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Incidental capture of seabirds by Japanese southern bluefin tuna longline vessels in New Zealand waters, 1988–1992

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Summary

Fishery observers recorded incidental capture of seabirds during 785 days on Japanese bluefin tuna longline vessels around New Zealand between April and August each year, 1988–1992. High numbers of albatrosses *Diomedea* spp. and petrels *Procellaria* spp. were caught on longline hooks during setting and drowned. Twelve seabird taxa were recorded, six of them breeding only in New Zealand. Most were breeding adults, except for Grey-headed and Black-browed Albatrosses. No bias in sex ratio was evident except for Grey Petrels, of which nearly all were female. Winter-breeding species were most often caught. Birds were not caught randomly, but in a highly aggregated fashion suggestive of complex behavioural interactions with the fishery. Most albatrosses were caught by day in the south whereas most petrels were caught by night north-east of New Zealand. Highest capture rates occurred at dawn and dusk off north-east New Zealand in June–August. Very large catches at specific sites contributed disproportionately to the overall catch rate. The estimated minimum number of total seabirds caught in New Zealand waters declined from 3,652 in 1988 to 360 in 1992, probably as a result of mitigation measures introduced progressively by the industry and by government regulation. Use of tori lines to prevent birds seizing baits had an effect, as did setting in total darkness in the south. Considerably more work needs to be done on the development of improved mitigation measures. Greater observer coverage is required to measure accurately the mortality of individual seabird species on tuna longlines throughout the Southern Ocean and to determine the effectiveness of mitigation measures.

Introduction

Japanese longliners, commercial vessels which set long fishing lines horizontal to the sea surface, have been targeting southern bluefin tuna *Thunnus maccoyii* inside the present New Zealand Exclusive Economic Zone (EEZ) since 1962. Procellariiform seabirds, especially albatrosses, were caught from the outset as shown by band recoveries (Kinsky 1962, and subsequent reports in the same series). An opportunity to collect detailed information on seabird bycatch arose following the establishment of the New Zealand Ministry of Agriculture and Fisheries (MAF) Fisheries Scientific Observer Programme in 1986. Observers were placed on board two or three vessels for periods of up to three weeks during 1987, 1988 and 1989. Because of the numbers of seabirds recorded on longlines during these years, a collaborative programme was set up in 1990 between MAF Fisheries and the Museum of New Zealand to measure the extent of this mortality and to develop techniques for its reduction. The number of observers was increased to five in 1992, with progressively longer periods (up to 18 weeks) being spent at sea.

Concern about the impact of mortality of seabirds in the southern bluefin tuna longline fishery on albatross populations grew during the 1980s as the results of long-term banding studies on subantarctic breeding colonies, mostly begun in the late 1960s and early 1970s, gradually became available. Declines were initially observed for Wandering Albatrosses *Diomedea e. exulans*, which normally have a very slow breeding rate but high survivorship. Between 1974 and 1978 Tomkins (1985) measured a 48% fall in the small population on Macquarie Island, associated with very high adult death rates, which he suggested were due to accidental capture in commercial fisheries. Weimerskirch and Jouventin (1987) provided the first suggestion that declines in Wandering Albatross populations were linked to abnormally high mortality rates of adults, especially females, caused by capture on longline hooks. Between 1968 and 1983 the population on the Crozet Islands declined by half. The higher mortality of females was considered by Weimerskirch and Jouventin to result from differences in their range at sea. Females foraged over subtropical and convergence waters (35–45°S) where longliners are known to concentrate (Figure 1 in Michael *et al.* 1987, Figure 1 in Brothers 1991), whereas males fed further south over antarctic waters (50–60°S).

A detailed study of breeding success, breeding frequency, recruitment and survival of Wandering Albatrosses at Bird Island, South Georgia, 1961–1989 (Croxall *et al.* 1990) showed the same pattern of decline (though at a lower rate of 1% per year) associated with high adult mortality, especially of females. During this period breeding frequency remained constant and breeding success increased slightly, as on Crozet and Macquarie Island. This suggested that the population decline was due to human rather than environmental factors such as food supply. Moreover, Croxall *et al.* (1990) showed that present levels of breeding success could not compensate for the higher level of adult mortality, and that recruitment had also fallen. An analysis of recoveries of Wandering Albatrosses banded at South Georgia, 1975–1988 (Croxall and Prince 1990), showed that 63% of those recovered away from the breeding area were caught during fishing operations and 64% of these were from tuna longliners. High proportions of females (73% of sexed birds) and of adults (64%) were found amongst recent (1984–1986) longline captures along the edge of the continental shelf of Brazil and northern Argentina, 33–35°S (Croxall and Prince 1990). Croxall *et al.* (1990) concluded that additional deaths due to the longline fishery accounted for an annual mortality of at least 2–3% of adults and up to 25% of juveniles, and that this was sufficient to establish longline fisheries as the most likely factor to account for the population decline of Wandering Albatrosses on South Georgia.

The first direct measurements of seabird mortality on bluefin tuna longlines were made by Brothers (1991), using data collected by himself and three Australian Commonwealth Fisheries Observers on seven voyages south and east of Tasmania in May–June 1988. Forty-five albatrosses were caught at an average rate of 0.41 per 1,000 hooks. Multiplication of this figure by the mean number of Japanese bluefin tuna longline hooks set in the Southern Ocean each year, 1981–1986 (107.9 million), resulted in an estimate of 44,000 albatrosses killed annually on Japanese longlines (Brothers 1991). Even higher estimated rates of capture of oceanic seabirds (63% of them albatrosses) were recorded in 1988–1989 by Murray *et al.* (1992) for New Zealand seas.

In this paper we provide more detailed information on seabird capture on foreign-licensed and New Zealand company chartered Japanese bluefin tuna longliners in the New Zealand region in 1988–1992, together with a preliminary evaluation of the effectiveness of various preventative measures.

Description of the fishery

World fishing strategy for southern bluefin tuna

Japan is the major fishing nation for tuna species, landing 28% of the 1988 world catch (Bergin and Howard 1992). In 1987 between 250 and 300 Japanese longline vessels fished for southern bluefin tuna in the Southern Ocean (Michael *et al.* 1987). Despite steep declines in southern bluefin tuna catches (e.g. Table 1, also Murray and Edwards 1988), they remain profitable (Campbell and Nicholl 1991, cited in Bergin and Howard 1992) and, because of the high value of southern bluefin tuna, additional vessels have recently been built (Michael *et al.* 1987).

The main spawning area for southern bluefin tuna is the eastern Indian Ocean, between north-western Australia and Indonesia. From here young fish migrate down the west coast of Australia into the Great Australian Bight. Some then cross the Indian Ocean into African and Atlantic waters, while the remainder swim south past Tasmania to New Zealand waters, eventually passing north into the subtropical South-West Pacific (Michael *et al.* 1987). The main fishing areas are off the western and eastern Cape (southern Africa), in subtropical convergence waters across the Indian Ocean to Fremantle, in the cooler waters of the Great Australian Bight, intensively around Tasmania, and around New Zealand.

In the generalized account by Michael *et al.* (1987) of the Japanese fishing strategy for southern bluefin tuna in the Southern Ocean, vessels put to sea for 12–18 months and begin fishing for southern bluefin tuna off southern Africa in February–May, continuing across the Indian Ocean until August–November, when they reach Fremantle. Periods of fishing for other tuna such as bigeye *Thunnus obesus*, yellowfin *T. albacares*, albacore *T. alalunga* and billfish such as marlin *Makaira* and *Tetrapturus* spp. and swordfish *Xiphias gladius* in the tropical Indian Ocean off Somalia and Western Australia and in the Coral Sea, as well as trolling for bluefin tuna on the high seas, occur during intervening periods. The main fishery south of Australia extends from January to July, and around New Zealand from January (or March, since 1990) to September.

Japanese longline fishing strategy in New Zealand

Two distinct foreign longline fleets have been licensed to fish in the New Zealand EEZ since 1979. Although they operate in different areas and target different species, Japanese vessels may be licensed for both fisheries. The Northern Fishery (for distribution of fishing effort north and east of New Zealand, see Figure 2 in Murray *et al.* 1992) is made up of a variable number of Japanese and

South Korean vessels targeting albacore, yellowfin and bigeye tuna, and swordfish, with a small bycatch of southern bluefin tuna. No observers have been on these vessels and no information, except for band recoveries, is available on seabirds caught. The remainder of this paper is therefore concerned with the Southern Fishery.

This consists entirely of Japanese vessels targeting southern bluefin and, to a lesser extent, bigeye tuna and swordfish. The distribution of longline sets in 1988–1992 is shown in Figure 1. Fishing commences over the Solander Trough, north-west of the Snares Islands (Figure 4, p.196), in March, with vessels moving northward with the bluefin tuna. A dense concentration of sets west of Fiordland indicates the northern limit (44°16′S) allowed here for foreign-licensed vessels, for protection of the domestic bluefin tuna fishery off the West Coast of the South Island. An increased level of fishing activity west of Fiordland

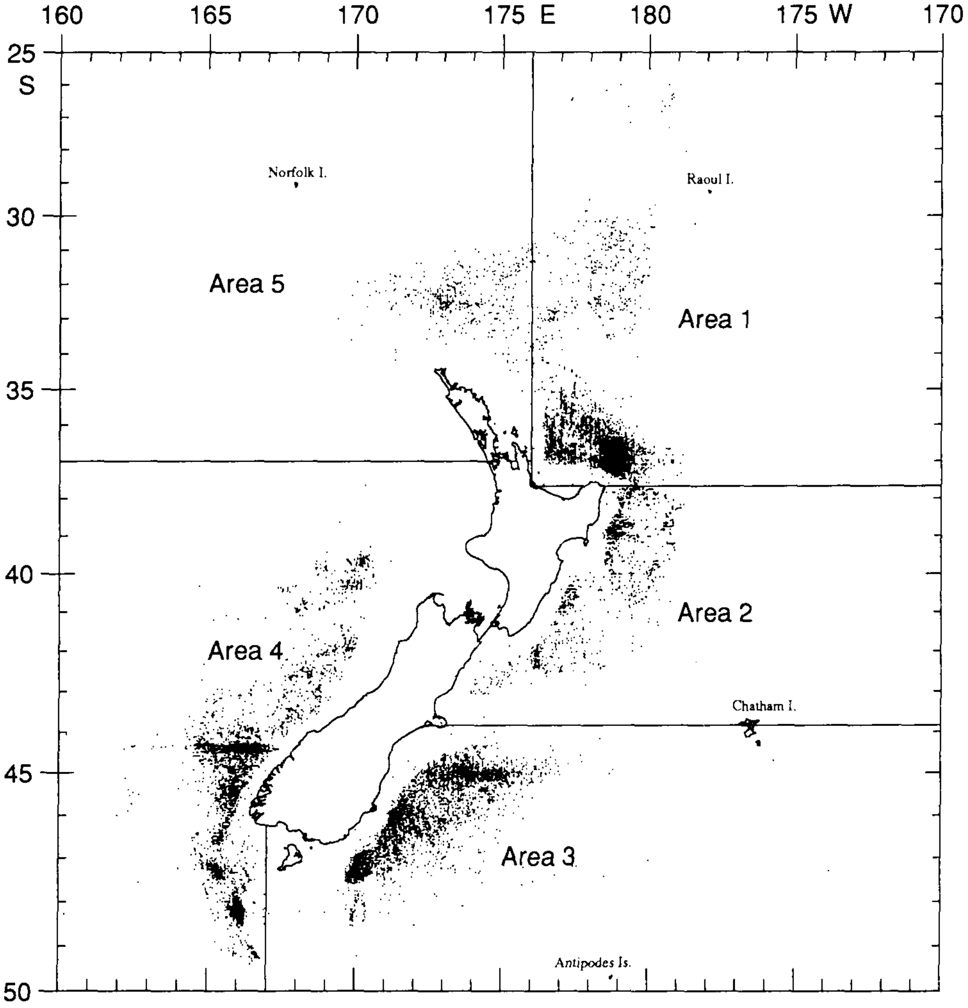

Figure 1. Fishery areas with reported Japanese southern bluefin tuna longline set positions in the New Zealand 200-mile Exclusive Economic Zone, 1988–1992.

since 1990 is evident from comparing Figure 1 with Figure 1 in Murray *et al.* (1992). Japanese longline vessels may, however, fish in the West Coast exclusion zone under charter to New Zealand fishing companies.

In May waters east of Otago and along the southern slope of the Chatham Rise are fished, but there are few observed sets here (Figure 3). In 1988 all vessels worked in this area in April and May (Michael *et al.* 1989). Fishing begins off the east coast of the North Island in May and June and continues around East Cape in July and August as the tuna migrate into the Bay of Plenty and then far north and east of New Zealand in a broad front extending from Norfolk to Raoul Island (Figure 1). Vessels leave this fishery in August and September.

Table 1 shows reported southern bluefin tuna catch and effort in New Zealand waters (i.e. within the 200-mile EEZ declared in 1977) since 1967. In recent years the most conspicuous change in effort occurred between 1981 and 1984 when the number of vessels fell sharply from 85 to 34. However, the mean length of longlines increased from 102 km in 1980 to 133 km in 1992, with an increase in average number of hooks per set from 2,420 to 2,900 over the same period. This reflects the replacement of the smaller, older vessels with new, larger and faster ones.

Table 1. Southern bluefin tuna reported catch and effort by Japanese longline vessels in New Zealand waters, 1967–1992 (sources: Japan Fisheries Agency and New Zealand MAF Fisheries unpubl. data).

Year	No. vessels	No. sets (thousands)	No. hooks (millions)	Mean line length (km)	No. bluefin tuna caught (thousands)
1967	-	2.1	4.4	-	41
1968	-	1.9	3.6	-	48
1969	-	6.3	12.7	-	106
1970	-	6.0	12.4	-	79
1971	-	11.2	22.8	-	145
1972	-	10.2	19.8	-	151
1973	-	6.7	11.9	-	70
1974	-	8.0	15.2	-	77
1975	-	7.0	13.0	-	78
1976	-	14.8	30.2	-	157
1977	-	8.5	17.8	-	39
1978	-	1.4	3.2	-	10
1979	-	7.7	18.2	-	72
1980	87	10.7	25.9	102	117
1981	85	10.3	26.2	108	91
1982	72	8.9	23.5	107	47
1983	55	5.7	15.6	113	26
1984	34	4.4	12.7	117	23
1985	34	3.9	11.3	119	26
1986	33	3.9	11.4	123	19
1987	38	5.0	14.7	128	22
1988	38	4.2	12.2	123	12
1989	32	3.2	9.4	122	12
1990	28	2.5	7.4	125	14
1991	41	4.3	12.6	130	13
1992	35	3.1	9.0	133	12

Fishing strategy

Japanese fishermen report that southern bluefin tuna travel in many small schools (10–20 fish) dispersed over a broad front. These schools tend to follow the 1,200–2,000 m contours of the continental shelf around New Zealand, swimming at depths of 50–100 m. A fleet of up to 30 vessels may cooperate to locate and maintain contact with these schools (Michael *et al.* 1987). Convergence zones, sharp temperature gradients, and bathymetric features tend to concentrate prey items and tuna.

Longlines are usually set across or along slopes over depths ranging from 1,200–1,750 m to 4,000 m. Evening and early morning fishing is often best because southern bluefin tuna may then feed within 100 m of the surface (Michael *et al.* 1987). Moon phase is also important perhaps because at full moon tidal currents are stronger and convergences better defined, thus concentrating the prey. Also, as southern bluefin tuna are primarily visual feeders, a bright moon is likely to silhouette prey items (and baits!) more effectively. When fishing in close proximity, vessels set lines at the same time and in the same direc-

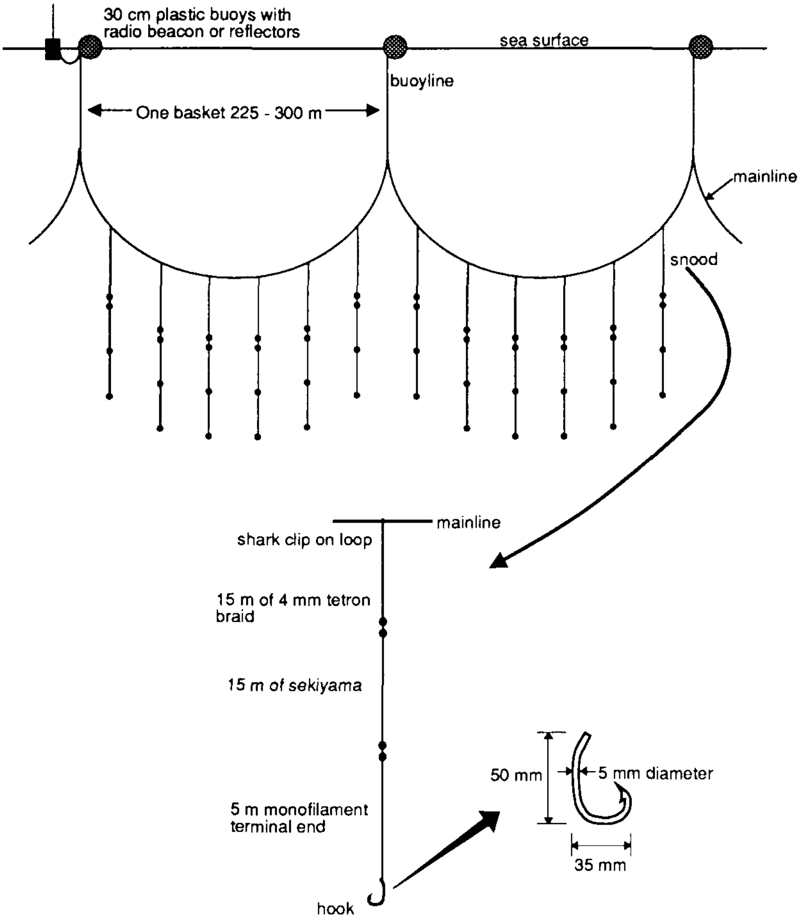

Figure 2. Structure of a Japanese southern bluefin tuna longline.

tion (to avoid tangles), 2–4 km apart. The baits are generally set at depths of 60–180 m (Michael *et al.* 1987).

Tuna longlines consist of a continuous length of 7 mm diameter kuralon nylon rope (the mainline) suspended beneath the sea surface from buoylines at regular intervals (Figure 2). Hanging from the mainline are a series of branch lines (snoods), each typically 35 m in length, with baited hooks or artificial lures. Long snoods are necessary to allow hooked bluefin tuna to swim about so that they can be hauled aboard alive and bled. Bleeding doubles the value of landed bluefin tuna for the *sashimi* market, and prices of US$ 10,000 for a single 100 kg fish on the Tokyo market are common.

Setting and hauling

Longlines are normally set once each 24-hour period. Sets are usually made with a following sea. The mainline is cast off the stern by an automatic feeder at 400–450 m per minute with the vessel steaming at about 10 knots. Approximately every six seconds a pre-baited snood is clipped onto the mainline and thrown from the stern of the vessel. It takes 5–6 hours to set 130 km of longline. After setting, the line is left to fish for 4–5 hours while the crew sleep.

The end of the longline which was set last is usually the end retrieved. Hauling usually takes 12 hours, during which the vessel steams back along the longline at 3–8 knots. The mainline is winched aboard the well-deck forward of the bridge. Snoods are rapidly unclipped from the mainline and coiled ready for re-use. Bait and unwanted fish species are discarded into the wake.

Data collection and analysis

Data sources

Comprehensive data on Japanese longline tuna catch and fishing effort have been published annually since 1951 by the Japan Fisheries Agency. However, to monitor in more detail the activities of foreign tuna longline vessels fishing under licence in the newly established EEZ, New Zealand introduced a fisheries statistics logbook, vessel registration and activity reporting system in time for the 1980 fishing season. The Japanese fishing master is required to record catch and effort figures on a set-by-set basis to be supplied to a New Zealand Fishery Officer at the end of each voyage. Records must include the position at the start of the set and the time of the start and end of each set and haul, length of the mainline, number of hooks set, and bait type. Effort data thus recorded are considered reliable (in the southern bluefin tuna fishery non-reporting of effort data is usually less than 2% in New Zealand), and have been used throughout this paper, in Tables 1, 2 and 8, and in Figures 1 and 3. However, in New Zealand seabirds are not protected further than 12 miles from shore and fishing masters are not required to supply information on seabird bycatch.

Observer coverage

From 1987 New Zealand placed fishery observers on selected foreign-licensed and some domestic-chartered Japanese vessels in the southern bluefin tuna fishery. Initial coverage was very low (fewer than 1% of sets made in 1987 and 1988) and confined to the East Cape area in June–July (Michael *et al.* 1987, 1989; Table 2 in this paper). From 1989 geographic and temporal coverage was more even, with an observer south of New Zealand in areas 3 and 4 (Figure 3) for the first time. However, overall coverage was still only 2.7% of total sets. A fall in the level of fishing activity in 1990 improved observer coverage (Table 2), but it was not until 1992 that 11% coverage was reached by using five observers (in all) throughout the season (April–August).

Low observer coverage in 1988–1991 has resulted in uneven sampling of fishing effort in the main fishing areas (compare Figures 1 and 3). Sampling of the fishery in the Solander Trough to the south-west of New Zealand (Area 4) was

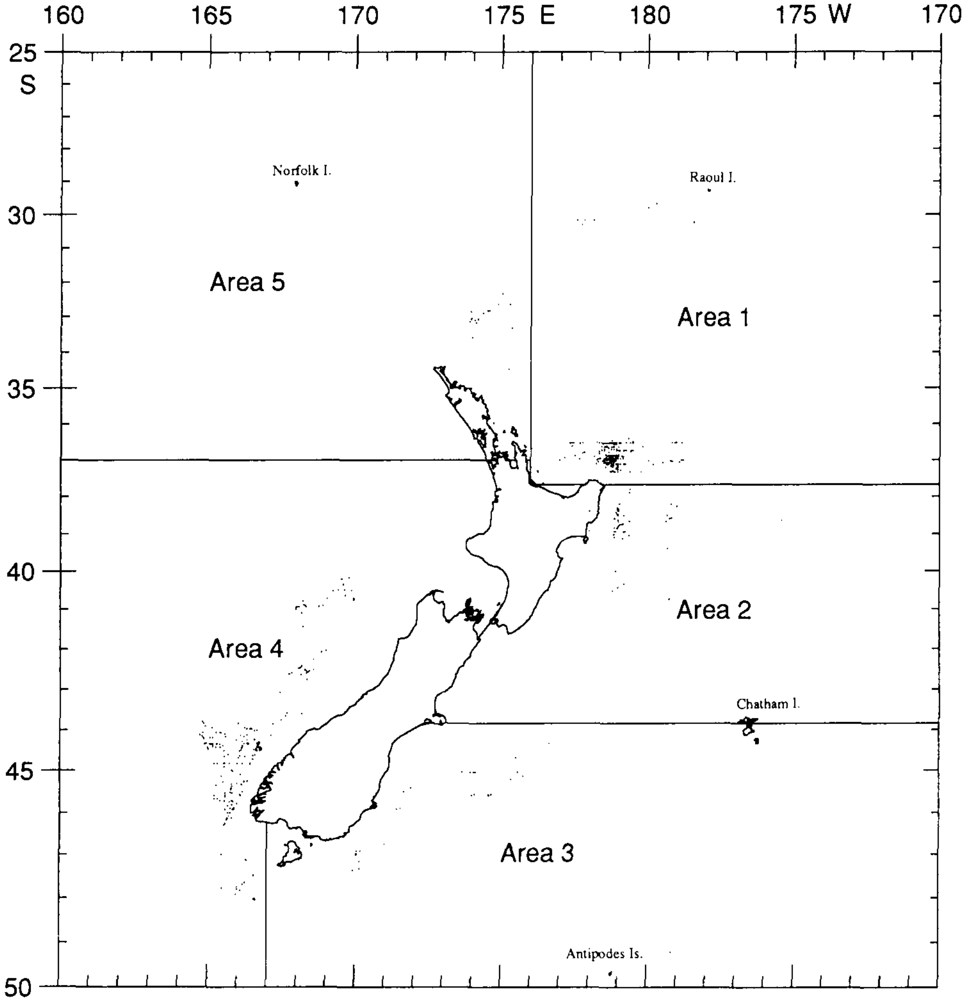

Figure 3. Distribution of Japanese southern bluefin tuna sets monitored by MAF Fisheries observers, 1988–1992.

Table 2. Numbers of Japanese southern bluefin tuna longline vessels, fishing effort and sets observed in New Zealand waters, 1988–1992.

Year	No. vessels	No. hooks	No. sets	No. sets observed
1988	38	12,152,613	4,190	41
1989	32	9,418,562	3,249	88
1990	28	7,369,824	2,529	154
1991	41	12,640,143	4,290	150
1992	35	9,006,248	3,100	352

particularly low, as well as for all of Area 3 east of Otago and into the Bounty Trough (Figure 1). Areas east of the Wairarapa and Kaikoura coasts were not sampled at all (Area 2, Figure 1). A modest level of coverage was achieved only east of Gisborne and around East Cape into the Bay of Plenty (Figure 3).

Observer data

The primary purpose of the Scientific Observer Programme is to record fishery statistics for analysis of catch and effort. However, seabird bycatch was also recorded from the outset, and from 1989 seabirds were routinely returned for identification at the Museum of New Zealand. Because observers are required to be on deck for at least 12 hours to record the haul, they must sleep during the set, when nearly all birds are caught. This means that information on the circumstances of seabird capture must be inferred from observations made during the haul. We have no data on setting which would allow inclusion of estimates of bird strikes or of loss of hooked birds prior to landing on board. In this respect the observations of Brothers (1991), though limited in extent, are extremely valuable.

In response to high levels of seabird kills in 1988–1990 (Table 8), detailed information on the efficacy of Brothers's (1988, 1991) recommendations to reduce mortality was collected in 1992. New Zealand observers were provided with a diagram of a tori line (a line which trails above the wake of the vessel to deter ship-following seabirds from seizing baits during setting) designed and rigged according to the recommended specifications of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR 1990 and see Figure 6). They were required to record details of tori line use, including frequency, length of tori line, height of attachment above sea surface, number of streamers, and distance of bait entry point from tori line, vessel mid-line and stern of vessel. Whether baits were frozen or thawed was also noted. The data thus collected relevant to seabird bycatch are summarized in Tables 8 and 10. Accurate estimation of average distance of bait sinking proved to be impossible without binoculars and because most sets were made at night.

Seabird specimen recovery

A programme to return birds to the Museum of New Zealand for identification and autopsy was initiated in 1989. This was formalized because analysis of fishery observer records from longliners showed that they could identify fewer than half (46%) to a major group such as "albatrosses" *Diomedea* spp. or "petrels" *Procellaria* spp. Observers attached a label recording vessel and observer name, date, position, haul number, sample number and time landed to the leg of each bird. Not all birds caught were retained for identification because when seabird catch rates were high observers sometimes had difficulty in persuading crews to retain them. At the museum, specimens were identified to species and subspecies and their age category (e.g. juvenile, subadult, adult) determined by plumage and/or gonad condition. Nomenclature used follows CCOSNZ (1990), except for Wandering Albatrosses, where the revision of Medway (1993) was followed. Birds were autopsied to determine sex and gonad state.

Analysis of capture rate

Because of small sample sizes of identified birds it was not possible to calculate capture rates for individual species. However, by pooling species and areas we have been able to provide estimates of total seabird catch (Table 8). We have assumed that seabird catch rate is the same on observed and unobserved vessels and constant for an area during the season.

The frequency distribution of seabird captures is shown in Table 3. This shows that although seabird capture is a relatively rare event, of 320 captures recorded, 197 (62%) were at a rate of three or more birds per set. The high degree of

Table 3. Frequency distributions of seabird capture observed and expected from a Negative Binomial model, 1988–1992.

No. birds per set	Observed frequency	Expected Frequency
0	653	655
1	69	64
2	27	30
3	15	15
4	7	9
5	1	4
6	5	1
7	2	3
8	2	1
9	0	0
10	1	1
11	0	0
12	1	1
13	1	1
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	1	1

$\chi^2 = 14.473$, diff. N. S. $\alpha = 0.05$, df = 10 skewness towards low capture rates and the over-dispersion evident in Table 3 (variance : mean ratio = 13.1) indicate that a Negative Binomial rather than a normal or Poisson distribution best describes these data. Hilborn and Mangel (in press) found Bartle's (1991) seabird bycatch data from Soviet trawlers in the New Zealand subantarctic to be similarly well described by a Negative Binomial model. Comparing the observed frequency distribution of seabird capture on tuna longlines (Table 3) with that predicted from a Negative Binomial model, we found no significant difference between observed and expected ($\chi^2 = 14.473$, df = 10).

It was therefore possible to use a Negative Binomial model to describe the probability of catching seabirds on tuna longlines. We could thus estimate the mean and variance of the number caught per set directly, rather than through a resampling procedure such as the bootstrap (Efron and Tibshirani 1986), as we had done previously (Murray *et al.* 1992). It also meant that by grouping estimates from 1988 to 1990 and from 1991 to 1992, when mitigation measures were apparently more widely used, it was possible to compensate for the very limited observer coverage of the first two years and for areas when we had no observers in that particular year. The model used was:

$$P(r) = \left(\frac{\mathrm{m}}{\mathrm{m} + \mathrm{k}}\right) \left(1 - \frac{1-\mathrm{k}}{r}\right) \quad P \quad \left(r - 1\right)$$

$$\text{variance of distribution} = \mathrm{m}\left(1 + \frac{\mathrm{m}}{\mathrm{k}}\right)$$

where $P(r)$ is the probability of catching r birds in a set where $r = 0, 1, 2 \ldots,$

$$\mathrm{m} = \frac{\text{number of birds caught}}{\text{number of observed sets}}$$

k was estimated iteratively using the observed

$$\mathrm{P}(0) = \left(1 + \frac{\mathrm{m}}{\mathrm{k}}\right)^{-\mathrm{k}}$$

Calculation of time of seabird capture

As observers were unable to record events during setting we had to estimate the time of seabird capture. From the time of landing recorded, we were able to calculate the proportion of the length of haul at which the capture was made, back-calculate the position on the set and thus the time.

Given the time the haul began (SH), the duration of the haul (HT) and the time of landing of the seabird (TL), we estimated the point of capture from the proportion along the length of the haul. An average haul time of 11.9 hours (95% confidence interval ± 3.2, n = 12,398) was used. As most longlines are hauled from the end set last, the reciprocal proportion of the haul was used to estimate the point of capture during the set. Knowing the time the set began (SS) and the time it ended (ES), we could calculate the duration of the set and the point of capture of each bird. This was then related to the start time (SS) to estimate the time of capture. Thus:

$$\text{Time of bird capture} = \text{SS} + (\text{ES} - \text{SS})\left(1 - \frac{(\text{TL} - \text{SH})}{\text{HT}}\right)$$

Where the longline was hauled from the start of the set the following expression was used:

$$\text{Time of bird capture} = \text{SS} + (\text{ES} - \text{SS})\left(\frac{(\text{TL} - \text{SH})}{\text{HT}}\right)$$

Table 7 summarizes the number of birds caught in relation to the time at which the hook was set grouped by two-hour time intervals. Times of sunrise and sunset were taken for the date in the middle of the observer period in each area and the port closest to the geographical centre of the fishing area (Anon. 1985). Data are presented separately for the northern and southern fishing areas because of the differences in bird species involved in each fishing area (Table 5).

Results

Magnitude of incidental mortality

A total of 320 seabirds was recovered from 785 sets observed between 1988 and 1992. The number of birds caught will have been higher than this because some escape longline hooks but die later (Weimerskirch and Jouventin 1987) and an unknown proportion of hooked birds are torn off by sharks or mechanically during hauling (Brothers 1991). Brothers found that directly observed bird catch was 27% higher than the number eventually hauled aboard. However, we have not scaled our figures for this unknown and probably highly variable rate of bird loss from hooks.

Minimum estimates of the total number of birds caught by Japanese bluefin tuna longline vessels in New Zealand were thus calculated from this sample and scaled up to include the total fleet. A Negative Binomial model was used to take into account the highly aggregated nature of seabird bycatch (Table 3). This gave a figure of 3,652±1,283 birds caught in 1988, within 95% confidence limits (Table 8). The estimated seabird catch remained high in 1989 and 1990, with a sharp drop to much lower levels in 1991 and 1992, finally reaching 360±188 birds.

Discussion

How seabirds are caught

Ship-following is a marked behaviour among many Southern Ocean seabird species. Seabirds recognize individual ships and preferentially follow fishing vessels to scavenge on fish waste, sometimes in very large numbers (hundreds or even thousands of individuals). Competition to seize anything edible churned up in the wake is fierce. Dominance is based on size (Bartle 1974), though smaller species such as *Procellaria* petrels frequently out-manoeuvre albatrosses, can follow a vessel more closely and (unlike the large albatrosses) can also dive readily to considerable depths (more than 10 m) for fish waste (J.A.B. pers. obs.).

Most ship-following oceanic seabirds are natural scavengers and, for them, squid is the preferred diet (Lipinski and Jackson 1989). Uneaten squid baits are struck off tuna longline hooks during hauling, thus encouraging seabirds to follow such vessels. Setting hooks baited with squid also provides a powerful attractant for seabirds to follow longline vessels. All but two of the 135 birds listed in Table 4 were caught during line setting. In the interval between landing in or near the ship's wake and sinking, baits are seized by seabirds and swallowed. Birds down to the size of Grey Petrels *Procellaria cinerea* can easily swallow standard baited bluefin tuna hooks (*contra* Brothers 1991). If firmly hooked, all birds are quickly pulled underwater by the weight of the mainline and drowned. Most albatrosses and petrels recovered had been hooked in the oesophagus. Perhaps many caught in the mouth struggle free, but some of these die as the result of their wounds (Weimerskirch and Jouventin 1987).

Occasionally birds are caught as the longline is being hauled. These birds seize uneaten baits as they surface alongside the vessel. Both the Cape Pigeon *Daption capense* and a South Georgian banded Wandering Albatross caught during hauling were able to be released alive.

Species composition and numbers

Seabirds are caught selectively on tuna longlines, with certain species, age-classes and sexes more at risk. Three features characterize the species caught.

Table 4. Identity of birds caught on Japanese tuna longlines in New Zealand waters, 1989–1992.

Species	Number
Wandering (Snowy) Albatross *D. e. exulans*	2
Antipodes Wandering Albatross *D. exulans antipodensis*[a]	3
Auckland Is. Wandering Albatross *D. exulans gibsoni*[a]	8
unindentified Wandering Albatross *D. exulans* ssp.	13
Total Wandering Albatrosses	***26***
New Zealand White-capped Albatross *D. cauta steadi*[a]	6
Southern Buller's Albatross *D. b. bulleri*[a]	22
Grey-headed Albatross *D. chrysostoma*	6
Southern Black-browed Albatross *D. m. melanophrys*	8
New Zealand Black-browed Albatross *D. m. impavida*[a]	17
Total other albatrosses	***59***
Southern Giant Petrel *Macronectes giganteus*	1
Cape Pigeon *Daption capense*	1
Westland Petrel *Procellaria westlandica*[a]	1
Grey Petrel *Procellaria cinerea*	47
Total seabirds	***135***

[a] endemic New Zealand species or subspecies.

First, although only nine of the 45 procellariiform species which commonly frequent New Zealand seas were recovered from longlines in 1988–1992, all but Grey-headed Albatrosses *Diomedea chrysostoma* are well-known ship-followers in the New Zealand region (Bartle 1974). In addition to those listed in Table 4, there are only two other ship-following species which congregate in numbers around fishing vessels in the area mostly worked by the longliners during the fishing season (Figure 1), and both (Southern Royal Albatross *Diomedea e. epomophora* and White-chinned Petrel *Procellaria aequinoctialis*) were recorded in 1993 when observer coverage improved. Second, 74% of the individuals identified (Table 4) were of winter-breeding species. Of these winter breeders, 86% were identified as breeding adults (Table 9) by gonad and/or brood-patch condition. Third, six of the 12 taxa caught are confined to New Zealand for breeding. Fourth, large numbers of breeding Wandering Albatrosses (all subspecies) and Grey Petrels were caught, although the longline fishery operates far from their subantarctic breeding sites.

The diversity of species caught, together with an insufficient proportion of birds accurately identified (Table 4), prevented estimation of the number of each species killed. However, the number of Wandering Albatrosses caught (19% of total seabirds, Table 4) is disproportionate relative to the abundance at sea around New Zealand of other ship-following albatrosses and petrels (Jenkins 1971, Vooren 1972, 1977, Bartle 1974 and unpubl.). Another species of special concern is the Grey Petrel (35% of birds caught, Table 4), particularly because most were probably from a single colony (Bartle 1990), and at least 91% were breeding females (Table 9). The behaviour of these two species is probably responsible for their high capture rate. Wandering Albatrosses dominate smaller species in bait-seizing conflicts (Bartle 1974, Brothers 1991), and a relatively low density of albatrosses and high percentage of lines set at night in a favoured foraging area off East Cape (Bartle 1990) is thought to be responsible for the many Grey Petrels killed.

Rates of capture in different areas

There were large differences in capture rate with area both within and between years (Table 8). Consistently large catches of Grey Petrels and Black-browed

Table 5. Numbers of birds recorded from Japanese tuna longlines by fishing area, 1989–1992 (fishing areas as shown in Figure 1).

Species	Area 1 + 2 Bay of Plenty – Wairarapa (no. sets = 356)	Area 3 + 4 Challenger – Chatham (no. sets = 371)	Area 5 Three Kings (no. sets = 17)
Diomedea exulans	12	10	1
D. cauta	0	5	0
D. bulleri	0	21	0
D. chrysostoma	1	5	0
D. m. melanophrys	4	0	0
D. m. impavida	11	0	5
Total albatrosses	28	41	6
Macronectes giganteus	1	0	0
Daption capense	1	0	0
Procellaria westlandica	0	1	0
P. cinerea	45	2	0
Total petrels	47	3	0
Unidentified seabirds	144	52	1

Albatrosses (both subspecies) in areas 1 and 2 (Table 5) resulted in an average catch rate of 0.72 birds per set over five years, compared with 0.39 birds per set over four years in the southern areas (areas 3 and 4). However, more albatrosses were caught in the southern areas. Seasonal differences in fishery exploitation of each area (April–June for areas 3 and 4, June–August for areas 1 and 2, and August for area 5) were insufficient to explain these trends. In the following section it is shown that these large-scale differences in the composition of seabird bycatch reflect marked differences in the seabird fauna of the different zones.

Small-scale differences in capture rate

In this section a finer-grained analysis is attempted, using smaller areas defined by bathymetric features in which oceanographic conditions are likely to be relatively homogeneous. Rather than looking at overall catch rate for all seabird species combined, we have attempted to allow for major differences in inter-area abundance of seabirds (Ainley and Boekelheide 1983) and the seasonal flux of species through New Zealand waters (Bartle 1974) by examining which species were caught in which areas in which month. The six areas selected for analysis (Figure 4) are discrete or semi-discrete fishing zones with distinctive bird faunas as shown by the different frequencies of capture in each. When the percentage of seabirds caught is listed by small-scale area (Table 6), substantial differences emerge between areas and between species, and these are discussed below for each.

(1) Wandering Albatross *Diomedea exulans*. Twice as many were caught at East Cape than elsewhere, partly reflecting greater observer coverage. However, all Wandering Albatrosses caught in the Solander Trough or on the Puysegur Bank were breeding adults from the Auckland Islands, whereas many of the Auckland, Antipodes and South Georgian birds caught at East Cape and Hikurangi Trench were immature. Thus the mortality at Solander and Puysegur may have a more immediate impact on the population. Adult Wandering Albatrosses resembling those from the Auckland Islands occur over slope waters from Kaikoura south to Campbell Island throughout the year, but young birds and adults are found in the Bay of Plenty and northern waters mostly in winter (J.A.B., pers. obs.). Thus the pattern of capture generally agrees with their occurrence at sea.

(2) White-capped Albatross *D. cauta*. All were caught at Puysegur and all were breeding adults. This species is very abundant over continental shelves around central and southern New Zealand during almost all seasons (Bartle 1974 and unpubl.), though largely absent from waters north of East Cape, even in winter (Vooren 1972). Numbers caught do not seem high when compared with the large population size (Robertson 1975) or numbers caught in the squid trawl fishery (Bartle 1991).

(3) Southern Buller's Albatross *D. b. bulleri*. All recorded captures were at Puysegur Bank, adjacent to the only colonies of this autumn-winter breeding subspecies at the Solander and Snares Islands. The tendency of Buller's Albatross to feed only on shelf areas (J.A.B., pers. obs.) explains its rarity in other

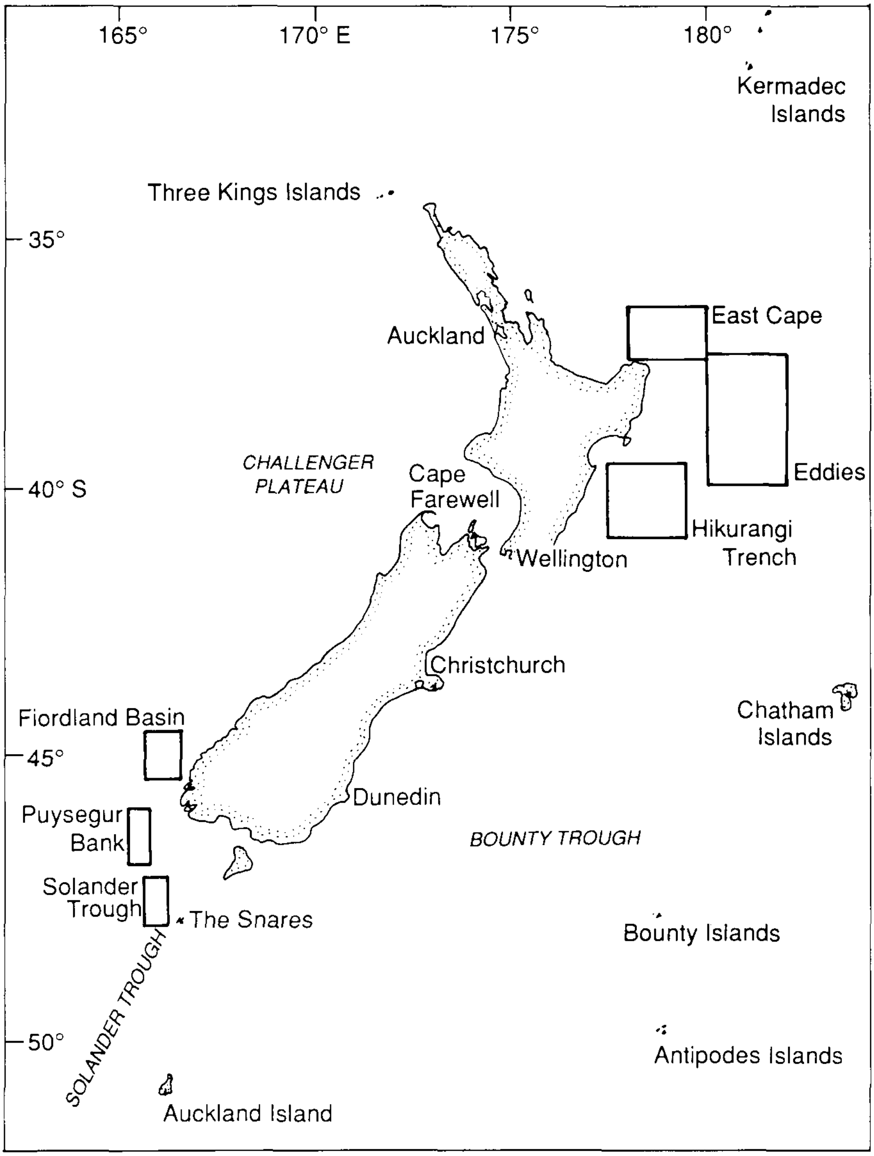

Figure 4. Location of small-scale sampling areas.

southern areas, and Vooren (1972) and Bartle (1974) noted its absence or rarity in northern waters.

(4) Westland Petrel *Procellaria westlandica*. A female with a partly formed egg (< 2 weeks from laying) was caught at Puysegur Bank, near the limit of the usual range of the species.

(5) Grey-headed Albatross *D. chrysostoma*. This species, unlike any other, was most often caught at Fiordland. All Grey-headed Albatrosses caught here and

Table 6. Percentage of birds caught on Japanese tuna longlines in selected small-scale areas, 1989–1992.

Species	No.	Percentage caught in each area					
		East Cape (Jun–Aug)	Puysegur Bank (Apr–Jun)	Eddies (Jun)	Hikurangi Trench (Jun)	Fiordland Basin (Jun)	Solander Trough (Apr)
D. exulans	23	48	26	-	13	-	13
D. cauta	5	-	100	-	-	-	-
D. bulleri	14	-	100	-	-	-	-
P. westlandica	1	-	100	-	-	-	-
D. chrysostoma	6	16	16	-	-	68	-
D. m. melanophrys	5	80	-	-	20	-	-
D. m. impavida	10	100	-	-	-	-	-
P. cinerea	39	67	-	31	2	-	-
Total birds	103	50	26	12	5	4	3

at Puysegur were thought to be immatures, 2–4 years of age. At East Cape a single juvenile was caught. Grey-headed Albatrosses are rare over shelves (Bartle 1974, Weimerskirch *et al.* 1988), and tend not to scavenge from vessels (Bartle 1974). They are not generally found in northern coastal waters (Vooren 1972). These characteristics are sufficient to explain why the pattern of capture of this species differs from other albatrosses.

(6) Southern Black-browed Albatross *D. m. melanophrys*. Although a subantarctic breeding species, all were captured in the northern areas, at East Cape (80%) and Hikurangi. The East Cape birds were all juveniles, apparently only 1–2 months old, but the Hikurangi bird was adult. Seasonal movements of Southern Black-browed Albatrosses through New Zealand coastal waters were described by Bartle (1974). The high percentage of juvenile birds caught near the shelf edge off East Cape reflects the importance of such areas for young Black-browed Albatrosses in winter.

(7) New Zealand Black-browed Albatross *D. m. impavida*. This distinctive subspecies which breeds only on Campbell Island was captured only at East Cape. Nine of those caught were juveniles, apparently only 1–2 months old; the other was immature, banded as a chick on Campbell Island three years earlier. The abundance and the high proportion of young birds in this northern area in winter was documented by Vooren (1972) and Bartle (1974).

(8) Grey Petrel *Procellaria cinerea*. This species breeds in winter on subantarctic islands yet was caught only at Hikurangi, Eddies and East Cape. Forty-three (91%) of the birds caught were breeding females. The occurrence of this species in New Zealand waters was summarized by Bartle (1990); it is a deep-water species occurring mostly east of New Zealand, foraging far north of its subantarctic breeding grounds in winter.

These data show how the vulnerability of species can differ with fishing area and that in some places the seabird catch will have more impact than in others. For example, most albatrosses caught at Puysegur were endemic subspecies from nearby breeding populations.

Seabird capture in relation to time of day

The time seabirds were caught, relative to the percentage of sets fished, is shown in Table 7. These figures are given separately for northern (areas 1 and 2) and southern (areas 3 and 4) fishing areas because the distribution of seabird catch differed. In the south, 73% were caught in daylight, with a smaller number in the two-hour period before dawn (Table 7). Nearly all birds caught in the south were albatrosses (Table 5). In the north, 44% of birds were caught within 1½ hours of dawn or dusk. A mid-day peak, as found in the south, is entirely lacking (Figure 5) and more (42%) were caught at night (Table 7). Most birds caught here were petrels (60%) rather than albatrosses (Table 5).

Table 7. Time distribution of Japanese tuna longline sets and seabird catch by fishing area, 1988–1991.

Fishing area	Time intervals	Time of sunrise and sunset	Percent of sets	Percent of birds caught
Bay of Plenty – Wairarapa (Areas 1 and 2)	0001–0200	-	19.2	1.1
	0201–0400	-	5.8	1.1
	0401–0600	-	3.7	1.1
	0601–0800	-	1.2	11.6
	0801–1000	0819	1.0	14.9
	1001–1200	-	3.5	3.3
	1201–1400	-	8.6	8.8
	1401–1600	-	16.7	11.0
	1601–1800	1658	16.3	19.9
	1801–2000	-	6.9	10.5
	2001–2200	-	8.3	8.8
	2201–2400	-	8.8	7.7
Sample size			*1,180 sets*	*181 birds*
Challenger – Chatham (Areas 3 and 4)	0001–0200	-	6.0	2.3
	0201–0400	-	7.5	2.3
	0401–0600	-	11.9	0.0
	0601–0800	-	9.7	11.4
	0801–1000	0807	17.0	17.0
	1001–1200	-	11.0	28.4
	1201–1400	-	3.3	15.9
	1401–1600	-	2.8	5.7
	1601–1800	1702	9.0	5.7
	1801–2000	-	13.3	2.3
	2001–2200	-	2.4	2.3
	2201–2400	-	6.1	6.8
Sample size			*1,009 sets*	*88 birds*

Times of sunrise and sunset are means for the port most central to the fishing area and season (31 May at Dunedin for Challenger – Chatham, 20 June at Gisborne for Bay of Plenty – Wairarapa).

We know of only one quantitative study of the diurnal feeding rhythm of Southern Ocean petrels, that of Ainley *et al.* (1984). They recorded 16,857 observations of feeding in seven aerial species (six of them petrels) south of 60°S in the Ross Sea. Their Figure 41 shows two distinct peaks of activity, from 06h00 to 09h00 and from 18h00 to 21h00 (local time), despite continuous daylight. When our data on seabird bycatch were similarly plotted by three-hourly intervals (Figure 5), a close resemblance between bird catch in areas 1 and 2 and the pattern of feeding in the Ross Sea was revealed, presumably reflecting the similarity of innate feeding rhythms of petrels. Their dawn and dusk peaks of activity coincide with the vertical migration of their planktonic and nektonic prey. Albatross activity was not recorded by Ainley *et al.*, but these scavengers are predominantly diurnal (Bartle 1974, Weimerskirch and Wilson 1992) and there is little similarity between the pattern of seabird catch in areas 3 and 4 with that further north (Figure 5) or seabird activity in the Ross Sea (Ainley *et al.* 1984).

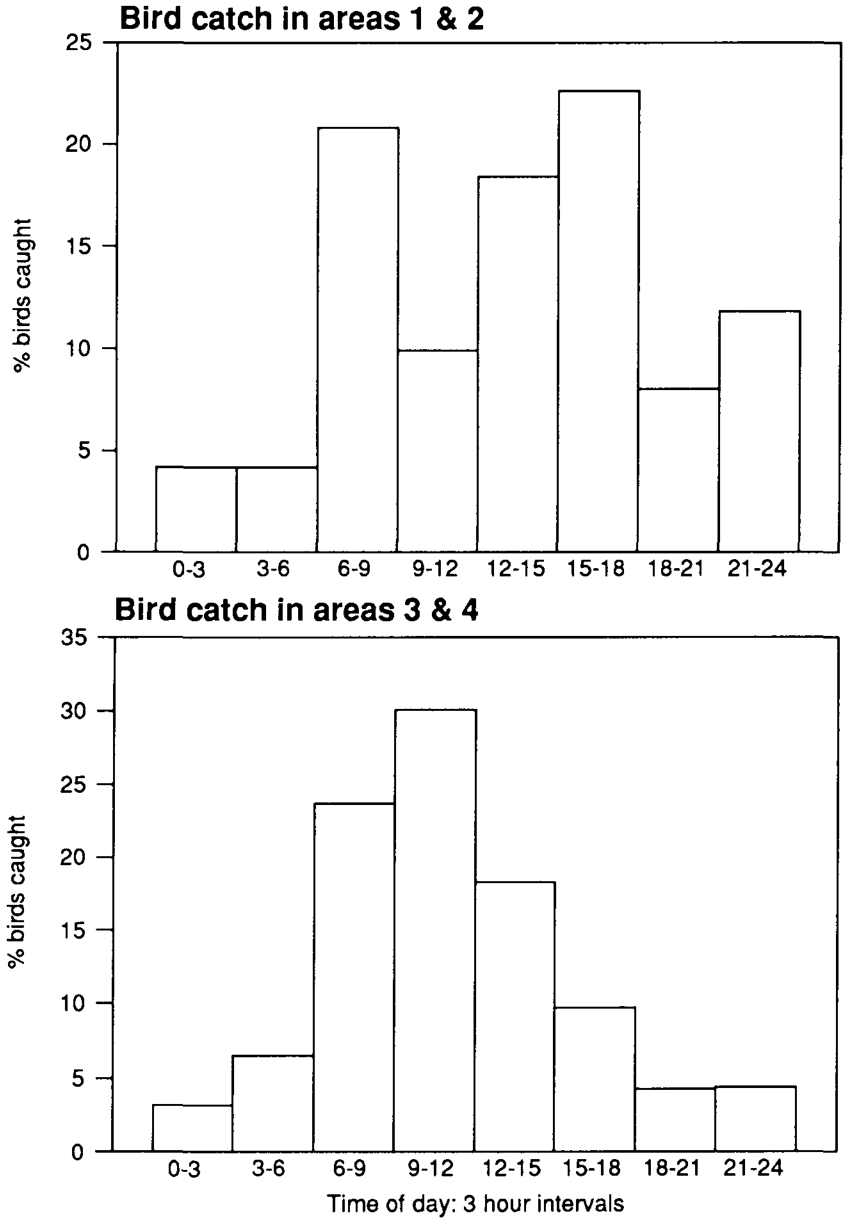

Figure 5. Time distribution of seabird catch on Japanese tuna longlines by fishing area (see Figure 1).

Comparison of seabird catch with the percentage of sets fished by two-hour intervals (Table 7) shows that neither the basic patterns nor the differences between them reflect fishing effort. For example, the levels of fishing activity around noon in the south and around dawn in the north were very low, but many birds were caught at these times. The large number of sets observed in each area (Table 8) strongly suggests that these area differences in pattern of seabird capture are real, and have implications for the use of night setting as a mechanism to reduce seabird bycatch.

Long-term trends in seabird capture

The reason for the decline in estimated numbers of seabirds caught during this study was thought to be increased use of tori lines and night fishing, especially in the south, where seabird catch dropped by 95% from 1989 to 1991 and 1992 (Table 8). However, this interpretation must be treated cautiously because catch rates vary from year to year (Table 8) and preliminary figures for 1993 again show a sharp increase in catch rate. Although the estimated total number of birds caught declined, capture rate per observed set has been highly variable (Table 8), with highest to lowest rates being in 1989, 1990, 1988, 1987 (0.3 birds per set, Michael *et al.* 1987), 1991 and 1992, respectively. The number of sets fished over the period was fairly constant, but much lower (Table 1) than for 1969–1982 (except in 1978, when Japanese vessels were virtually excluded from New Zealand waters), suggesting that seabird mortality on longlines was more severe in the 1970s and early 1980s.

Table 8. Estimated total number of seabirds caught on Japanese tuna longlines by fishing area in relation to fishing and observer effort, 1988–1992.

Fishing Area	Year	No. sets fished	Sets fished during observer period	No. sets observed	Bird captures recorded	Rate of capture per set observed	Estimated no. birds caught ±95% confidence limits
Three Kings – Bay of Plenty – Wairarapa (Areas 1,2 & 5)	1988	1,969	769	41	15	0.37	2,040 ± 622
	1989	1,114	456	48	91	1.90	1,154 ± 352
	1990	903	814	77	76	0.99	936 ± 286
	1991	1,623	1,300	122	36	0.30	339 ± 147
	1992	1,396	1,080	126	7	0.06	292 ± 127
Challenger – Chatham (Areas 3 & 4)	1988	2,221	0	0	0	-	1,612 ± 661
	1989	2,135	1,487	40	32	0.80	1,550 ± 636
	1990	1,626	1,365	77	53	0.69	1,181 ± 485
	1991	2,667	70	28	1	0.04	107 ± 96
	1992	1,704	1,384	226	9	0.04	68 ± 61

Effects of incidental mortality in longline fisheries on seabird populations

Between April and August New Zealand shelf and slope waters support not only numerous breeding and non-breeding seabirds from large adjacent colonies but also many from New Zealand subantarctic breeding grounds. Additional non-breeding and juvenile seabirds congregate here from populations on more distant subantarctic islands from Macquarie westward to South Georgia. This is known from direct observations (Bartle 1974) and band recoveries (summarized in Marchant and Higgins 1990). The food resources of New Zealand's continental shelves are important for wintering birds from Indian and Atlantic Ocean populations which breed on high-latitude islands with harsh climates. However, although longline mortality in New Zealand waters may significantly influence populations elsewhere, the greatest impact appears to be on local populations.

Recent declines have been recorded in New Zealand populations of several procellariiform species which are caught on tuna longlines around New Zealand, in southern Australian waters, and on the high seas. On Campbell Island photographic counts show that mixed colonies of Black-browed and Grey-headed Albatrosses have declined by 38–57% since the 1940s (Moore and Moffat 1990). Colonies where Grey-headed Albatrosses predominated, such as Courrejolles Isthmus, decreased by up to 88%. Breeding success (16% in 1984–1985, 50% in 1987–1988) of Grey-headed Albatrosses on Campbell Island seemed too low for recruitment to balance adult mortality (Moore and Moffat 1990). This could suggest that environmental factors were more important in this decline than longline mortality, but mean breeding success in the large South Georgia colonies averaged only 39% over 17 years, and has fallen below 17% twice since 1975 (see Table 5 in Prince *et al.* in press). On Adams Island, in the Auckland Islands, counts showed a 45% decline in the largest breeding population of Wandering Albatrosses in the world, from 7,250 pairs in 1973 to 4,000 pairs in 1991 (Walker *et al.* 1991) and 1993, supported by a similarly low rate of band recovery (A. Davis, pers. comm.). Despite some uncertainty as to the extent of this decline, caused by failure to count this biennial-breeding species in successive years (Walker *et al.* 1991), the trend was supported by a fall of 79% from 1968 to 1991 in the number of Wandering Albatrosses banded at Malabar and Bellambi, a natural feeding area off the coast of New South Wales (Murray 1992), where non-breeders from all Southern Ocean colonies including Adams Island congregate in winter (Marchant and Higgins 1990).

In contrast, counts of annual-breeding White-capped Albatrosses (Disappointment Island, Auckland Islands: Dept. of Conservation unpubl. data) and Buller's Albatrosses (Snares Island: Sagar *et al.* in press) showed no decline, but in the absence of information on recruitment, it is difficult to be confident that these populations are secure. For example, although the population of Westland Petrels at Punakaiki has increased greatly since 1958 (Marchant and Higgins 1990), survival of adult females has averaged 5% lower than males since 1977 and, given current rates of productivity, recruitment and age at first breeding, the population must now decline (J.A.B. and H. Weimerskirch unpubl.). On South Georgia the population index of Grey-headed Albatrosses fell on average only 1.8% per year between 1977 and 1990 (from 14,777 to 11,583), but this masked a collapse in the rate of recruitment by 85% since 1977, thought to be caused by the death of juveniles in longline fisheries (Prince *et al.* in press). Even if juvenile mortality of Grey-headed Albatrosses could be instantly reduced to natural levels, on the most optimistic scenario it would be more than 12 years before the population stopped declining and a recovery in numbers of breeders could begin.

A sex bias in capture is likely to result in an unequal sex ratio in the population, thus reducing breeding opportunities by prevention of pairing since long-lived procellariiforms are monogamous and the expected sex ratio is 1 : 1. Additionally, following the loss of a partner, procellariiform birds cannot raise chicks on their own, so the death of a mate results in breeding failure and usually reduces breeding success in several successive years. For example, in the Short-tailed Shearwater *Puffinus tenuirostris*, pairs need to breed together for more than three years to achieve maximum productivity, and fewer than 30% of adults produce offspring during their reproductive careers (Wooller *et al.* 1989). Procellariiform birds cannot sustain a significant rate of loss of successful breeders unless there is a surplus of adults prevented from breeding by a shortage of nest-sites. Some petrels but few albatrosses are in this situation.

The strategy of procellariiform birds in the marine environment has been to maximize mobility for the exploitation of food resources on an ocean-wide scale (Jouventin and Weimerskirch 1990), thus reducing exposure to temporal and local variation in food supply. As part of this strategy a life-history regime involving delayed maturity, a very low reproductive rate and high adult survival has evolved. This is why populations of procellariiform birds are more affected by small changes in adult survivorship than most other animals. Increased mortality will have the greatest effect on ultimate population size when breeding adults are differentially removed.

Table 9. Age and sex distribution of seabirds caught on Japanese tuna longlines in New Zealand waters, 1988–1992.

Species	Juvenile	Subadult	Adult	Male	Female	Unknown
Diomedea e. exulans	-	2	-	-	1	1
D. e. antipodensis	1	1	1	1	2	-
D. e. gibsoni	1	2	5	6	2	-
D. exulans ssp.	2	1	10	6	5	2
D. cauta steadi	-	-	6	2	3	1
D. b. bulleri	-	-	22	11	10	1
D. chrysostoma	5	1	-	3	3	-
D. m. melanophrys	6	-	2	2	5	1
D. m. impavida	11	1	5	8	8	1
Macronectes giganteus	1	-	-	-	1	-
Procellaria westlandica	-	-	1	-	1	-
Procellaria cinerea	-	-	47	2	43	2

Table 9 shows the age and sex of seabirds caught. Adults, often of breeding status, predominate except among Black-browed and Grey-headed Albatrosses. As shown by Prince *et al.* (in press), the high mortality rate of juveniles of both species on South Georgia from the 1960s to the 1980s is mainly responsible for some population declines. However, it is the high capture rate in New Zealand of adults of other species, particularly Wandering Albatrosses, where average annual survival of adults needs to be about 96% for population stability (Weimerskirch and Jouventin 1987, Croxall *et al.* 1990), which is of greatest concern. However, unlike the Indian and Atlantic Oceans, where more adult females are caught, the sex ratio of Wandering Albatrosses caught in New Zealand is equal. Finally, the selective capture of high numbers of breeding adult female Grey Petrels (Table 9) will reduce breeding success and cause a decline in numbers of pairs breeding (Bartle 1990).

Recommendations

Mortality of significant numbers of seabirds on tuna longlines is unacceptable and, for many species, unsustainable. Conservation managers responsible for seabirds in the Southern Ocean have, as their principal objective, the recovery of populations to levels where productivity and mortality are balanced and survival sufficient to withstand short-term environmental fluctuations. Biologists in conservation agencies should therefore monitor the breeding populations, survival and productivity of species caught on tuna longlines. For New Zealand the most vulnerable species appear to be Wandering, Grey-headed and Black-browed Albatrosses, and Grey Petrels. Programmes to collect yearly demographic data for these species need to be established urgently.

Measures to reduce seabird bycatch

Reduction of capture by use of tori poles and streamer lines

Brothers (1988, 1991) strongly advocated the use of tori poles and streamer lines to reduce seabird bycatch. His recommendations were taken up by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and a standard design (Brothers 1988, CCAMLR 1990) adopted, as shown in Figure 6. Many vessels observed in New Zealand waters used a version of this equipment from 1987 (Michael *et al.* 1987). By 1991 72% of Japanese bluefin tuna longline vessels observed in port ($n = 33$) had some form of tori pole or streamer system visible (A. Tennyson, pers. comm.) and observer reports show that additional vessels fitted systems at sea. However, data on specifications and use of tori lines in New Zealand routinely collected by fishery observers from 1992 show that they were not always used, and varied greatly in design and effectiveness (Table 10). In 1992 New Zealand licences required either night setting *or* the use of a tori line (of unspecified dimensions) to reduce seabird bycatch, but this did not increase the proportion of vessels fitted with tori lines (13 out of 18 checked in port: A. Tennyson pers. comm.).

The data given in Table 10 suggest that seabird capture rates may be reduced in New Zealand waters when tori lines are used, even if not of standard speci-

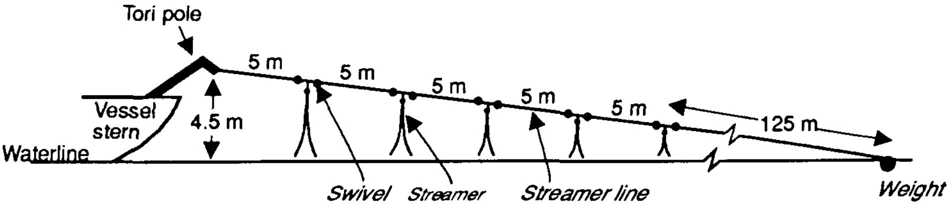

Figure 6. Diagram of a tori line to CCAMLR specifications (source: CCAMLR 1990).

Table 10. Frequency of use, specifications, and effect of tori lines on rate of bird capture on ten Japanese tuna longline vessels in 1992.

Vessel	% sets with tori line	Length of tori line (m)	No. sets	No. birds caught	Rate of capture
24	100	100	20	0	0
26	100	100	17	0	0
20	100	-	10	0	0
25	71	100	24	0	0
27	52	15	29	0	0
21	11	130	45	3	0.06
19	10	200	49	0	0
23	5	-	19	4	0.21
28	0	-	34	7	0.21
22	0	-	10	0	0

fication. These preliminary results should be treated cautiously because the sets were not continuously observed and tori lines may have been put up or taken down during sets, unknown to the observer. In future analyses data should be stratified by area, month, time of set, weather, bait type and whether frozen or thawed, and bird species caught, to assess the effectiveness of different designs under different conditions and, hopefully, to improve them. Such a study would require a far higher level of observer coverage than was achieved in 1988–1992.

Reduction of capture by means of night setting

Night setting as a way of reducing seabird capture was suggested by fishing masters following high albatross catches around Tasmania (Brothers 1988, 1991) and Hawaii (TenBruggencate 1991). Licences issued to Japanese longline vessels to fish in New Zealand waters since 1992 have stipulated that either lines must be set during darkness (i.e. from one hour after sunset to one hour before sunrise) or tori poles and streamer lines must be used. Reluctance on the part of biologists to stipulate night setting as a requirement (e.g. N. Brothers *in litt.* to NZ Dept. of Conservation, 27 January 1992) reflected industry concerns that tuna catch could be lowered. However, an unpublished MAF Fisheries study showed no significant difference in tuna catch rate between day and night in New Zealand waters. Enforcement of night setting is more straightforward than for other mitigation measures and was thought likely to reduce albatross bycatch.

Several recent quantitative studies on the foraging of procellariiform birds (e.g. Harrison *et al.* 1991, Pitman and Ballance 1992) have cast doubt on earlier work (e.g. Imber 1973, 1976, Harper 1987) suggesting that most procellariiform birds feed at night. Analysis of satellite-tracked Wandering Albatrosses (Jouventin and Weimerskirch 1990) and especially those fitted with stomach temperature sensors (Weimerskirch and Wilson 1992) has shown that 89% of prey (by mass) is caught by day and that birds mostly rest at night. Most squids eaten by seabirds float when dead (Lipinski and Jackson 1989), and the principal method of foraging of Wandering Albatrosses is to scavenge dead floating squid from the sea surface (Weimerskirch *et al.* 1986) located by systematic search patterns (Jouventin and Weimerskirch 1990). These studies support the observations of Bartle (1974) for New Zealand seas where all seven species and subspecies of albatross were largely diurnal, activity beginning two hours before sunrise. In contrast, several petrels (giant petrels *Macronectes* spp., Cape Pigeons, Westland Petrels and Fairy Prions *Pachyptila turtur*) were found to be active at night (Bartle 1974), though not shearwaters (five species of *Puffinus* studied).

Therefore, in southern New Zealand (areas 3 and 4, Figure 1), where 93% of birds caught on longlines are albatrosses (Table 5) which are mostly (73%) caught by day (Table 7 and Figure 5), seabird mortality could be reduced if it were mandatory that all sets be made entirely in darkness, ending at least two hours before dawn (Table 7). This may be difficult to achieve if the present trend towards longer lines and more hooks (Table 1) continues. It is also unfortunate that there is less difference between day and night activity of albatrosses when the moon is full. Wandering Albatrosses are nearly as active on windy, moonlit nights (Jouventin and Weimerskirch 1990) and full moon is also the best time to fish for bluefin tuna (see *Fishing strategy*). Under such conditions rigorous use of a range of mitigation measures (tori lines, weighted snoods, thawed baits) is needed, especially in areas such as the Solander Trough and Puysegur Bank (Figure 4), where albatross abundance is very high.

Night setting is commoner (54% of all sets: Table 7) in the north, although only 35% of sets (Table 7) extend through the dawn and late afternoon peaks of seabird capture (57% of birds caught at these times: Table 7). It appears that petrels are most successful at seizing baits where albatrosses are not common (Brothers 1991) and it may be this factor, rather than any great abundance of petrels, which accounts for the higher capture rate of petrels in the north. Observations on numbers of seabirds around New Zealand (J.A.B., pers. obs.) show higher densities of both petrels and albatrosses in areas 3 and 4 where capture rates averaged 0.39 rather than the 0.72 for areas 1, 2 and 5 (Table 8). Perhaps the higher catch rate of petrels in the north is caused by more baits being set at night and therefore inaccessible to albatrosses except in moonlight, allowing more to be taken by petrels which would otherwise be excluded. The much greater skill of petrels in diving may also mean that the baits are effectively available for a longer period if albatrosses are not around. Brothers particularly noted the tendency of Grey Petrels to dive on baits off Tasmania.

Thus it would appear unwise to recommend at present that night-setting be mandatory in northern areas, especially if bycatch mortality of petrels is ultimately found to have as much impact on the number breeding as is apparent in some of the biennially breeding species such as Wandering and Grey-headed Albatrosses. Demographic data on Grey Petrels from their main breeding site in the New Zealand region, Antipodes Island (Bartle 1990), is urgently needed to assess whether day or night setting is less damaging for seabird populations which forage off northern New Zealand in winter.

Recommended changes in Southern Ocean tuna longline fisheries

Because of the great mobility of procellariiform birds, conservation strategies must be agreed and implemented on a transnational basis. Similar considerations apply to the management of the highly migratory southern bluefin tuna stock and its fishery. The first requirement is for a firm commitment by fishing companies and fishery managers to collect sufficient information for accurate estimation of the incidental mortality of seabirds and for the identification and development of techniques for its reduction. Once this information is available, fishery managers and the industry must then ensure that seabird bycatch is quickly reduced to acceptable levels. In Wandering Albatrosses, for example, the demographic studies cited show that adult survival of 0.96 is necessary for population stability, and hence longline mortality will need to be reduced to near zero.

This study illustrates the value of placing independent scientific observers on fishing vessels to monitor the fishery and measure impacts on non-targeted species. However, at present observer data are not available for vessels fishing on the high seas, and thus we cannot fully assess the effects of tuna longline fisheries over most of the Southern Ocean. The study also highlights the need for a much higher level of observer coverage than was achieved even within the New Zealand fishing zone in 1988–1992, and for improved geographic and temporal sampling. Estimates of the numbers of each species killed in New Zealand could not accurately be made with the data available. Very high catches of seabirds on longlines are rare (Table 3) but can contribute disproportionately to the impact on populations, especially when particularly vulnerable species, age-classes or sexes are involved. The design of an observer programme should also take these biological realities into account. Unfortunately most programmes assume a mean level of bycatch to be likely (Hilborn and Mangel in press) and coverage is set accordingly. For the New Zealand subantarctic squid trawl fishery, Hilborn and Mangel estimate that observer coverage of trawls would need to be 100% to measure observed seabird mortality (Bartle 1991) within a coefficient of variation (CV) of less than 10%. The pattern of seabird mortality recorded here from tuna longlines suggests that a similarly high level of coverage would be necessary if overall catch and mortality rates for each species are to be measured by area and season within narrower CVs than at present. Demographic studies cited show that even small changes in survivorship affect long-term viability in several vulnerable species.

One way to obtain more information would be to require fishing masters to record bycatch of seabirds along with that of marine mammals and non-target fish species. Although this would not provide specific identifications it would reduce uncertainty for estimation of total catch. The cooperation of Japanese fishing masters in returning bands allows identification of many birds and can provide detailed information on their breeding status.

Another aspect of observer coverage revealed by the present study is the need for two observers on each vessel so that events during both setting and hauling can be logged. The greatest impediment to this at present is the limited accommodation provided on Japanese tuna longline vessels.

Seabird bycatch data analysis is a major task which would be facilitated if international data centres were established under the auspices of existing fisheries management agencies. These should be staffed to receive, identify and autopsy all seabirds caught.

Between 1988 and 1992 estimated seabird catches diminished (Table 8), presumably as the result of progressive introduction of mitigation measures, but none was used consistently. Stratified sampling is needed to assess the relative effectiveness of different measures in different areas and seasons to determine how much industry should invest in them.

The use of tori lines and night setting appear to have a positive effect in reducing seabird kills, and the specific recommendations listed below will allow definitive measurement of seabird bycatch on tuna longline vessels in the Southern Ocean and the development and refinement of techniques to prevent high levels of capture.

(1) A study is needed to determine the level of observer coverage required to measure mortality rates of each seabird species accurately in different areas and seasons within acceptable CVs. It will be necessary to increase substantially the number of observers on tuna longline vessels in the Southern Ocean (both within national EEZs and on the high seas). Observer data should be collated on a real time basis by specialist data centre staff. Feedback to observers is necessary for assessment of the effectiveness of the various methods for reduction of seabird catch under varying conditions.

(2) Modify design of future tuna longline vessels by provision of accommodation for two fishery observers.

(3) Fishing masters on unobserved as well as observed vessels should be required to record seabirds as well as fish in their catch logbooks and make available this information to the data centres at the end of each voyage. The band number of any bird caught must be recorded. Fishing masters should ensure that all seabirds caught are retained and that their frozen bodies together with labels showing the date and position caught are sent to the nearest data centre.

(4) Setting of longlines should be completed at night (Civil Darkness) when fishing south of 40°S.

(5) Mandatory use of a tori line during setting at all times. Present information suggests that this should be of kuralon, 150 m in length, with seven pairs of weighted streamers attached by swivels, each streamer long enough to reach the water. This tori line must be rigged so as to be above the baits when thrown.

(6) Snoods should be fitted with weighted swivels as near the hook as possible to facilitate rapid sinking.

(7) During hauling all uneaten bait to be removed from hooks, re-frozen and returned to port for disposal or dumped at sea in frozen blocks.

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