 1996). No mortalities of shearwaters were reported in Moreno et al. (1996).

4. Bycatch by other fisheries

Apart from longline and gillnet fisheries, there are numerous other techniques used to catch fish including ‘trawl net’, ‘purse seine’, and ‘jig fishing’. Trawling is one of the most popular fishing methods (Fig. 5). This involves one or two boats towing a trawl net either along the ocean bottom or at a specified water depth (‘mid-water trawling’). Cables (‘warps’) connect the net to the trawler. Two trawl doors (‘boards’) form the mouth of the net, so that fish can enter. The fish are dragged towards the back of the net (‘codend’). The mesh size of the codend determines the selectivity of the trawl net (Pikitch et al. 1995). Purse seines are a modified type of gillnet that encircles surface-feeding fish such as tuna (Fig. 6). A small boat (‘skiff’) tows one end of the net around the school of fish, while the other end of the net is anchored to the mothership. Once the fish are surrounded, ropes at the bottom of the net are drawn in to form a purse-shaped trap. The net is hauled once the fish are completely

Figure 5. Type of trawl net, as it is used in bottom and mid-water trawling. (From Hayes 1983, p. 132; Sainsbury 1971, fig. 51, p. 60.)



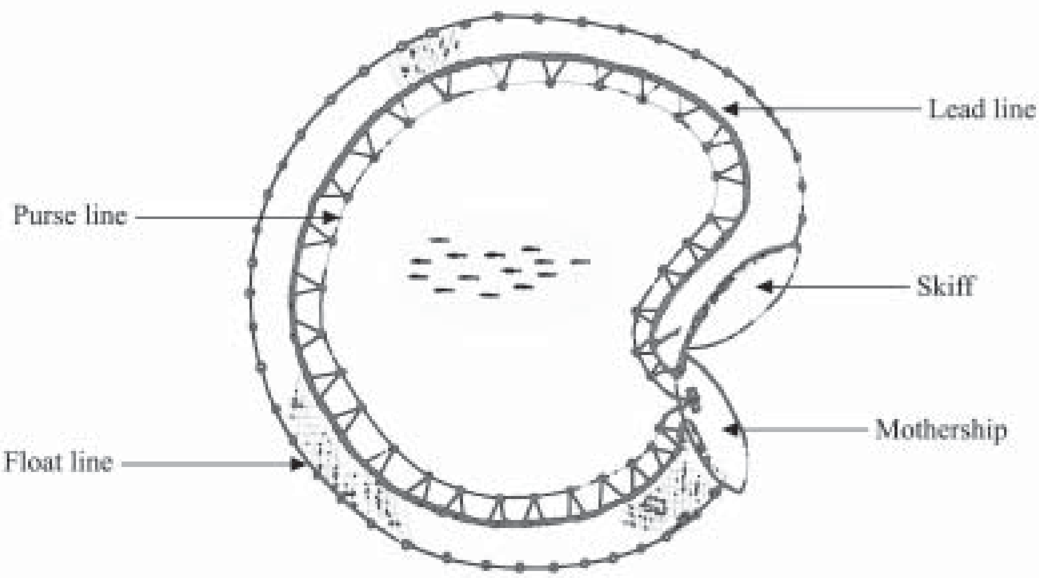


Figure 6. General type of purse seine net. (From Sainsbury 1971, fig. 70, p. 80.)

enclosed. Jig hooks and lines are typically used to catch squid at night (Fig. 7). Very powerful lights illuminate the water, attracting the squid. Lines are deployed alongside the boat with numerous lured hooks attached at short intervals.

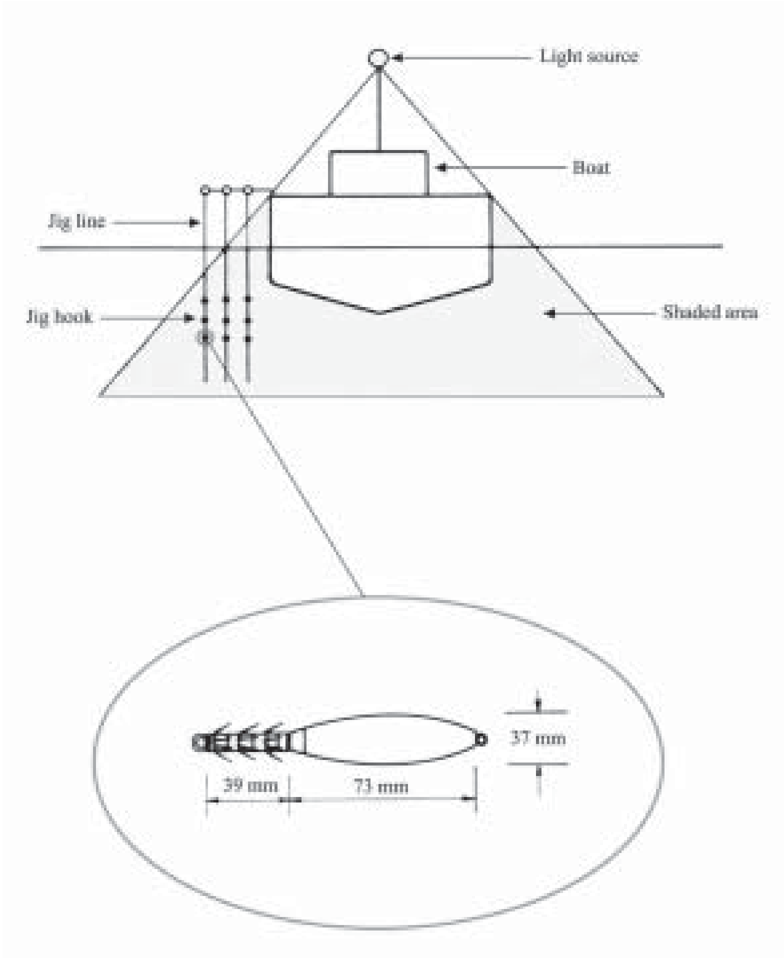


Figure 7. General type of jig fishing gear and method. (From Hamabe et al. 1982, fig. 6, p. 17; fig. 13, p. 27.)

A joint report of the Circumpolar Seabird Working Group of the Conservation of Arctic Flora and Fauna (CAFF) programme of the Arctic Council details mortalities of seabirds in groundfish trawlers in the Bering Sea and the Gulf of Alaska (Wohl et al. 1998). These fisheries have been monitored since 1988. Observer coverage levels depend on the size of the boat (vessels < 18 m do not require an observer, vessels between 18 and 38 m long require 30% coverage, and all vessels over 38 m require 100% coverage). Although trawlers harvest more than 80% of the annual groundfish landing in the Bering Sea and Gulf of Alaska regions, seabird bycatch rates are much lower than those from the longline fleets (K. Rivera, pers. comm.). The proportion of shearwaters in the bycatch is not known.

Japanese, Korean and joint-venture jig vessels have fished for squid from December to June in the EEZ of New Zealand since 1971 (Tyson et al. 1984). Two observers boarded Japanese and Chinese jig vessels fishing off the Otago coast between January and March 1999. Although present during the fishing operation, no sooty shearwaters attacked squid caught on jig lines (Blezard & Burgess 1999).

The main species caught by bottom- and mid-water trawlers in New Zealand are hoki (*Macrunuronus novaezelandiae*), hake (*Merluccius australis*), ling (*Genypterus blacodes*), orange roughy (*Hoplostethus atlanticus*) and squid (*Nototodarus* spp). Squid and hoki trawl fisheries are major fisheries in New Zealand (Tyson et al. 1984; Ballara & Hurst 1997; MFish, unpubl. data). Potential interactions of the squid trawl fisheries with sooty shearwaters are likely, because: trawl fishing seasons are typically from December to May (which overlaps with the breeding period of sooty shearwaters); fishing is centred in subantarctic waters (overlapping with favourable foraging habitat of sooty shearwaters); and the fishery targets squid (which is preferred prey of sooty shearwaters). Accurate records on seabird mortalities from some trawl fisheries in New Zealand are available, but only for recent periods (Bartle 1991; Bartle 2000a, b; Robertson 2000, Baird 2001b; Robertson & Bell 2002a, b).

Since 1 April 1978, when New Zealand declared a 200 mile EEZ, catch of deepwater trawlers was monitored via logbooks (King et al. 1985). Sixty percent of the trawling fleet in the 1978/79 seasons were from the Soviet Union (n = 38) (King et al. 1985). New Zealand Ministry of Fisheries observers were placed on board Soviet trawlers fishing for squid, primarily arrow squid (*Notodardus sloanii*) in waters around the subantarctic Snares and Auckland Islands between January and May 1990 (Bartle 1991). Altogether 27 different Soviet trawlers participated in the subantarctic squid fishery during the 1990 season, generally lasting from December until May. In total, 4349 tows were made, of which 897 (21%) were monitored by observers on board four of the vessels. There is no further description in Bartle (1991) whether observations represented a random sample. Altogether, 30 sooty shearwaters were killed in trawling gear during the 1990 season, mostly as a result of collision with the 'net sonde' monitor cable. As the mean catch rate was 0.03 birds per tow, between 95 and 195 (according to 95% binomial confidence limits) may have been killed in total. This is likely to be an underestimate, because birds that collided with the cable did not entangle in the trawl net and went undiscovered (Bartle 1991). Recent observer records revealed that 179 sooty shearwaters were taken in 116 observed tows between 1996 and 2000 translating into an estimated take of 25 to 3709 birds in total (Uhlmann 2001). The use of net sonde monitor cables is now prohibited in New Zealand's EEZ (CCAMLR 2000). However, if fishing effort of Soviet trawlers had been consistently high around the Snares and Auckland Islands shelf between November and May each year of regulated fishing after 1978, the bycatch risk of sooty shearwaters might have been higher in the past than estimated.

Trawlers fishing for shrimp (*Pleoticus muelleri*), hake (*Merluccius hubbsii*) and blue whiting (*Micromesistius australis*) in waters of the Argentinean Patagonian shelf (42°–56°S, 52°–66°W) used net sonde monitor cables similar to the Soviet fleet in New Zealand (Schiavini et al. 1998). Trawl fishing is an important fishery in Argentina, where a fleet of about 149 vessels make 33 103 trawls per year (Schiavini et al. 1998). It is not known whether sooty shearwaters from South American colonies or migrants from New Zealand die from collisions with the net sonde cables of Argentinean trawlers.

Mortalities of seabirds in trawling gear for Patagonian toothfish has been reported from Antarctic waters around Macquarie Island (55°S, 160°E) and Kerguelen Island (47°S, 70°E) (Williams & Capdeville 1996). Collisions with net sonde monitor cables were responsible for most of the kills. However, shearwaters did not interact with the fishing vessels (Williams & Capdeville 1996).

Seabird mortalities in deep-sea and coastal trawling in Atlantic waters of Uruguay are believed to be low (Stagi et al. 1998).

5. Discussion

5.1 LACK OF INFORMATION FROM SOME FISHERIES

Assembling data to evaluate the overall level of bycatch for an individual seabird species is often hampered by the incompleteness or absence of records of both bycatch and fishing effort for many fisheries (Gales 1998; Brothers et al. 1999a; Gilman 2001). This case study for sooty shearwaters and short-tailed shearwaters was no exception. Detailed fisheries statistics were not available in many cases, because fishing effort information of past and present fisheries are not easily accessible to the public, and there are far too many fisheries active for all of them to be surveyed regularly. Therefore, it was almost impossible to either accurately determine total fishing effort in the Pacific Ocean or scale bycatch risks for sooty shearwaters and short-tailed shearwaters in all known fisheries. These shearwaters are likely to interact with many more fisheries than reviewed here (Table 3) and unreported or unobserved bycatch of these two species might be common.

Major fishing nations, such as China, Indonesia, Peru and Chile, are just beginning to investigate seabird–fishery interactions, and detailed information is lacking (Baird 2001a). Gaps in essential data were prominent for coastal fisheries in the USA, Russia, China, Korea, Indonesia, New Zealand, Australia, Chile and Peru, and for fisheries in tropical pelagic Pacific waters. The combined efforts of these fisheries may be considerable and may threaten sooty shearwaters and short-tailed shearwaters (Uhlmann 2001). Countries such as New Zealand and Australia are relatively advanced in the field of seabird bycatch assessment, but still could promote investigations of their large-scale coastal commercial and recreational fisheries in order to monitor seabird bycatch more systematically.

Most of the studies in the southern hemisphere examined interactions of seabirds with longline fisheries, and most of the work in the northern hemisphere studied gillnet fisheries. This does not necessarily mean that more longline fishing takes place in the South Pacific than North Pacific, nor that more seabirds are caught on longlines than in gillnets in the southern hemisphere and vice versa in the northern hemisphere. It may be because many more albatross species are abundant in the South Pacific (Warham 1990; Robertson & Nunn 1998), and because several of their populations are considered threatened (Gales 1998). Large albatrosses are more likely to be killed on longline hooks than in net fishing gear (Alexander et al. 1997).

The literature shows greater focus on bycatch of rarer species than that for abundant species. The absence of shearwater bycatch records among some of the reviewed material therefore does not necessarily reflect an actual absence of accidental entanglements. The diversity of seabirds caught during observations can be large, so reporting bycatch for even common species could swamp the report with detail (Murray et al. 1993). This could explain why reporting of bycatch rates may be biased towards rarer procellariiforms.

5.2 OTHER LIMITATIONS OF THE AVAILABLE INFORMATION

Even where some information was provided for a fishery, it was often of limited use because of the absence of necessary detail needed for robust estimation of bycatch rates. The reporting of bycatch data needs to follow a standardised protocol to be fully useable (Cousins & Cooper 1998). Essential detail such as estimates of statistical error of bycatch rates was absent for 86% of the studies (n = 42) reviewed here. Bycatch is highly variable and influenced by an array of factors (e.g. geographical location, time of the year, type of interacting fishing vessel, gear configurations, fishing strategy, composition of interacting species, weather) (Brothers et al. 1999; Manly et al. 2002). Estimates of variance are therefore essential to quantify uncertainty, especially because estimates of non-fish bycatch are often used for management purposes (Caswell et al. 1998). The highly variable nature of bycatch events in time and space and limited resources for observer schemes often prevent calculation of bycatch estimates within narrow statistical error limits (Hilborn & Mangel 1997).

Some input parameters used in ratio estimation to extrapolate bycatch totals lack accuracy if the fishery is not well monitored (Manly et al. 1998). It may sometimes be better to replace data with more precise data available from similar fisheries. This approach has often been taken if the official commercial fisheries statistics were kept secret by state fisheries agencies (e.g. Japanese land-based salmon driftnet fishery) or if the information was non-existent (e.g. toothfish fishery outside of CCAMLR regulated waters). However, substitution could over- or under-estimate total mortalities, because such extrapolations can be risky (e.g. Ryan & Boix-Hinzen 1998). Similarly, data gathered on board research vessels may not reliably estimate bycatch totals for commercial fisheries because differences in gear configurations and fishing procedures may make extrapolations from one to the other misleading (Ainley et al. 1981; Northridge 1991).

It is also important to differentiate between units of observer sampling effort when estimating bycatch totals, because the probability of single bycatch events may not be independent from the sampling unit. For example, it can make a difference whether bycatch is estimated as the number of animals killed per tow, per number of consecutive tows, per vessel day, or per fishing trip. Such difficulties on deciding which is the most appropriate unit for ratio estimation of bycatch have been discussed in several study designs, e.g. Johnson et al. (1993), Klaer & Polacheck (1997), Manly et al. (2002).

There are various sources of potential bias in observer coverage and data-recording procedures that may lead to consistent over- or under-estimates of bycatch in any one fishery (Cousins & Cooper 1998). For example: if large quantities of different species were caught in single gear sections observers would not have had much time for accurate identifications and counts (Fitzgerald et al. 1993); and if birds dropped off before they were decked, observers might not have noticed them. Also, if observers were repeatedly assigned to a non-randomly selected subsample of boats (e.g. in the Bering Sea groundfish trawl and longline fishery), resulting mortality estimates could be biased according to whether the selected vessels caught less or more birds than the others.

The apparent lack of accuracy and consistency in the summarising and reporting seabird bycatch information, particularly the absence of estimates of uncertainty associated with species-specific bycatch rates, clearly indicates the need to standardise the protocol of data gathering and publication to allow studies estimating total takes of seabirds in fisheries to reconstruct and obtain valuable information more easily. Therefore it is recommended that published reports of seabird bycatch data should provide detailed information and discussion for at least the following key variables:

- latitudes and longitudes co-ordinates of geographical and seasonal distribution of fishing effort;
- gear characteristics including gear dimensions and fishing strategies;
- number of observed and unobserved fishing operations, gear units and fishing trips and potential scale of biases;
- design features of the observer programme: selection of vessels, coverage levels, randomisation of sampling effort, and sampling strategies;
- observed and estimated numbers of every seabird species caught (including estimates of sampling error and biases) with careful discussion on the choices of sampling units, frequency distributions and capture probabilities.

5.3 PAST COMPARED TO CURRENT RISKS

Bycatch of sooty and short-tailed shearwaters has been evidenced from 14 net fisheries (of 17 reviewed), five longline fisheries (n = 9) and one trawl fishery (n = 3, including jig and pot fisheries) (Table 12). The order of magnitude of bycatch of sooty shearwaters and short-tailed shearwaters reviewed here suggests that millions of both species were killed over the last 50 years of fishing in the Pacific (Table 12). The most birds were taken by past North Pacific pelagic driftnet fisheries. However, total mortalities of sooty shearwaters and short-tailed shearwaters in these key fisheries could not be summarised accurately because information often lacked consistency in the way data were gathered, analysed and reported. Total bycatch magnitudes for sooty shearwaters and short-tailed shearwaters have been estimated within robust statistical limits by reconstructing missing fishing effort and bycatch information from key fisheries. Results are presented elsewhere (Uhlmann 2001).

TABLE 12. ORDER OF MAGNITUDE OF OBSERVED ANNUAL AND TOTAL ESTIMATED BYCATCH OF SOOTY SHEARWATERS (SOSH), SHORT-TAILED SHEARWATERS (STSH) AND DARK SHEARWATERS (DASH).

Blanks indicate that no bycatch was observed/estimated and reported.

Source	Fishery	Region	Season	Active period	Obs. period	Obs. average bycatch SOSH	Obs. average bycatch STSH	Obs. average bycatch DASH	Est. total bycatch SOSH	Est. total bycatch STSH	Est. total bycatch DASH
Net fisheries											
29	BCSFD	BC, Canada	Aug–Oct	1995–97	1997	10^1			?		
17	BCSQE	BC, Canada	Jun–Sep	1983, 85–87	1983, 85–87	10^2	10^1		?	?	
41	CAGF	California, USA	May–Oct	1970?–2000	1980–87	10^2	0	0	10^2	0	0
24	JLAMFD	North Pacific	Nov–Mar	1973?–1991	1990/91	10^1	0	10^1	10^3	0	10^3
15	JLBSFD	North Pacific	May–Jul	1952–88	1977–87	10^2	10^2	10^2	10^3	10^4	10^4
35	JLBSFD	North Pacific	May–Jul	1952–88	1974–87	?	?		10^4	10^4	
16	JMOSFD	North Pacific	May–Jul	1953–88	1981–84	10^1	10^3	10^3	10^2	10^4	10^4
3	JSFDR	North Pacific	May–Jul	1990–pres.	1993–97	?	?	?	10^2	10^4	10^5
24	JSQFD	North Pacific	May–Dec	1978–90	1990	10^3	10^2	10^4	10^5	10^4	10^5
24	KSQFD	North Pacific	Apr–Dec	1979–90	1990	10^2	10^1	10^2	10^4	10^2	10^4
40	NZSF	New Zealand, EEZ		?–pres.	1973	10^2			?		
43, 44	PWSFD	Alaska, USA	May–Sep	?–pres.	1990/91	$<10^1$			10^1		
24	TLAMFD	North Pacific	Jan–Dec	1980–90	1990	10^1	10^1	10^1	10^2	10^1	10^3
43,44	UPSFD	Alaska, USA	Jun–Aug	?–pres.	1990	$<10^1$	$<10^1$		?	?	
Longline fisheries											
39	ALOUS	Alaska, USA	Mar–Nov	?–pres.	1989–93	10^1	10^1	10^2	?	?	10^2
10, 11	AUDTL	Australia, AFZ	Mar–Sep	1989–pres.			$<10^1$			?	
9	AUJTL	Australia, AFZ	Mar–Oct	?–pres.	1988–96	$<10^1$			?		
11	NZDTL	New Zealand, EEZ	Mar–Sep	1968–pres.	1988–96	$<10^1$			?		
*	NZJTL	New Zealand, EEZ	Mar–Sep	1956–pres.		$<10^1$			?		
Other fisheries											
6	NZSQT		Jan–Apr	1978–pres.		10^1			10^2		

* Manly et al. (2002).

It has been shown that different types of fisheries pose differential risks to sooty shearwaters and short-tailed shearwaters. Both species are vulnerable to incidental capture in gillnets, trawl nets and longlines (in order of decreasing risk). Although both may be more susceptible to capture in gillnets than in other fishing gear, bycatch risks depend also on patterns of spatial and temporal overlap between operating fisheries and distribution of the birds (Uhlmann 2001).

Current risks are much lower than they were earlier, because 50% (10 out of 20) of the Pacific fisheries identified as catching sooty shearwaters and short-tailed shearwaters stopped fishing before 2001 (Table 12). Nevertheless, accurate estimation of numbers of these birds still being killed are likely to remain inaccurate, given the paucity of observer data globally and the number of active (legal and illegal) fisheries still operating or developing in the Pacific.

In New Zealand waters, most mortalities of sooty shearwaters derived from trawl fishing operations (Baird 2001b; Robertson & Bell 2002a, b) where bycatch was typically associated with the use of net sonde monitor cables (Bartle 1991). These cables also caused seabird deaths in Argentinean (Schiavini et al. 1998) and Antarctic trawl fisheries (Williams & Capdeville 1996). Although the use of this gear feature was prohibited in CCAMLR-regulated waters of the Southern Oceans in 1994/95 (Conservation Measure 30/X, CCAMLR 2000) and in the EEZ of New Zealand (Alexander et al. 1997), sooty shearwaters bycatch has not dropped in New Zealand trawl fisheries (Robertson & Bell 2002a, b).

5.4 RISKS FROM LONGLINE FISHERIES

Mortalities in longline fisheries in both the far North Pacific and South Pacific and Southern Oceans are generally low, even in waters around breeding grounds in Australia and New Zealand where both species are particularly abundant between October and May during breeding (Uhlmann 2001). This may be, because longline fishing effort for tuna species in Australia and New Zealand peaks in March until September (Gales et al. 1999), when most birds have migrated north of the equator (Serventy 1953). Most of the tuna longline sets in New Zealand are observed west of the South Island and northeast of the North Island (Bagley et al. 2000), both areas where sooty shearwaters rarely occur (P. Scofield, pers. comm.). Longline fishing effort in the Gulf of Alaska and Bering Sea regions was lowest between June and August when abundance of sooty shearwaters and short-tailed shearwaters generally peaks there (Uhlmann 2001). Differences in the frequency of capture between sooty shearwaters and short-tailed shearwaters by Australian longline fleets may be explained by differences in fishing equipment, time and area of fishing (domestic operations occur closer inshore and more often at night) (Gales et al. 1999), but how these differences affect the differential catch probabilities of the two shearwaters in these fisheries has yet to be clarified.

Monitored mortalities of sooty shearwaters and short-tailed shearwaters on longline hooks in North Pacific fisheries were higher than in South Pacific. Observer coverage of the groundfish longline fleets in the Gulf of Alaska and Bering Sea region was twice as high, with 23% of all hooks observed (1993 to 1997) compared to 11% coverage in New Zealand (1990 to 1996). However, assuming random observer effort and similar distribution of a single bycatch event, lower coverage levels do not necessarily imply that, in New Zealand waters, bycatch mortalities have been underestimated, if observer coverage was not biased.

Medium-sized petrels like sooty shearwaters and short-tailed shearwaters are probably less likely to be caught on longline hooks than larger species, because of their morphology. Bill length and/or oesophagus width may limit the capability of sooty shearwaters and short-tailed shearwaters to swallow baited longline hooks (Murray et al. 1993). Previous investigations have shown that hook sizes in longline fisheries markedly affect catch composition of seabirds (Moreno et al. 1996). However, this relationship has yet been investigated for both sooty shearwaters and short-tailed shearwaters and requires quantification.

5.5 RISKS FROM SQUID DRIFTNET FISHERIES

Substantial numbers of sooty shearwaters and short-tailed shearwaters were taken by past commercial driftnet fishing for squid in the North Pacific. Large temporal and spatial overlap of fishing grounds with favourable habitat (and prey) of migrating sooty shearwaters and short-tailed shearwaters existed, probably causing this high risk (Ogi et al. 1993; Uhlmann 2001). Sooty shearwaters were more prevalent than short-tailed shearwaters in bycatch samples of Japanese, Korean and Taiwanese squid driftnet fisheries, whereas short-tailed shearwaters predominated in the Japanese driftnet fisheries for salmon. The Japanese squid driftnet fishery caught by far the most sooty shearwaters during its observed periods. This fishery was systematically observed only in the last two years of active fishing (1989/90). Although observer coverage level was comparatively high in 1990 (10% of all gear units deployed), total bycatch of shearwaters in earlier years may have been over- or underestimated if the distribution of the number of birds caught per set of driftnet was highly variable. Information on variability is essential for determining sufficient observer coverage levels (Hilborn & Mangel 1997). It will make a considerable difference to uncertainty and necessary observer coverage if only a few birds are consistently taken in each operation rather than high numbers at irregular intervals. Nevertheless, a sophisticated design was instigated for the Japanese squid driftnet fisheries in the 1990 season (Fitzgerald et al. 1993) to guarantee bycatch estimates within low variance intervals (Hilborn & Mangel 1997). According to Johnson et al. (1993), sooty shearwaters mortality showed a coefficient of variation of less than 5%. Coefficients of variation are recommended to determine sufficiency of observer coverage levels and should be less than an arbitrary 20% (Manly et al. 2002).

The Korean squid driftnet fishery was the second largest Asian squid driftnet fishery (with respect to its fleet size and fishing effort measured as number of tans deployed). This fishery received observer coverage of 2.5% in 1990. Mortality estimates of sooty shearwaters from this fishery had a CV of about 13% (Johnson et al. 1993). The Taiwanese squid driftnet fishery operated with lowest effort and 6.3% of all vessel days in the 1990 season were observed (Johnson et al. 1993). Sooty shearwaters kills were less common in Korean and Taiwanese fisheries than in Japanese squid driftnets, probably as a result of less intense fishing effort and use of different fishing grounds (Uhlmann 2001).

5.6 RISKS FROM SALMON DRIFTNET FISHERIES

Driftnet fisheries for salmon also caused immense mortalities of sooty shearwaters and short-tailed shearwaters. The Japanese land-based and the mothership fishery both stopped fishing in the early 1990s, although Japanese vessels still operate in Russian waters between May and July each year. Fishing activity of the Japanese salmon driftnet fishery in Russia (JSFDR) is concentrated east of Kamchatka and the Kuril Islands in the first half of the fishing season (from mid-May until mid-June) and shifts into the Sea of Okhotsk in the second half until mid-July (Artyukhin & Burkanov 2000). Distribution of sooty shearwaters and short-tailed shearwaters in the Sea of Okhotsk and Bering

Sea overlap with fishing vessels and both species are most likely to be there in June and July when the fishing fleet moves south along the eastern side of the Kamchatka Peninsula into the Sea of Okhotsk (Shuntov 2000).

Mortality records from the Japanese salmon driftnet fishery in Russia observer programme between 1993 and 1997 showed that observed and total estimated mortalities of sooty shearwaters and short-tailed shearwaters peaked in two zones southeast of the Kuril Islands and were lower in the northernmost zones east and west of Kamchatka Peninsula (Artyukhin & Burkanov 2000) (Fig. 2). This reflects seasonal differences of fishing effort and bird migration (Artyukhin & Burkanov 2000). As this is the last large-scale driftnet fishery operating nowadays, bycatch risks persist at least for short-tailed shearwaters.

Distributional limits for short-tailed shearwaters were further north than for sooty shearwaters and overlapped with fishing grounds of the Japanese mothership salmon driftnet fishery (JMOSFD), especially between June and August (Uhlmann 2001). Fishing effort peaked in the southern areas of the western Aleutian Islands, which probably explained why more short-tailed shearwaters than sooty shearwaters were found in the sample of observed bycatch of the Japanese mothership fishery (DeGange et al. 1985). Mortalities of short-tailed shearwaters peaked sharply in 1983, indicating potential relationships with increased abundance in the fishing area, exceptionally poor body condition of first-year birds forcing them to scavenge along gillnets, and/or extremely good feeding conditions (DeGange et al. 1985). There is strong competition between short-tailed shearwaters and salmon, with both feeding on euphasiids, which were the dominant prey item in short-tailed shearwaters stomachs when many of them were caught in one haul (Ogi 1984). Recruitment and production of salmon were correlated with large-scale sub-surface temperature anomalies (Pacific decadal oscillation index, PDO) in the North Pacific (Mantua et al. 1997). These anomalies may have been the driving mechanism for the distributional 'clash' of short-tailed shearwaters with salmon driftnet fisheries. Increased natural prey abundance may reduce the number of birds attempting to feed on netted fish/squid, or vice versa (DeGange et al. 1985). However, the assumption that large-scale climatological phenomena such as El Niño/La Niña and/or North Pacific temperature oscillation events affect bycatch probabilities of short-tailed shearwaters more than sooty shearwaters requires further investigation.

Although both sooty shearwaters and short-tailed shearwaters were known to actively pass through the fishing regions of the Japanese land-based salmon driftnet fishery (JLBSFD) (Ogi et al. 1993), risks for both species might be differentiated, because adult and immature short-tailed shearwaters arrive later and in lesser numbers than sooty shearwaters in waters east of Japan (Watabe et al. 1987). Higher densities of sooty shearwaters than short-tailed shearwaters were recorded within 200 nautical miles of northern Japan and, accordingly, bycatch numbers in the inshore component of the land-based salmon driftnet fishery were higher (Ogi et al. 1993).

5.7 RISKS FROM OTHER DRIFTNET FISHERIES

Shearwater mortalities in the North Pacific Japanese large-mesh driftnet fishery (JLAMFD) were comparatively low, probably because the fishery was active outside the main migratory period, used larger meshes which posed lower risks for pursuit diving seabirds to become entangled, and operated with less effort than for example its squid component (Table 9).

Although fishing seasons of coastal gillnet fisheries in Alaska (PWSFD, PWSFS, UPSFD, see Table 2 for fisheries codes) coincided with peaking migratory abundance, observed levels of dark shearwaters bycatch were low overall (Wynne et al. 1991; Wynne et al. 1992), probably because the birds typically aggregate further offshore in frontal and continental shelf waters (Gould et al. 1982; B. Fadely, pers. comm.). In contrast, sooty shearwaters and short-tailed shearwaters were regularly observed in coastal waters of British Columbia and California (Chu 1984; Morgan et al. 1991) and mortalities in coastal gillnet fisheries (CAGF, BCSFD, see Table 2) there were reported to have occurred more often. Changes in climate and prey abundance regimes may explain such differences in distributional abundance patterns.

With the adoption of the UN resolution 45/225, 46/215 pelagic driftnet fishing in international pelagic waters ceased in 1992 and removed the largest known bycatch risk to shearwater species, although driftnetting in Russian waters still persists. It is expected that the large number of mortalities caused by these fisheries in the past will have long-term effects on demographics of these two long-lived shearwaters.

6. Conclusions

Past North Pacific driftnet fisheries for salmon and squid caused the largest bycatch of sooty shearwaters and short-tailed shearwaters. There are other longline, gillnet and trawl fisheries that also capture these two species, but this incidental take is probably insignificant, because of relatively low effort, less interaction with fishing gear, and operations outside the birds' occurrence intervals. However, a lack of scientific investigation means that there are still major gaps in our knowledge about which fisheries kill seabirds in general, and sooty shearwaters and short-tailed shearwaters in particular. Risks for both shearwaters persist, even though large pelagic driftnet fisheries of the 1980s have vanished.

Information from many different sources is needed for any thorough assessment of bycatch risks to seabird species. Reporting of bycatch information must follow a standardised protocol to simplify the synthesis of data, in particular when evaluating bycatch risks for migratory birds, which potentially interact with many different fisheries. Estimating and presenting bycatch estimates within robust procedures and narrow limits of statistical error remains the main challenge to future work and better evaluation of ongoing risks.

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