The Impact of Pelagic Longline Fishing on the Flesh-footed Shearwater *Puffinus carneipes* in Eastern Australia.

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Introduction

Tens of thousands of seabirds are accidentally killed each year on longline hooks set in the world's oceans. Seabird bycatch during longline fishing occurs when birds are attracted to fishing vessels by discards and baits and ingest baited hooks during the setting or, less commonly, hauling of the longline. The hooked birds are subsequently pulled under the water by the weight of the line and drown. The impact of longline fishing activities on seabirds is regarded as a serious threat, causing widespread declines in populations across the world (Alexander *et al*. 1997; Birdlife International 1995; Gales 1998; Croxall 1998).

Oceanic longline fishing is used to target pelagic and demersal finfish and shark species. Its use as a fishing technique in the southern oceans commenced in the 1950's and today operates in almost all Australian waters. The "incidental catch (or by-catch) of seabirds during oceanic longline fishing operations" is listed under Australian legislation (the *Environment Protection and Biodiversity Conservation Act 1999*) as a key threatening process which could endanger 14 species of seabirds (Environment Australia 1998). In 1998 a Threat Abatement Plan (TAP) was finalised to manage this threat (Environment Australia 1998).

The objective of the TAP is to reduce seabird by-catch in all fishing areas, seasons or fisheries to below 0.05 seabirds per thousand hooks. Based on the described level of fishing effort in the Australian Fishing Zone (AFZ) in 1998 (12 million hooks), achievement of this objective equates to a reduction of up to 90% of seabird by-catch within the AFZ. At this level of longline effort the proposed reduction in seabird bycatch was considered achievable within the five-year life of the Plan (Environment Australia 1998).

At the time the TAP was written the only available data for seabird bycatch in Australian pelagic tuna fisheries was that collected by fishery observers on Japanese longline vessels. These vessels fished under licence in the AFZ from 1986 until 1997 (Caton et al. 2002). This data set was extensive, with over 10 million hooks observed. Bycatch levels within the AFZ in this fishery were estimated at 0.15 birds per 1000 hooks set. (Gales et al 1998). The most commonly caught birds at that time were albatrosses (74%), with the species composition differing according to season and area (Gales *et al.* 1998). Flesh-footed shearwaters comprised 9.6% of the bycatch recorded on these Japanese longline vessels.

Longline fishing in Australian domestic tuna and billfish fisheries commenced in 1986 but effort was limited for many years. Following the withdrawal of Japanese longline vessels from the AFZ in 1997, fishing effort in the domestic fishery increased substantially, rising from 6.7 million hooks set in 1997 to over 17 million hooks in 2001 (Caton et al. 2002). Most of this effort was concentrated off the east and west coasts of Australia between latitudes 25^0 to 40^0, and around Tasmania. As no observer program had ever been established, there was little data on the composition and rate of seabird bycatch in these longline fisheries (Brothers et al. 1998).

During the Austral summers of 2001/02 to 2002/03, the performance of an underwater setting chute and various line-weighting regimes, designed to minimise seabird bycatch, was monitored by fishery observers employed by the Australian Fisheries Management Authority (AFMA). The trials occurred of eastern Australia, between latitudes 28^0 to 37^0 South. A total of 461,311 hooks was observed, with 278 seabirds caught at an overall rate of 0.6 birds per 1000 hooks. All of the 20 vessels participating in the trial caught seabirds. The principal species caught was the flesh-footed shearwater, which comprised 254 (91%) of all birds taken (AFMA unpublished).

The Flesh-footed Shearwater is a medium-sized seabird (c.700 g), and is listed as both a Migratory Species and a Marine Species under the *Environment Protection and Biodiversity Conservation Act 1999*. It frequents the waters of Australia and New Zealand during September to May, when it breeds, and migrates to the northern hemisphere between June and August. More than 80% of the world's estimated population of approximately 430,000 pairs breed in Australian waters (Baker *et al*. 2002). This species was nominated as being at risk from longline fishing when oceanic longline fishing was listed as a key threatening process in Australia (Environment Australia, 1998).

Although the level of bycatch observed in the seabird bycatch mitigation trials was based on a small number of hooks observed, it raised concerns as to the viability of the eastern Australian population of flesh-footed shearwaters. This population breeds at only one site, Lord Howe Island, and was estimated to comprise 12,575 breeding pairs in 2002 (Priddel and Carlile unpublished). In order to gain an understanding of the impacts of longline fishing on this population, a cohort life-table model was developed (Caughley 1977, Krebs 2001). Using this model a number of different levels of fishing mortality was investigated to determine those that would threaten the survival of the Lord Howe Island population.

Methods

1. Fishing effort and bycatch rates

Fishing effort in the Eastern Tuna and Billfish Fishery for the period 1986 to 2002 was assessed from shot-by-shot data provided in logbooks submitted by fishers to the AFMA. Effort (number of hooks set) was collated into seasonal (Austral summer, defined as the period September—May) and annual totals, to examine the spatial and temporal changes within the fishery.

Bycatch rates of flesh-footed shearwaters were determined from observer data collected during seabird bycatch mitigation trials conducted in the Eastern Tuna and Billfish Fishery from 2001 to 2003. The data were stratified by time of set (night and day) and area (5 degree latitude bands). Time of set is known to influence bycatch of seabirds in many fisheries (Brothers et al. 1999) and was defined as the time that line-setting first commenced, with night being the hours between nautical dusk and nautical dawn, and day being all other times.

Bycatch rates and distribution of fishing effort were used to estimate the number of birds killed each year and to calculate the overall fishing-related mortality on the flesh-footed shearwater population. The number of birds killed was estimated by multiplying observed bycatch rates by the mean fishing effort between latitudes 25-35^0 S during the Austral summers of 1998 to 2002. Fishing-related mortality rates were derived by dividing the estimate of the population size at 2002/03 (D. Priddel and N. Carlile unpublished) by estimates of the mean number of birds killed under a number of scenarios (see below).

2. Basis for selection of parameters

The demography of flesh-footed shearwaters is poorly known and longitudinal data sets are not available to assist in selecting model inputs. Therefore estimates of population parameters were 'borrowed' from research carried out on congenors of similar size (short-tailed and sooty shearwaters, *Puffinus tenuirostris, P.griseus*). These species have biological and ecological characteristics similar to the flesh-footed shearwater in that they breed in southern Australia in the Austral summer, and migrate to the northern Pacific Ocean from May to August (Marchant and Higgins 1990; Serventy and Curry 1984; Hamilton and Moller 1995).

3. Assumptions

A number of assumptions were made in developing the model.

— Flesh-footed shearwaters are found off the east coast of Australia within the AFZ between 25^{O}S to 35^{O}S (Fraser Island to the NSW/Victoria border), during the months of September to May (Lindsey 1986). It is assumed that all birds found in this area are from the Lord Howe Island population.

- The flesh-footed shearwater population on Lord Howe Island is stable in the absence of fisheries-related mortality. The Lord Howe Island population was estimated to comprise 12,575 breeding pairs in the 2002/03 breeding season (D. Priddel and N. Carlile unpublished). Assuming that 25% of adults of breeding age do not breed in any one year (Wooller et al., 1990), the total adult population was calculated to comprise 31,500 adults.
- Flesh-footed shearwaters are assumed to live to 40 years of age and breed for the first time at seven years old. Survival and fecundity at age estimates (Table 3) were based on published data for the short-tailed shearwater (Wooller et al. 1989, Wooller et al. 1990, Bradley and Wooller 1990, Bradley and Wooller 1991a, Bradley and Wooller 1991b, Bradley et al. 1991, Bradley et al 1999a, Bradley et al. 2000) and sooty shearwater (Hamilton and Moller 1995). Fecundity means the successful fledging of a female chick and incorporates the assumption that 25% of the adult female population do not breed in a given year (Wooller et al. 1990).
- All but 2 of 149 birds autopsied (R. Gales unpublished) were sexually mature. We have assumed that both sexes have an equal probability of being hooked, although a sample of 139 birds was slightly male biased 78:61. However an additional 10 birds could not be accurately sexed because of the condition of the corpses but were thought to be females. If they are included with the other birds as females, the sex ratio is 1.1:1. Of 12 birds caught by the Japanese fleet in eastern Australia, the sex ratio was 1:1.
- All longline vessels operating in this area during this period have an equal probability of encountering this species. We assume that fishing effort will remain constant for the foreseeable future. AFMA is proposing to limit effort by restricting the number of hooks set each year in a management plan currently being developed. Annual effort is likely to be capped at 13.5 million hooks although the management plan is unlikely to restrict where effort is directed (AFMA unpublished).

4. *Life-table models*

The development of a simple cohort life-table model (Caughley 1977, Krebs 2001) was considered appropriate, as information on flesh-footed shearwaters is poorly known necessitating the use of data from other shearwaters with similar biological and ecological characteristics to provide model inputs.

The life-table model was developed where the female population size ($N^f_{y,a}$) each year y and for each age a (for ages 1 to 40 years) was calculated from the survival at age (s_a) and the fishing-related mortality rate (F) by

$$N^f_{y,a} = \begin{cases} N^f_{y,1} & a = 1 \\ s_{a-1} N^f_{y-1,a-1} & 1 < a < 7 \\ s_{a-1}(1-F) N^f_{y-1,a-1} & 7 \le a \le 40 \end{cases} .$$

Fishing was assumed to only impact the adult population, which includes all individuals seven years or older. The initial female population was simulated in the absence of fishing until a stable age structure was achieved. This stable female population was transformed to become the initial female population age structure ($N^f_{0,a}$) using estimates of the total adult population size ($\hat{N}$) on Lord Howe Island.

Total number of individuals fledged ($N^f_{y,1}$) each year y that survive to age one was calculated from the fecundity (b) by $N^f_{y,1} = b \sum_{a=7}^{40} N^f_{y-1,a}$. As it was assumed that females and males are represented in equal proportions, the adult population was calculated as $N_{y,a} = 2\sum_{a=7}^{40} N_{y,a}^{f}$. Population halving time ($y_{0.5}$) was used as a reference point to describe the population's state and define critical levels of fishing on a population, and was calculated when $N_{y_{0.5}} = 0.5N_0$.

Deterministic and stochastic population survival and fecundity parameters were considered. The deterministic parameters represented average levels of survival at age and fecundity obtained from the literature (Table 3). Stochastic parameter values were randomly selected from a uniform distribution on the interval determined by the range of estimates obtained from the literature (Table 3). A uniform distribution was used, as there is no information on which to base an alternative assumption. Four scenarios were examined to assess the impact of fishing-related mortality on the population:

— Scenario 1 assumes the observed bycatch rate for all sets (night and day) in 5 degree latitude bands is representative of all hooks set in latitude bands 25-30^0 S and 30-35^0 S respectively
— Scenario 2 assumes the observed bycatch rate for night sets in the total fishery is representative of all hooks set in the area 25-35^0 S.
— Scenario 3 assumes the observed bycatch rate for day sets in the total fishery is representative of all hooks set in the area 25-35^0 S.
— Scenario 4 assumes the observed bycatch rate for all sets in the total fishery is representative of all hooks set in the area 25-35^0 S.

In addition population-halving reference points were calculated for levels of fishing mortality rates ranging from 0% to 100%.

Results

Fishing effort and bycatch rates

Fishing effort in the Eastern Tuna and Billfish Fishery has increased substantially since the fishery commenced in 1986, and particularly between 1997 and 2002 (Figure 1). Much of the effort since 1998 has been directed toward the area between latitudes 25-35^0 S during the Austral summer when flesh-footed shearwaters are present (Figures 1 and 2).

Observed bycatch rates for flesh-footed shearwaters in the seabird bycatch mitigation trials were generally high (Table 1), and ranged from 0 to 1.009 birds/1000 hooks within the distributional range of the species. Bycatch was higher when hooks were set during the day rather than at night. The total observed bycatch rate for the fishery was 0.286 birds/1000 hooks for night sets, and 0.646 birds/1000 hooks for day sets. Although observer effort is low, no birds were observed caught north of latitude 25^{0}S, and only eight caught south of latitude 35^0 S (Table 1).

Estimates of the number of birds killed each year, based on the product of the observed bycatch rate multiplied by the amount of effort in the fishery, ranged from a mean of 1,307 to 2,947 birds for the period 1998 to 2002 (Table 2). The total number of birds killed over this five-year period ranged from 6,800 to 15,328. The calculated fishery-related mortality rates for the four scenarios were 5.4, 4.3, 9.7 and 8.3% for Scenarios 1 to 4, respectively.

Deterministic simulations

The cohort life-table model was used to simulate the flesh-footed shearwater population on Lord Howe Island subjected to the estimated fishery-related mortality levels of the Eastern Tuna and Billfish Fishery from an initial population unaffected by fishing mortality. Deterministic simulations were carried out for each of the four scenarios of bycatch-related mortality (Table 3). In the absence of fishing mortality the simulated population increases substantially. Conversely the impact of ETBF longline fishing mortality is to cause a decline in all four scenarios with respective median halving times of 44, 80 16, 21 (Figure 3). The mortality level of 0.05 birds per 1000 hooks, specified by Australia's Threat Abatement Plan as a maximum target level, produced a slight increase in the simulated populations, assuming that fishing does not exceed 13.5 million hooks (Figure 3). In all simulations fishing-related mortalities greater than 5% will reduce the population halving times to less than 54 years (Figure 4).

Stochastic simulations

Stochastic simulations were carried out using the cohort life-table model with randomly selected age specific survival and fecundity (Table 3). In all stochastic simulations the populations declined (Figure 5) except for scenarios 1 and 2 where 3% and 14% of the simulations increased, respectively. The median population halving times for the four scenarios were 42, 61, 16 and 20 years.

Discussion

The bycatch of flesh-footed shearwaters in the Eastern Tuna and Billfish Fishery is currently at a level that threatens the persistence of the eastern Australian population. Between 1998 and 2002 the mean fishing effort within the shearwaters breeding distribution each summer has exceeded 4.7 million hooks, and it is likely this level will be maintained or increased in the foreseeable future. The overall bycatch rate is high when compared with contemporary rates in other fisheries, such as those observed in the demersal toothfish fishery in the sub-Antarctic (SC-CCAMLR 2003). These bycatch rates have led to an estimated 1,300 — 2,500 shearwaters being killed annually over that time, which has resulted in increased mortality at the population level of 4.3% — 9.7%.

Under most modelling scenarios the level of seabird bycatch observed in the fishery is unsustainable. The eastern Australian flesh-footed shearwater population is predicted to decline by 50% under the most optimistic of modelling scenarios within 49 years, and on this basis would meet the IUCN criteria for listing as Vulnerable or Endangered (IUCN 1994).

Our models assumed that fishing mortality was only impacting breeding birds, but this assumption is based on a small autopsy sample of bycatch birds. It is possible that juvenile birds are also impacted and, if this is the case, then obviously recruitment will be affected. The mean level of recruitment has been observed to have a large influence on the growth rate of populations in other modelling studies (e.g. Cuthbert et al. 2001). Longline fishing impacts on recruitment of flesh-footed shearwaters will accelerate population decline.

Additional mortality from other fisheries was also not considered in our modelling, but this may also be contributing to a decline in the population. Eastern Australian shearwaters may be impacted by other fisheries located either adjacent to the breeding grounds, or in the north Pacific where the population is present from June to August. There are large bigeye tuna (*Tunnus obesus*) fishing grounds located to the east of Lord Howe Island that are currently utilised by the Japanese distant-water longline fleet (Tuck *et al*. 2003). The overlap of breeding birds from the Australian population and this fishery is likely but has not been substantiated. Bycatch of flesh-footed shearwaters banded on Lord Howe Island has been recorded from salmon and squid driftnet fisheries in the north Pacific (Australian Bird and Bat Banding Scheme unpublished). The level of bycatch from these fisheries was estimated at 999 birds in 1990 (Johnson et al. 1993) although not all of these birds can be assumed to be from the Australian population. While high-seas driftnet fishing has now ceased, inshore set nets fisheries in northern Pacific waters are still operational and may catch flesh-footed shearwaters.

The level and composition of seabird bycatch observed in the ETBF fishery differed greatly from that reported for Japanese vessels operating within Australia's Fishing Zone (Brothers et al. 1999, Gales et al. 1998). While over 90% of seabirds caught the Eastern Tuna and Billfish Fishery were flesh-footed shearwaters, bycatch on Japanese vessels comprised mainly albatross species, with flesh-footed shearwaters forming only 9.6% of carcasses examined (Gales et a. 1998). While there are obvious temporal and spatial differences in the Japanese and Australian fleet characteristics, a striking difference between both fleets is the type of bait used. Japanese vessels use large squid baits, where Australian vessels have widely adopted the use of live fish bait since the mid 1990s (AFMA unpublished). It is possible that live bait is more attractive and available to flesh-footed shearwaters, which have greater diving capabilities than albatrosses. The impact of bait-type on bycatch of shearwaters and other seabird species merits further investigation.

There is clear evidence from other fisheries that seabird bycatch can be greatly reduced when appropriate mitigation measures are applied during fishing operations (SC-CCAMLR 2003). Unfortunately, mitigation measures such as mandatory night-setting of longlines have not worked in the Eastern Tuna and Billfish Fishery. The observed bycatch rate for all night-set lines within the fishery was 0.286 birds/1000 hooks, and even higher (0.422 birds/1000 hooks) in areas adjacent to the birds breeding site where fishing effort is high. Although these rates are lower than that observed for day sets, they are not sufficiently low to ensure population viability in the medium to long term at current fishing levels.

There is therefore an urgent need to develop a suite of mitigation measures that will halt or greatly reduce the level of bycatch currently being experienced. The initial purpose of the ongoing mitigation trials was to examine mitigation measures during daylight sets, such as an underwater setting chute, or 38g or 60g weighted swivels on branchlines in combination with twin bird-scaring lines. These measures were not successful in reducing bycatch and resulted in higher bycatch rates than those observed in night sets — 0.646 birds/1000 hooks for all day sets in the fishery, and 1.009 birds/1000 hooks in areas of high shearwater abundance, although further trials will occur. Other measures that warrant investigation include the application of more weight to branchlines (e.g. >80g placed close to hooks), or the imposition of seasonal closures between latitudes 25^0S to 35^0S, and particularly between 30^0S to 35^0S, for part or all of the flesh-footed shearwater breeding season. The use of seasonal closures has proven extremely effective in managing bycatch problems in other fisheries. The introduction of seasonal closures around major seabird-breeding sites by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is the main reason that seabird bycatch has been reduced to extremely low levels (> 0.002 birds/1000 hooks) in the demersal toothfish fishery (SC-CCAMLR 2003).

It should be noted that although the population is relatively small, low levels of bycatch within the fishery can be sustained. If the fishing industry could reduce their bycatch to less than 0.05 birds per 1000 hooks at current effort levels, it would not only meet the seabird target bycatch level required by the Australian government (Environment Australia 1998), but also ensure the population was not adversely impacted. At present, this does not appear to be an easy task. Fishing methods which rely on lightweight gear for operational effectiveness, and which are deployed in areas where seabirds with highly developed diving capabilities such as shearwaters and white-chinned petrels are present, represent the greatest challenge to those seeking to minimise bycatch problems. Achieving this goal will require a dedicated approach by all stakeholders in the fishery, but the experiences of CCAMLR (2003) in a fishery with an historically high level of bycatch demonstrate that this is entirely achievable.

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Table 1. Bycatch rates of flesh-footed shearwaters observed during mitigation trials in the Eastern Tuna and Billfish Fishery during the Austral summer (September - May) from 2000 to 2003. Fishing areas have been stratified by 5 degree latitude bands. The bold indicates the distributional range of birds during the bird's breeding season.

Area	Time of set	Hooks observed (number)	Birds caught	Bycatch rate (birds/1000 hooks)
20^0S - 25^0S	day	0	0	0.000
20^0S - 25^0S	night	3,555	0	0.000
20^0S - 25^0S	total	3,555	0	0.000
25^0S - 30^0S	**day**	**18,141**	**4**	**0.220**
25^0S - 30^0S	**night**	**9,510**	**0**	**0.000**
25^0S - 30^0S	**total**	**27,651**	**4**	**0.145**
30^0S - 35^0S	**day**	**205,201**	**207**	**1.009**
30^0S - 35^0S	**night**	**83,023**	**35**	**0.422**
30^0S - 35^0S	**total**	**288,224**	**242**	**0.840**
35^0S - 40^0S	day	115,791	8	0.069
35^0S - 40^0S	night	26,090	0	0.000
35^0S - 40^0S	total	141,881	8	0.056
All areas	night	122,178	35	0.286
All areas	day	339,133	219	0.646
All areas	total	461,311	254	0.551

Table 2. Estimated fishing-related mortality of flesh-footed shearwaters in the East Coast Tuna and Billfish Fishery during the period 1998 to June 2003. The number of birds killed each year was estimated by multiplying the bycatch rates for each of four scenarios (see text) by the mean number of hooks set between latitudes 25^0S and 35^0S during the Austral summer (September - May). Estimates of annual mortality are for a population of 31,500 breeding adults.

Year	Number of hooks set by area during Austral summer (1000 hooks)			Estimated number of birds killed Scenarios			
	25^0S - 30^0S	30^0S - 35^0S	Total	1	2	3	4
1998	2,863	999	3,862	1,253	1,106	2,494	2,126
1999	3,215	1,163	4,378	1,442	1,254	2,827	2,411
2000	2,956	1,517	4,473	1,701	1,281	2,889	2,463
2001	3,256	1,627	4,883	1,837	1,399	3,153	2,689
2002	4,021	2,119	6,140	2,361	1,759	3,965	3,381
Total	16,311	7,425	23,736	8,594	6,800	15,328	13,069
Mean	3,262	1,485	4,747	1,719	1,360	3,066	2,614
Estimated annual fishing bycatch rates (%)				5.5%	4.3%	9.7%	8.3%

Table 3. Survival and fecundity parameters used to model the impact of longline fishing on the Lord Howe Island population of flesh-footed shearwaters. Shearwater population size was estimated at 31,500 adults (ages 7-40). The four scenarios used to predict fishing effects are based on bycatch rates shown in Table 1. U represents a uniform distribution. NA is not applicable.

Age	Stage	Age specific survival		Fecundity	
		Average	Random	Average	Random
1	Fledged	0.500	U (0.48, 0.52)	NA	NA
2-6	Pre-breeders	0.940	U (0.93, 0.95)	NA	NA
7-40	Adults	0.940	U (0.93, 0.95)	0.263	U (0.225, 0.3)

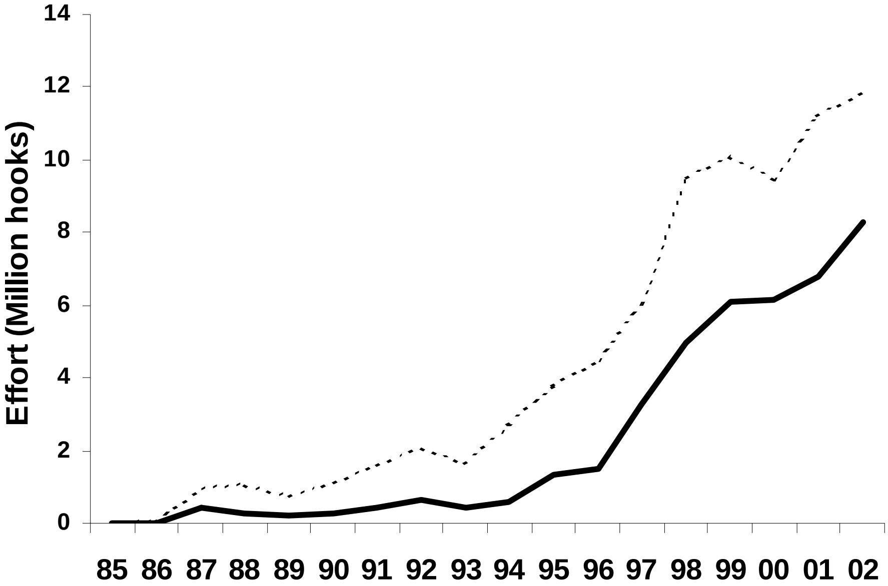

Figure 1.Annual effort (million hooks) in the ETBF from 1985 - 2002 for both latitudes 25-35^0 S inclusive (solid line) and the total fishery (dashed line).

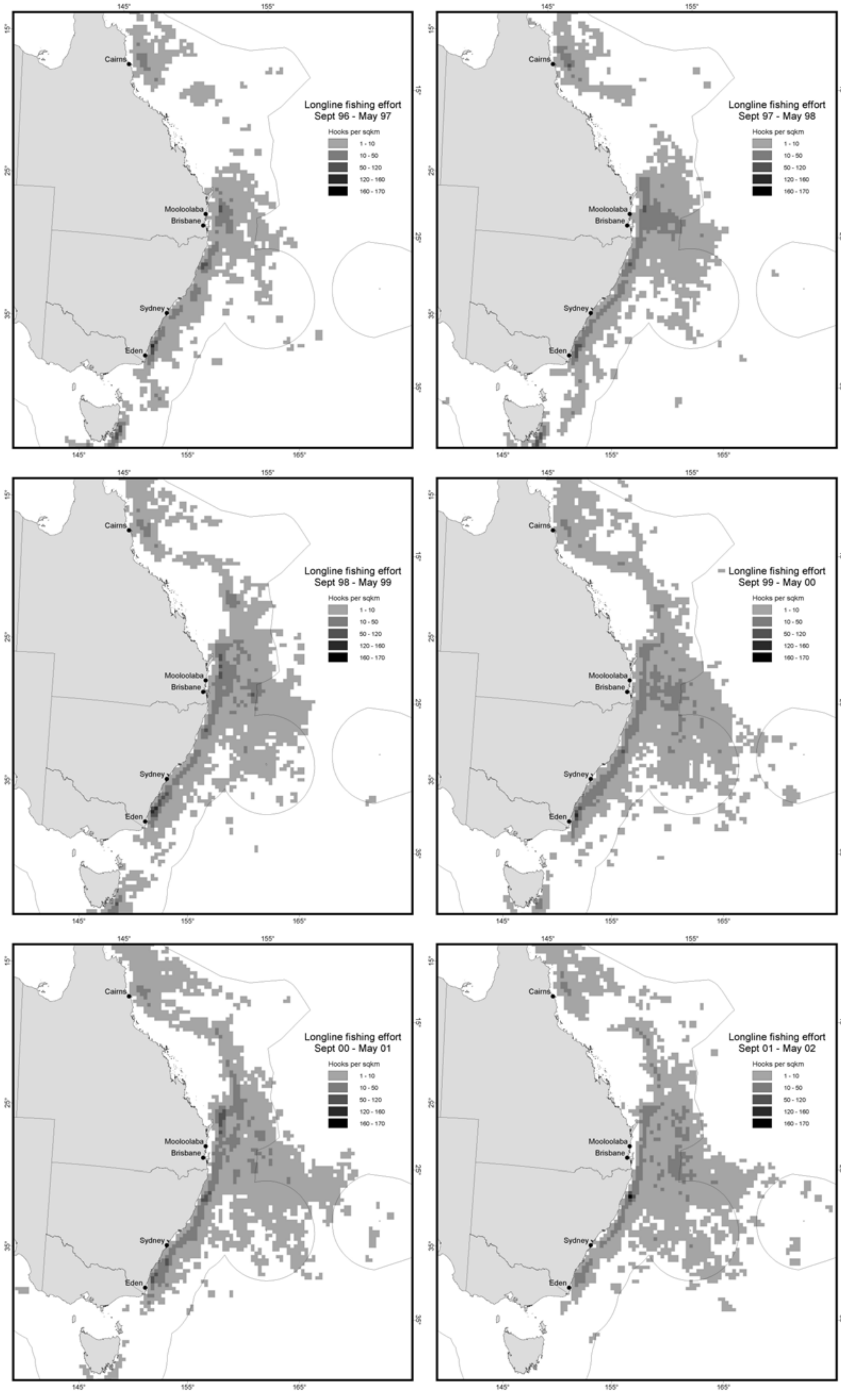

Figure 2 Eastern Tuna and Billfish Fishery longline fishing effort for September to May for the period September 1996 to May 2002. Effort in grids with less than five vessels has been removed.

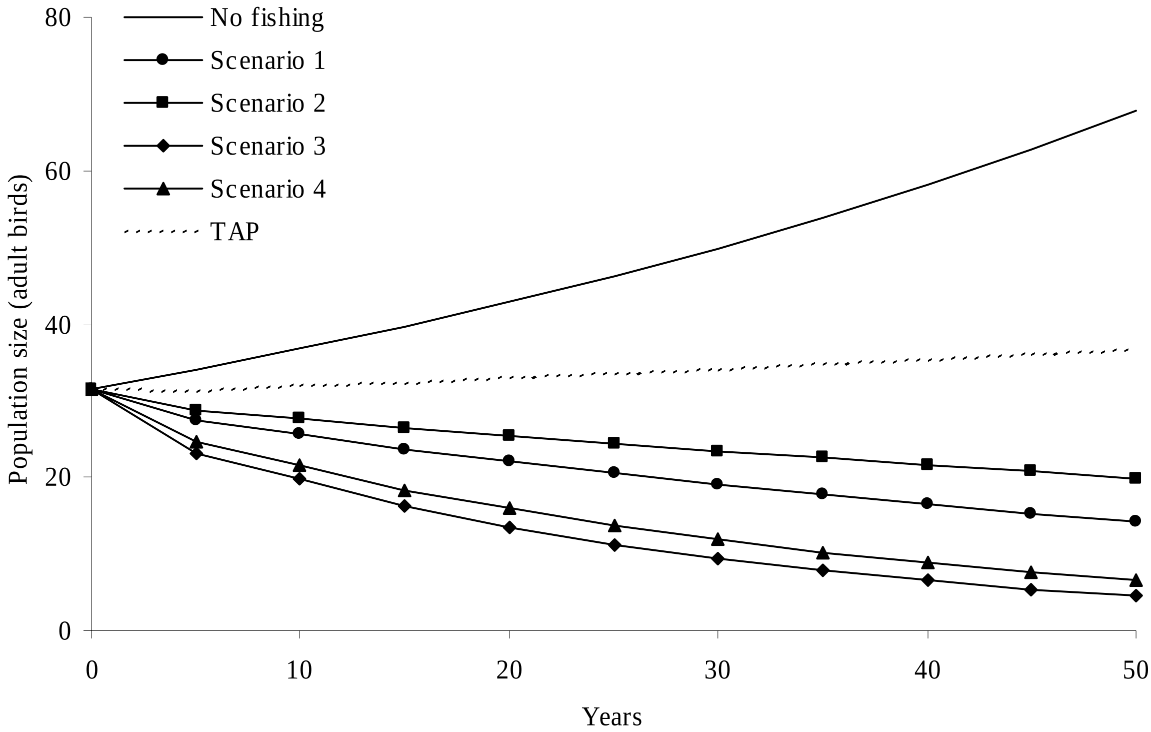

Figure 3. Deterministic simulations under conditions of no fishing, fishing-related mortality using four scenarios (Table 2) and TAP level.

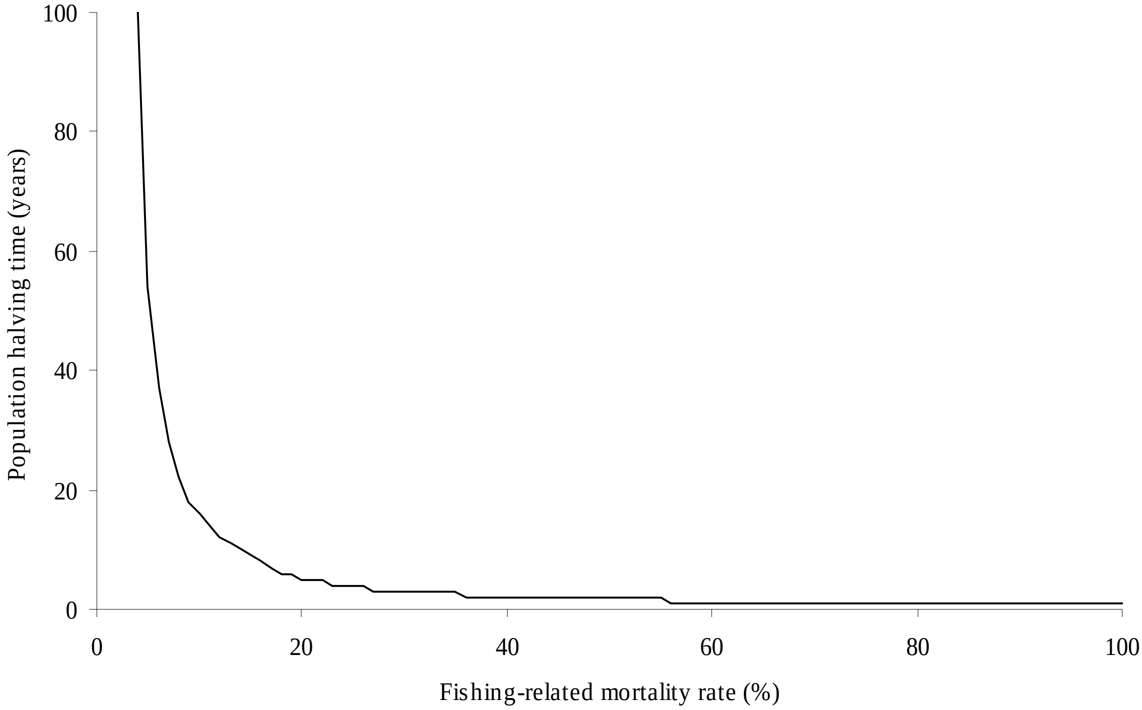

Figure 4. The population halving time resulting from fishing-related mortality (0% to 100%) on the Lord Howe Island population of flesh-footed shearwater.

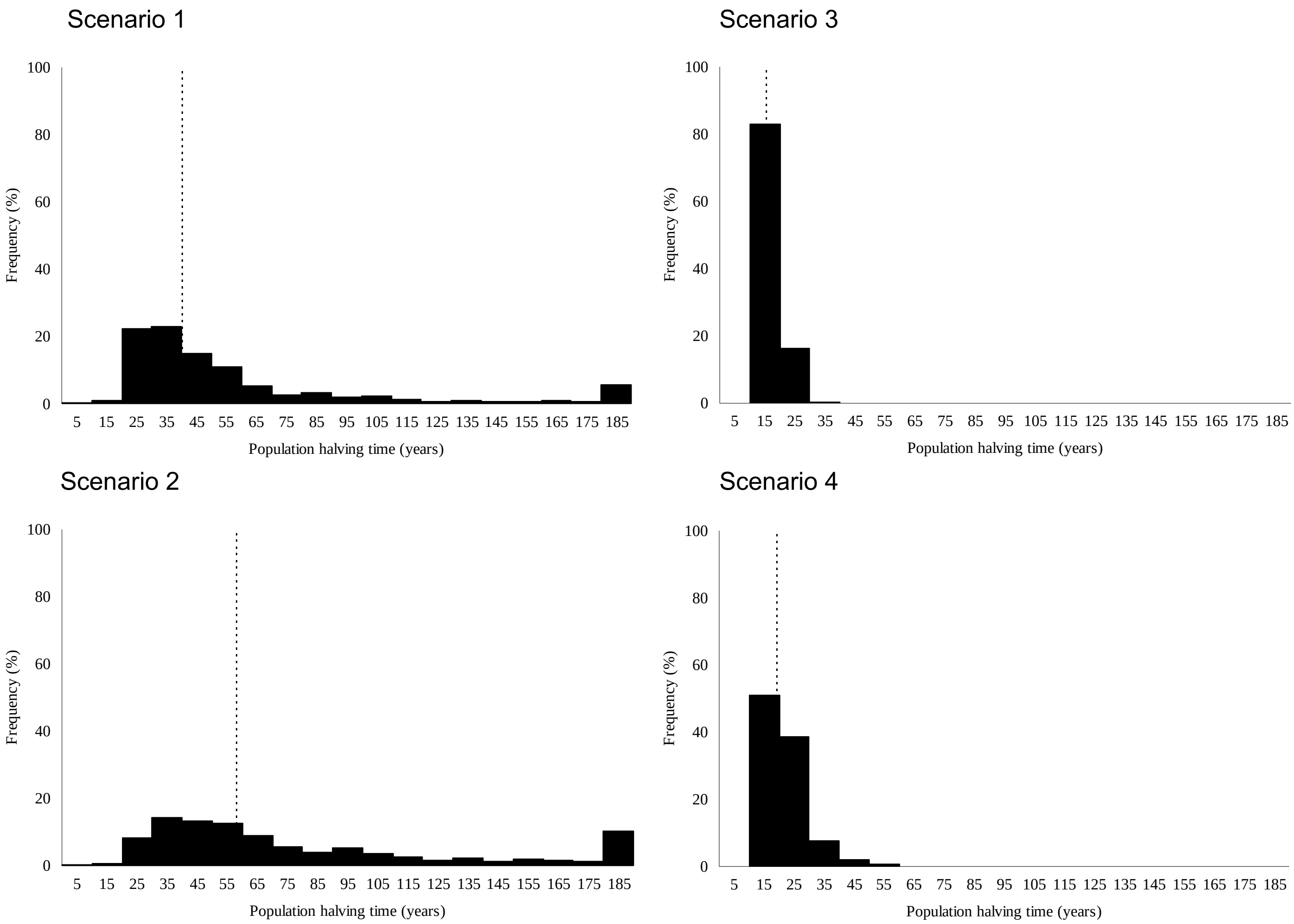

Figure 5. Stochastic simulations for four scenarios (Table 2). The doted lines represent the median halving times and are 42, 61, 16 and 20 years for scenarios 1-4 respectively.