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Assessing the impacts of fishing and habitat loss on the Lord Howe Island population of flesh-footed shearwaters

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Abstract: The flesh-footed shearwater *Puffinus carneipes* is a medium-sized seabird with a single eastern Australian population breeding on Lord Howe Island. Other breeding populations exist in New Zealand, south-western Western Australia and St. Paul Island in the Indian Ocean. Tagging and banding studies indicate that breeding birds of the Lord Howe Island population inhabit waters mainly to the west of the Island during October to May. Birds then migrate north to waters surrounding Japan during the Austral winter.

Seabirds are attracted to the baited hooks of longline vessels and can become snagged and drown as the line sinks into the water. Observations of flesh-footed shearwater (FFS) bycatch in Australian waters have been recorded on both Japanese and domestic longline fishing vessels. Increased observer coverage between 2002 and 2004 on Australian longline vessels, in order to monitor the effectiveness of an under-water setting chute and various line-weighting regimes, showed large bycatch rates of seabirds, and in particular flesh-footed shearwaters (Baker and Wise, 2005). In addition, substantial reductions in colony size have occurred on the island due to housing development. As a consequence of these sources of additional mortality, concerns have been expressed about the population's sustainability.

Australia has international and national obligations to ensure that fishery interactions with seabird populations are not deleterious to their populations. The “incidental catch (or by-catch) of seabirds during oceanic longline fishing operations” has been listed under the Environment Protection and Biodiversity Conservation Act 1999 as a key threatening process for seabirds (Environment Australia, 1998). Flesh-footed shearwaters were nominated as being at risk from longline fishing.

This paper presents a quantitative impact assessment that fully integrates information on the biology, foraging distributions, links to oceanography, fishing interactions (Northern and Southern Hemisphere), and potential impacts from housing on Lord Howe Island. A discrete age-, sex- and colony-structured model is developed that accounts for natural and fishing mortality, together with potential consequences from the loss of nesting habitat on Lord Howe Island. The model is able to fit to tagging data on breeding foraging distributions. These data assist the model in predicting where the birds might be when at sea. The birds' position is assumed to be a function of time of year, sea surface temperature and longitude. Using the predicted positions, the model fits to data on the observed bycatch from the Australian domestic longline fishery. These data enable the model to predict the probability of catching a bird, given various operational characteristics (e.g. setting at night). The model also fits to data from the two surveys of breeding abundance that have occurred on Lord Howe Island.

Keywords: *Flesh-footed shearwater, Longline Fisheries, Impact Assessment*

1. INTRODUCTION

Longline fisheries have expanded throughout the world's oceans since major commercial distant-water pelagic fleets began fishing for tuna and tuna-like species in the early 1950s. Along with the more recent development and expansion of demersal longline fleets for species such as Patagonian toothfish, these vessels are a major source of mortality to several species of seabird (Brothers et al., 1999; Tuck et al., 2003). Vessels can set many thousands of baited hooks in a day across many kilometers of water. These waters are often used as foraging areas by wide-ranging seabirds. Attracted by baits and offal, the birds can be caught on the baited hooks and subsequently drown.

Because many seabirds, including flesh-footed shearwaters (FFS), are long lived and have low reproductive rates (at most only one chick per breeding season), the additional mortality associated with longline fisheries can pose a significant threat to the sustainability of individual colonies and the various species. Declines in many seabird populations have been observed that are concomitant with the development of longlining in the Southern Ocean. Longlining is thought to be the major source of the declines.

Despite the well-documented potential significance of such interactions, there have been few studies that have attempted to compare across-year variations in the distribution and intensity of longline fishing effort with changes in seabird populations. This is partly because of the difficulty of obtaining reliable fishing statistics for some fleets and the paucity of sufficiently detailed data on the demography of seabird populations. In addition, there is also a lack of appropriate models of both seabird population dynamics and interactions with fishing effort. Many previous seabird population models have focused primarily on the demographic estimation of rates of increases or decreases (Weimerskirch et al., 1997). However, the albatross models of Tuck et al. (2001) and Thomson et al. (2008) explicitly attempted to model interactions with fisheries and possible responses in the demographic parameters. The models presented here are an expansion of these models, and are applied to a population where census information is much reduced in comparison (only two abundance surveys, one in 1977/78 and another in 2002/03).

Figure 1. Flesh-footed shearwater

In this paper, a quantitative model is developed that integrates information on breeding biology, colony size, foraging ranges, bycatch observations, fishing effort and nesting habitat loss. The model is a discrete-time, density-dependent, colony-, age- and sex-structured model of FFS population dynamics that can then consider the potential impacts of interactions with longline fisheries of the Southern and Northern Hemisphere. This is done by using estimated FFS population parameters, tagging data, nesting habitat loss, data on longline fishing effort and observed bycatch, to fit the model to the best available data on breeding numbers by colony. The model is substantially different from the approach generally used to model seabird populations in that the FFS tag positions, observed bycatch and colony size are all components of a single objective function. The model is thus analogous to those used in the assessment of fish stocks and marine mammal populations. In this modelling approach, the fitting procedure produces estimates for unknown population parameters and ‘catchability coefficients’ that convert fishing effort to estimates of actual bycatch.

2. METHODS

2.1. Shearwater spatio-temporal distribution

An increase in the understanding of the spatio-temporal distribution of the population of FFS at Lord Howe Island has occurred through the tagging of breeding and non-breeding birds with geolocation archival tags (summers of 2004/05 and 2006/07). These studies have shown

- that the birds have foraging distributions that appear coincident with distinct SST ranges, with few birds being observed at SST below 20°C,
- that birds generally forage to the west of Lord Howe Island,
- that from April/May, once chicks have fledged, the non-breeding birds fly north to waters surrounding Japan, until October when they return to Lord Howe Island to begin re-establishing pair-bonds in preparation for the breeding season ahead (Figure 2).

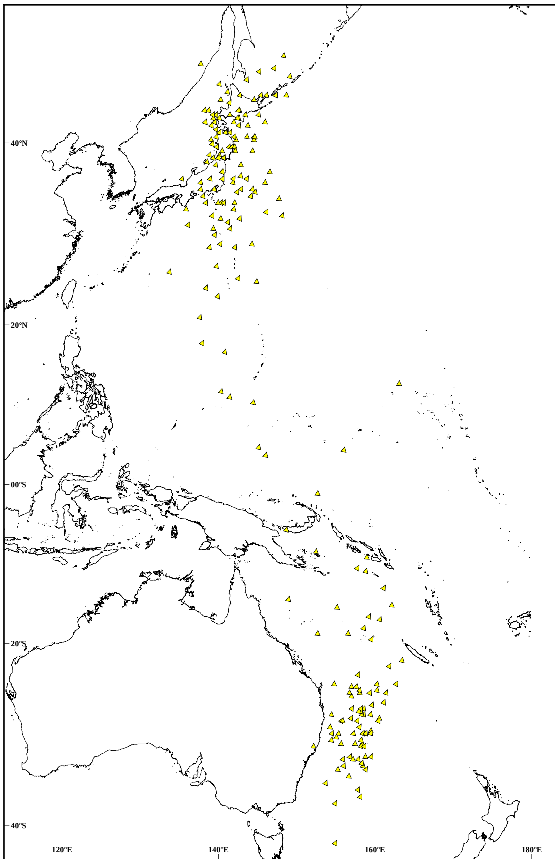

Figure 2. The estimated positions of a single flesh-footed shearwater, showing concentrations surrounding LHI and Japan.

Priddel et al. (2006) describe the census work done during the summers of 1977/78 and 2002/03. The number of breeding pairs in 1977/78 was estimated at between 20,000 and 40,000 pairs. This compares with approximately 17,500 pairs in 2002/03.

2.2. Commercial fishing spatio-temporal distribution and incidental catch

There are three main fishing fleets that either are known to catch FFS or are suspected to have caught FFS due to their overlap and gear type. These are (i) the Australian Eastern Tuna and Billfish Fishery (ETBF), (ii) the Japanese domestic coastal longline fishery and (iii) other domestic or distant-water longline fleets of the western Pacific Ocean.

ETBF. The Australian domestic pelagic longline fishery for tunas and billfish began in waters off New South Wales during the 1950s. The fishery expanded in the mid-1980s to take advantage of Japanese markets, and in 1999 nearly 14 million hooks were set. Since the early 2000's effort has reduced in magnitude and in spatial extent due to increases in fuel prices and a more northerly shift to target albacore and yellowfin tunas.

Observer coverage on Australian domestic pelagic vessels had been very low until an increase was required in the summer of 2002/03 in order to monitor the effectiveness of two experimental mitigation regimes in reducing bycatch rates. The experiment involved vessels either using an underwater setting device, or line-weighting in combination with bird-scaring streamers. A substantial bycatch of flesh-footed shearwaters was reported from observers on these vessels. Of the 278 seabirds caught from over 460,000 observed hooks, 253 were flesh-footed shearwaters. Observer records indicate that from the 4 Trial types monitored, the chute trial caught the most birds (Table 1). The mitigation trials ceased in August 2004 and observed sets since then are recorded as Trial type 4 (a 'typical' tuna set, denoted ECTBF).

Table 1. The number of observed shots and bycatch of flesh-footed shearwaters from each of the trials observed since 2002/03.

Project Ref Number	Trial Type Name	Number of shots	FFS bycatch	Birds per shot
1	Chute Trial	195	214	1.10
2	60g Trial	77	17	0.22
3	38g Trial	218	20	0.09
4	ECTBF	677	2	0.00
Total		1167	253	0.22

Of the 802 sets that were observed during the day, 189 birds were caught (0.24 birds per shot). This compares to 64 birds from 365 sets observed during night hours (0.18 birds per shot).

The incidental mortality of seabirds is known to be influenced by operational factors such as gear type, bait used and time of set (Klaer and Polacheck, 1998). While fish catch (since inception) and time of set (since 1996) has been well documented in logbook records of the ETBF, records of the bait type and operational characteristics used in longline sets, known as shots, have not been consistent. In order to overcome this problem, a statistical clustering algorithm was used in order to identify types of shots based on the reported species composition of the catch. It is then assumed that shots belonging to the same cluster are operationally similar (i.e. timing, gear and mix of baits used). Eight species clusters were identified based on maximum likelihood comparison between models with increasing numbers of clusters. The best fit model with eight clusters included shots directed at swordfish, albacore, bigeye, yellowfin tunas and mixes of these species.

Target species catch and effort data from the ETBF were available on a shot by shot basis from 1986. Fishery information used in the model included position of set, date and time of set (Day/Night), Cluster type (eg swordfish shot) and Trial type (eg chute trial or a typical ETBF shot).

A GLM was developed that modeled the probability of catching a FFS on a particular shot in a 1 degree cell as a function of the time of set, cluster type and trial type. This probability also accounts for the likelihood that a bird is at sea and the probability they are in a particular cell if they are at sea. The probability that a bird is caught is then translated into a fishing mortality for every year and month.

The Japanese coastal longline fishery. Little public information exists on this fishery, other than in nation reports of Japan (Anon, 2008) and catch statistics maintained by the Secretariat of the Pacific Community (SPC). The fishery is extensive, ranging from northern Japan, south to the equator and from 120˚E to 165˚E. Until 1993 yellowfin was the dominant catch species, but this has since moved to albacore. The main areas of longline effort in this fishery are found directly south of Japan where vessels are predominantly catching albacore. These are also regions where FFS are abundant. No bycatch information is available for this fishery, but given the gear type, overlap in distributions and large effort, especially between April and June, the potential for interactions is high.

As the albacore catch distribution is predominantly found within the region of interest designated to FFS foraging habitat, and substantial effort is recorded from April to September, it was assumed that effort from this fishery was proportional to the reported catch of albacore. Fishing mortality was then modeled as a function of the albacore catch and a catchability coefficient.

Distant-water and other longline fleets of the western Pacific. This category is dominated by the distant water fleets of Japan, Korea and Taiwan. It also includes the Pacific Island Nation and New Zealand pelagic fisheries. Effort for the distant-water fleet gradually progressed from coastal regions of Japan in the 1950s, to more equatorial latitudes in the 1980s and then strong southern concentrations of effort from the 1990s. Nation aggregated 5 degree monthly longline data were provided by the SPC. No information was available on high-seas bycatch of FFS for this fleet, and very few records exist for the Japanese fleet that fished within the Australian Fishing Zone (AFZ) during the early 1990s.

The method used to model FFS bycatch from the Northern hemisphere fleet assumes that fishing mortality is proportional to the fishing effort within the specified region in which the birds are found. Unlike the ETBF, as we do not have detailed information on either the bird or the effort distributions (nor bycatch observations) within the birds' period of Northern Hemisphere habitation, it is assumed that fishing mortality does not vary across the spatio-temporal bounds defined for this fishery. Fishing mortality is assumed to be a multiple of a constant catchability parameter and the effort with the northern region of interest.

For the Southern Hemisphere, as the model provides estimates of the probability of birds being within a monthly 1 degree cell, the estimated fishing mortality for a particular month is modelled as the sum of the probability that a bird is in cell if at sea multiplied by the probability that a bird is at sea, the fishing effort within that cell and a fishery catchability coefficient

2.3. Lord Howe Island commercial and residential development

There are six main colonies on the island, two of which have experienced substantial declines in colony area between the two surveys in 1977/78 and 2002/03. Priddel et al. (2006) assess that 36% of the island's nesting area has been lost to housing over this period and conclude that housing is likely to have contributed to the decline in abundance. To account for the loss of colony area between surveys in 1977/78 and 2002/03, a linear reduction in area for each colony was assumed. However, within this linear decline, aerial photographic images of colony area were used to model year-specific reductions coinciding with known construction dates for housing.

2.4. Resource dynamics

For modeling purposes, the regions of interest were restricted to 20°S to 40°S; 140°E to 170°E; months October to end of April in the Southern Hemisphere and 30°N to 40°N; 130°E to 145°E in the Northern Hemisphere.

Population model. The age-structure of the population is modeled by classifying FFS into fledglings, juveniles, and breeding adults. The number of birds fledged is dependent on both chick and adult mortality. FFS that successfully breed produce one chick per breeding attempt. On returning from the Northern Hemisphere, birds are assumed to be courting, re-affirming pair bonds and mating during October and November, incubating during December and January, attending the hatchling in brood-guard during the first half of February and then provisioning the growing chick until its successful fledging at the end of April.

The population model is a discrete-time (year and month), age-structured model of the number of male and female birds of each of the six colonies. It is assumed that there is no emigration from or immigration to Lord Howe from other island colonies or between the six Lord Howe colonies. Juveniles are assumed to reach sexual maturity at age 7.

Density Dependence. There is some evidence that seabird populations exhibit a density-dependent response to declining abundance (Weimerskirch et al., 1997). While no direct evidence of density-dependence in Lord Howe Island FFS exists, it is likely that the population is limited by its colony area, in particular through reductions in the numbers of burrows available due to habitat clearance. Colony area then acts as a time-varying carrying capacity. In essence, the relationship assumes that adult birds returning from the Northern Hemisphere experience higher burrow densities as a consequence of a loss of burrows and a subsequent increase in mortality. This may arise because of increased fighting for breeding sites, stress, disease and the direct and indirect impacts of an increased human footprint within close proximity to nesting areas (such as car strikes, removal, stress). The colony specific adult mortality increases as the area of each colony reduces.

Births. Egg laying in the model occurs on 1 December with the successful fledging of a single chick on 1 May. Chick mortality may occur directly through natural causes (e.g. environmental, physiological) or indirectly due to the death of either parent by natural or fishing mortality. It is assumed that the death of either parent leads to chick mortality due to the intensive nature of feeding required for the chick to survive.

Spatial distribution of FFS. The archival tagging data of FFS over the summers of 2004/05 and 2006/07 provide information on the birds' spatio-temporal distribution when at sea. A general linear model (GLM) was used to estimate the probability that a bird is in a particular 1 degree cell. It is assumed that the distribution of the birds is a function of month (breeding phase), SST and longitude. The probability that a tagged bird is in a 1 degree cell in a month was modeled as a function of three logistic curves; two that define the lower and upper SST range and one that defines the longitudinal range, and a parameter providing a background density of birds across all cells.

Temporal distribution of FFS. While the archival tagging data provide information on where the birds are when at sea, the model also needs to know the proportion of time birds are on land. Clearly, if birds are on land, for example during incubation of an egg, they are not available to longline fishing hooks. Monthly proportions of time spent at sea and land within their Austral summer breeding phase were provided by Thalmann (2005), Thalmann, S. (pers. comm.) and Reid, T. (pers. comm.).

2.5. Fitting procedure

The likelihood objective function includes three components (i) the archival tagging data which is used to estimate the probability of a bird being in a cell at a particular time of year, (ii) the ETBF bycatch data which is used to estimate the probability of a bird being caught from this fishery and (iii) the number of breeding pairs by colony in 1977/78 and 2002/03.

2.6. Population projections

To explore how the FFS population may react to potential future levels of longline fishing effort, simple deterministic projections were conducted over years 2001 to 2040. This was achieved by choosing a biological parameter set, such as the population's base-case parameter set, with its corresponding estimated parameters (initial numbers, parameters relating to the probability of being in a cell and being caught, fishing catchabilities) and then projecting the population into the future using a pre-determined annual effort scenario.

3. RESULTS

3.1. Base-case results

A base-case parameter set was established based upon the biological information provided by Baker and Wise (2005) and Priddel et al. (2006). As expected, the model is able to detect a clear relationship between SST and observed positions of birds from geo-location tagging. The probability of a bird being in a cell when the temperature is below 20°C and above 26°C is greatly reduced. Likewise, the model estimates that most birds will be found west of 159°E.

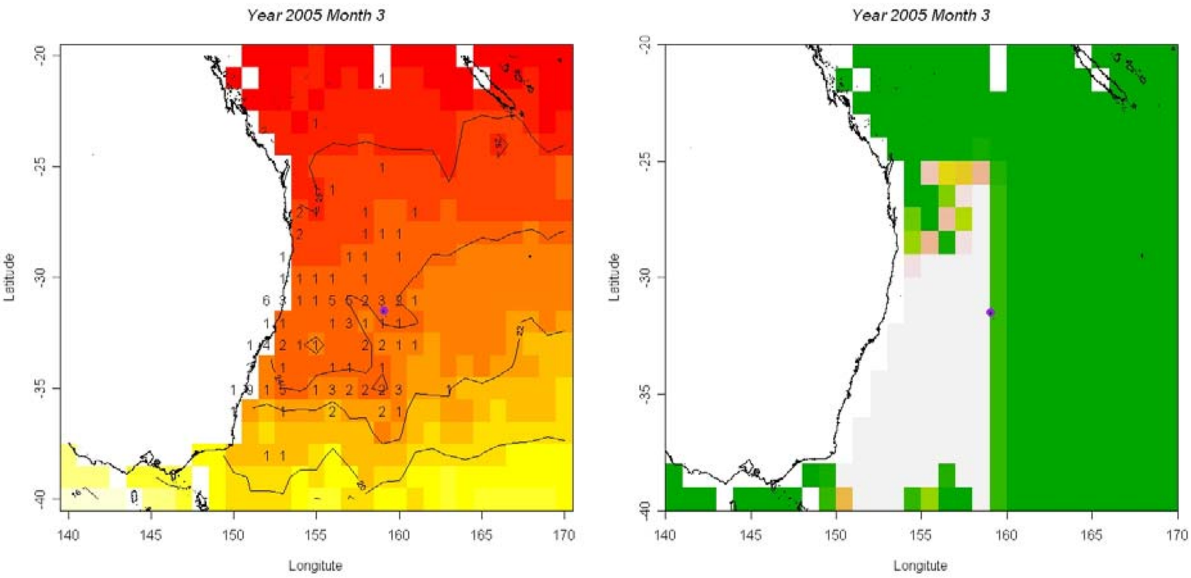

Figure 3. The observed positions of tagged FFS in March 2005 compared to the predicted probability distribution from the model. Red areas are warmer than yellow; dark green indicates a lower probability of being within a cell than light colours. The purple marker indicates the position of Lord Howe Island

Additional results will be presented at the meeting.

4. DISCUSSION

The flesh-footed shearwater is a medium sized seabird with a single eastern Australian colony on Lord Howe Island. The population on Lord Howe Island is known to have been impacted by a reduction in colony area (by 36% since 1977), and fishing mortality, as a result of its exceptional diving ability that enables it to retrieve baited hooks from longline vessels, has led to concerns about the population's viability. These concerns were brought to the fore by the observation of more than 200 birds being killed on Australian domestic longline vessel during mitigation trials between 2001 and 2004. As this species is afforded protected status under Australian legislation, there was a growing need to assess the likely impact of these sources of mortality on the population.

In this paper, an extensive integrated assessment model of the birds' biology, foraging distributions, fishery interactions and habitat loss is described. The model includes two general linear models (GLMs) and a fit to on-land survey data, all built within a single likelihood framework. These GLMs predict the influence of various factors (such as SST, longitude) on the probability of a bird being in a particular region (its availability), and the probability of a bird being caught if it is available. The second GLM has factors that include shot type (e.g. swordfish or albacore shot), time of day and trial type (eg chute-trial or a 'typical' tuna shot). Normally, these kinds of analyses are conducted outside of the model as an independent study.

Including them within the model allows trade-offs to occur between any conflicting data-sets and the best fit to all input data to be found (thus it is an 'integrated' assessment model). It also allows the population model to use the GLM factors to predict bycatch and population trends well beyond the scope of the observed data.

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