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ESTIMATING FISHERY BYCATCH AND EFFECTS ON A VULNERABLE SEABIRD POPULATION

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Abstract. Pelagic longline fisheries worldwide incidentally take long-lived seabird species. This mortality has led to fisheries restrictions to protect seabirds at risk, including Wandering (*Diomedea exulans*) and Amsterdam Albatross (*D. amsterdamensis*) in the South Pacific and Spectacled Petrel (*Procellaria conspicillata*) in the South Atlantic. Because pelagic longline fisheries involve multinational fleets operating in vast ocean regions, assessing total bycatch levels for a seabird is challenging. Here we present a case study of quantifying bycatch from a basin-wide pelagic longline fishery and assessing the population-level impact on a vulnerable seabird, the Black-footed Albatross (*Phoebastria nigripes*) in the central North Pacific. We develop an assessment method that uses observer data to estimate bycatch for one fleet and then uses scenario analysis to estimate bycatch for remaining fleets. Our method generates a bounded estimate of bycatch within an ocean region, ranging from the worst-case to the best-case bycatch scenario. We find that Black-footed Albatross mortality across all fleets in the central North Pacific may total as much as 10 000 individuals/yr. At this level of mortality, population declines are likely. However, even at the best-case bycatch estimate (5200 individuals/yr), population declines may occur over the next three generations (60 years). Although this analysis requires extensive estimation and extrapolation from existing data, it is critical to provide fisheries managers with bounded estimates of likely population-level effects of current fishing activity.

Key words: albatross; bycatch; fisheries impact; mortality; pelagic longline fisheries; Phoebastria nigripes; *population effects; seabird.*

Introduction

Seabirds encounter pelagic longline fishing vessels worldwide. Many seabirds forage in pelagic and shelf slope habitats, the same habitat targeted by pelagic longline fisheries (Croxall et al. 1998). Attracted to discarded fish and baited hooks on deployed lines, seabirds forage while gear is being set and are susceptible to becoming caught on hooks. Once entangled, the bird is pulled down with the line and drowned (Brothers 1991).

Pelagic longlines threaten the Wandering (*Diomedea exulans*), Amsterdam (*D. amsterdamensis*), Black-browed (*Thalassarche melanophrys*), and Grey-headed (*T. chrysostoma*) Albatrosses, White-chinned (*Procellaria aequinoctialis*) and Spectacled (*P. conspicillata*) Petrels as well as many other seabird species (Croxall et al. 1998, Brothers et al. 1999*a*, Weimerskirch et al. 1999, Weimerskirch and Wilson 2000). Because of their relatively late age at first reproduction and low fecundity, albatrosses are particularly vulnerable; they have one of the highest proportions of threatened species in any bird family (Croxall and Gales 1998). Pelagic longline activity has been significantly linked to albatross population declines in the Southern Ocean (Weimerskirch et al. 1997).

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Despite this evidence, quantifying the effects of pelagic longlining on any particular seabird population is challenging. Seabirds are highly vagile, traveling across economic zones, international waters, and encountering multinational fishing fleets. Within a fleet, accurate bycatch estimates require an observer program in which trained observers record the number of seabirds caught per set. Even with a comprehensive observer program, scientists must estimate bycatch rates for unobserved vessels within the fleet. For other fleets with no reported observer data, bycatch rates must be extrapolated or inferred.

Case study: Black-footed Albatross bycatch in the North Pacific

In the US Pacific Economic Exclusive Zone, two seabird species have been documented as bycatch of the U.S. pelagic longline fishery, Laysan (*Phoebastria immutabilis*) and Black-footed Albatrosses (*P. nigripes*). Of the two, Black-footed Albatrosses (BFAL) are thought to be the most heavily impacted; their smaller population sizes and higher bycatch rates suggest a risk of more immediate and pronounced population declines (NMFS 2000). In addition to the U.S. fleet, BFAL also encounter pelagic longline vessels from Japan and Taiwan.

Here we present a case study for estimating seabird bycatch from a fishery consisting of several fleets across a large ocean basin, using BFAL in the central

North Pacific. With U.S. observer and logbook data collected by the National Marine Fisheries Service (NMFS), we estimate overall BFAL mortality incurred by the U.S. pelagic longline fleet based in Hawaii. We then extend the analysis to include mortality from Japanese and Taiwanese (referred to as international) fleets operating within an area that overlaps with BFAL distribution. International bycatch rates are estimated using a scenario analysis approach (Wack 1985*a*, *b*; Peterson et al., *in press*). Finally, we use existing demographic data to project the likely impact of the estimated bycatch on the BFAL population.

Life history characteristics

Like all albatrosses, BFAL are long-lived species; they live 40–50 yr and are reproductively mature at 8–10 yr. Pairs mate for life, but they breed at most once per year (mean interbreeding interval is 2–3 yr) and produce one chick per breeding season (Rice and Kenyon 1962, Fisher 1976, Ludwig et al. 1998). Breeders converge at their nesting sites at the end of October, incubate and brood chicks from November to February, and provision chicks from March to June (Cousins and Cooper 2000). BFAL breed predominantly on the northwestern Hawaiian Islands (Cousins et al. 2000). Small colonies also have been established on Torishima Island, Japan, and Guadalupe and San Benedicto islands, Mexico (Ogi et al. 1994, Pitman and Balance 2002) Large-scale feather and egg harvests in the early 1900s locally extirpated populations at other breeding sites (Cousins and Cooper 2000).

BFAL are surface feeders, taking food by dipping and scavenging at the ocean's surface (Johnson et al. 1993, Gould et al. 1998). BFAL eat flyingfish eggs, squid, crustaceans, fish, and zooplankton and are likely to scavenge, even in the absence of ship discards (Harrison et al. 1983, Gould et al. 1998, Ludwig et al. 1998). During incubation and brooding, from November to February, adults forage close to the breeding grounds. During the chick provisioning period of March–June, BFAL make successively longer foraging trips northward to just south of the Aleutian Islands (Fernández and Anderson 2000). During the post-breeding period from July to October, birds move to the eastern edge of their range between 30° N–55° N and 160° E–120° W (Shuntov 1974, Fisher 1976, Cousins and Cooper 2000, Fernández and Anderson 2000). Once fledged, immature individuals are likely to spend their first 1–5 yr at sea without returning to colonies at all.

Like other long-lived species with low reproductive output, albatrosses are most vulnerable to perturbations that cause declines in adult survival (Russell 1999). As a result, small changes in adult survival can lead to large changes in population dynamics, regardless of the initial size of the population. Given their long-term pair bonds, adult mortality may also reduce reproduction due to lost mating opportunities. This effect, termed widowing, further depresses total reproductive output as surviving mates often miss several seasons (∼1–5 years) before forming another mating pair (Fisher 1976).

The most recent assessment of BFAL status concluded that the population is declining (BirdLife International 2000). In 1998, they were listed as Vulnerable based on the International Union for the Conservation of Nature and Natural Resources (IUCN) risk categories, as future population declines were believed likely to exceed 20% of the current population over the next 60 years, i.e., three generations. Recent estimates put the total population at approximately 300 000 individuals (E. Flint, *personal communication*).

Methods

Data sources

Data for the U.S. fleet in the central North Pacific (CNP) are from the NMFS observer program and logbook records from the period 1994–2000. The observer data are collected by trained, independent observers who record the number of protected species caught per set. Annual observer coverage ranges from 3% to 5% (∼6 out of 114 boats observed per year).

Spatial distribution of fishing effort by Japanese and Taiwanese fleets operating in the CNP was taken from a public domain database of the Ocean Fisheries Programme (OFP), a division of the Secretariat of the Pacific.[2] This data set lists fishing effort per 5° × 5° square per month. The data include all fishing effort reported by member nations in the area. However, the data do not specify the nations or vessels that account for the effort.

Extrapolating total mortality by the U.S. fleet

There are several obstacles that impede our ability to quantify total bycatch from the U.S. fishery. First, bycatch estimates are based on observer data; U.S. observers currently monitor only 3–5% of trips in this fishery, requiring extrapolation of bycatch to the rest of the fleet. Second, several methods have been used to extrapolate bycatch rates to the entire fleet, and each is based on different assumptions regarding the nature of the observer data. Finally, given the spatial and temporal variation in longline fishing effort, the changing seasonal distribution in seabirds, and the different skills and practices of individual longlining captains, seabird bycatch exhibits substantial inter-vessel variation within a fleet.

As there is no standard method for estimating total bycatch from observer data, we compared three published methods to assess the range of predictions among methods. The ''per hook estimator'' is an adaptation of a standard two-stage sampling estimator (Klaer and Polacheck 1997). It takes into account the unequal size of observer samples (sets observed) as well as number of cruises, sets, and hooks in observed and unobserved

[2] URL: ⟨http://www.spc.org.nc/oceanfish/⟩

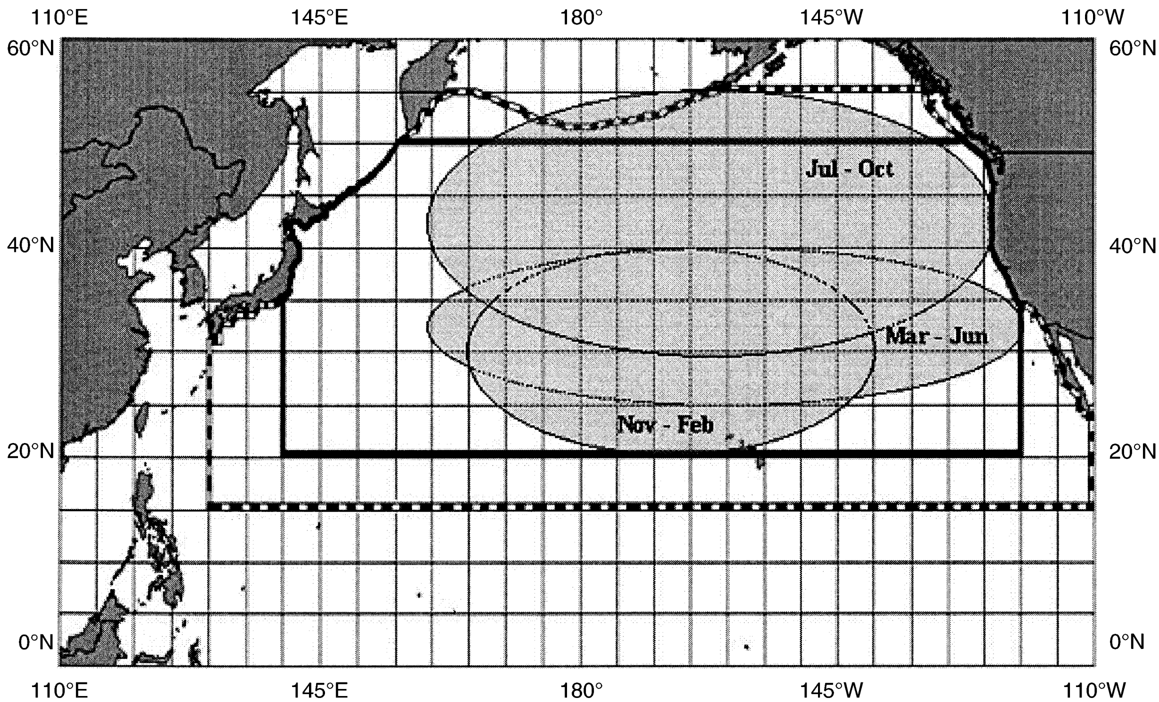

FIG. 1. The minimum, intermediate, and maximum areas of co-occurrence in which Black-footed Albatross could encounter international pelagic longline vessels. The minimum area, shown in gray, only included range extents for the three seasonal strata (November–February, 165° E–140° W, 20° N–40° N; March–June, 160° E–120° W, 25° N–40° N; July–October 160° E–120° W, 30° N–55° N). The intermediate area, outlined in bold black line, included all five-degree blocks with more than one bird encountered during at-sea surveys and extends from 20° N to 50° N and 140° E and 120° W. The maximum area, marked with a dashed line, included all five-degree blocks with one or more Black-footed Albatross encountered and covers 15° N–50° N and 130° E and 110° W.

vessels. Because observer data include many zeros (sets with no observed bycatch) and high variation, the ''Pennington method'' (Pennington 1983) estimates total bycatch based only on sets that have positive, or non-zero, bycatch. This method assumes positive bycatch cases follow a lognormal distribution. Estimates are the product of the proportion of bycatch events and the mean rate at which those events occur. This method has been used for other species groups with relatively few observed takes, e.g., marine mammals and sea turtles (Johnson et al. 1999, Yeung et al. 2000). The NMFS assessment of albatross mortality (NMFS 2000) used estimates from ''CART regression tree analysis'' (P. Kleiber, *unpublished data*). CART, categorical and regression tree analysis, uses continuous predictor variables to identify nonoverlapping groups, in this case if a bird is hooked or not hooked. Data are split into these nonoverlapping groups while trying to minimize differences within groups.

Using each of these methods, we calculated bycatch per unit effort (BPUE) for tuna and swordfish vessels based on NMFS observer data for three sampling time strata, November–February, March–June, and July–October, to reflect BFAL seasonal cycles in reproductive activity and at-sea distribution (Shuntov 1974, Fisher 1976). The data from each stratum were then averaged to yield an annual mortality estimate.

Estimating total mortality from international fleets

Japan and Taiwan account for a much larger proportion of fishing effort in this region than the U.S. fleet (Cousins et al. 2000). To account for bycatch effects from this international fleet, we used BFAL distribution based on data from at-sea surveys (in Cousins and Cooper 2000) and considered this to be the area in which international longline vessels and BFAL could co-occur. We delineated three areas based on probability of co-occurrence: minimum, intermediate, and maximum (Fig. 1). The minimum area of co-occurrence included range extents for the three seasonal strata (November–February, 165° E–140° W, 20° N–40° N; March–June, 160° E–120° W, 25° N–40° N; July–October 160° E–120° W, 30° N–55° N). The intermediate area included all five-degree blocks with more than one bird encountered according to at-sea survey data (20° N–50° N and 140° E and 120° W). The maximum area included all five-degree blocks with one or more BFAL encountered (15° N–50° N and 130° E and 110° W).

Using data from the OFP database, we then tallied the total fishing effort (number of hooks) recorded in

TABLE 1. Age classes and corresponding demographic parameters of Black-footed Albatross in the central North Pacific.

Age class	Age	Probability of surviving (P_i)	Probability of growing (G_i)	Fecundity
1	0–12 mo	···	0.577	···
2	1–3 yr	0.577	0.194	···
3	4–7 yr	0.689	0.166	···
4	8–20 yr	0.906 (0.90–0.93)	0.071 (0.07–0.08)	0.22 (0.21–0.27)
5	21–50 yr	0.96 (0.93–0.97)	···	0.22 (0.21–0.27)

Notes: Parameters are based on values in Cousins and Cooper (2000) and were estimated from fixed-stage duration equations in Caswell (2001). Values in parentheses represent reported ranges included in the population model as annual demographic stochasticity. Matrix elements were not correlated.

each of the areas of co-occurrences. Because this data set is not nation-specific, we subtracted the number of U.S. hooks in these areas and divided the remaining hooks between Japanese and Taiwanese fleets in proportion to the catch for each country as reported in recent swordfish and tuna commissions and international reports (NOAA 1997, IATTC 2000, Ward and Elscott 2000). Although Korea also deploys vessels in the Pacific region, their fishing effort tends to be centered on the equatorial belt (10° N–10° S) outside of the range of BFAL and thus was not included in our analysis (Cousins et al. 2000).

Once we tallied fishing effort, we then had to assign bycatch rates to this international effort. We accomplished this using scenario analysis (Wack 1985*a*, *b*). Scenario analysis provides a framework for evaluating alternatives of future conditions and is a useful tool to test consequences of different assumptions or models (Wack 1985*b*). Because we have no data on international bycatch rates, we created three bycatch scenarios: Scenario 1 assumes international fleets have higher bycatch rates than the U.S. fleet; Scenario 2 assumes international fleets have lower bycatch rates than the U.S. fleet; Scenario 3 assumes international fleets have comparable bycatch rates to the U.S. fleet. The percentage of change in bycatch rates for Scenarios 1 and 2 were derived from the known distribution of U.S. bycatch rates to insure that the bycatch scenarios were possible; we used the standard deviation of this distribution as the metric between scenarios. Scenario 1 is one-half standard deviation higher than the U.S. mean (26%), and Scenario 2 is two standard deviations lower than the U.S. mean (50%). There is evidence to support all three international bycatch scenarios. In support of Scenario 1, Brothers et al. (1999*a*) suggest that nylon monofilament mainline, which is thought to be prevalent in Asian fleets, leads to 3–7 times higher bycatch rates because the line is lighter and therefore sinks more slowly. In support of Scenario 2, it is also plausible that gear requirements and fishing distribution of international fleets could lead to lower bycatch rates. Japanese fisheries management agencies have taken a proactive approach to testing and implementing seabird bycatch mitigation measures in Southern Ocean fisheries (Satani and Uozomi 1998, Takeuchi 1998). In addition, international fleets do not have access to the fishing areas closest to BFAL breeding colonies that have been associated with higher bycatch (Boggs 2001). Scenario 3 assumes that, given overall gear similarities, bycatch rates for international vessels could be comparable to bycatch from the U.S. fleet. Although Japan has developed bycatch reduction technologies for distant-water fisheries, their implementation in the CNP is voluntary, and they have not yet ratified a national plan of action to reduce seabird bycatch (J. Cooper, *personal communication*).

The international fleets primarily target tuna. However, there are conflicting reports on the amount of targeted swordfish catch by Japanese and Taiwanese vessels (NOAA 1997, NMFS 2000, Ward and Elscott 2000). Identifying the amount of targeted swordfish catch is important because swordfish sets have been found to have bycatch rates as much as 10 times higher than tuna sets (Cousins et al. 2000; L. B. Crowder and R. Myers *unpublished manuscript*). Reports suggest that Japanese coastal and offshore pelagic longline vessels participate in a directed swordfish fishery between 140–180° E and 20–45° N, which is likely to bring them into contact with BFAL (NMFS 2000, Ward and Elscott 2000). Based on estimates from recent reports (NOAA 1997, NMFS 2000, Ward and Elscott 2000), we assumed the ratio of targeted tuna to swordfish was 80:20 for the international fleets.

Population level effects

Combining the bycatch mortality estimates for the U.S. and international fleets, we then asked what effect the mortality from pelagic longlining would have on BFAL populations. For this analysis, we constructed a basic age-structured matrix model using published demographic data for BFAL (Gould and Hobbs 1993, Cousins and Cooper 2000, Pyle 2000). We divided the population into five age classes of fixed duration (see Table 1). The parameters were separated into probabilities of growth and survival (Caswell 2001). We defined the probability of growing to the next stage given an individual has survived (γ_i) as

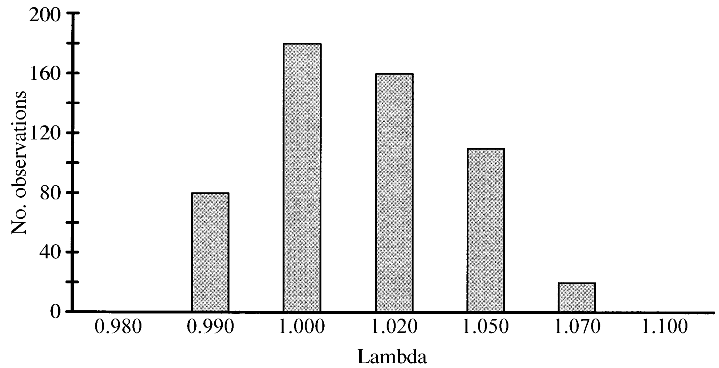

FIG. 2. Distribution of lambda values associated with the baseline population model. Data are from values in Table 1.

$$\gamma_i = \frac{\left(\frac{\sigma_i}{\lambda}\right)^{T_i} - \left(\frac{\sigma_i}{\lambda}\right)^{T_i - 1}}{\left(\frac{\sigma_i}{\lambda}\right)^{T_i} - 1} \qquad \lambda = 1 \qquad (1)$$

where T_i is time in stage i, σ_i is the survival probability in stage i, and λ is rate of population change, assumed to be 1. The data in Table 1 were used for the baseline population model and yield a stable population with a lambda value of $\approx$1 (see Fig. 2 for distribution of lambda values). Fecundity is the product of the mean proportion of the breeders in the population, the number of females, and the mean number of chicks fledged per adult. Although there is evidence for differential mortality from longline vessels between males and females for other albatross species (Weimerskirch et al. 1997), we have insufficient data to include this for BFAL and so assume equal mortality for both sexes. We assumed pelagic longlines caused mortality in the adult age ($\geq$8 yr) classes as initial modeling efforts found few differences between adult or juvenile mortality (Cousins and Cooper 2000). Density-dependent population regulation was excluded from the model as (1) historical population levels were substantially higher than current levels (Cousins and Cooper 2000) and (2) density dependence assumes that reproductive success is higher at low population sizes. If a population decline is linked to a decline in resources, there is evidence that adult albatross curtail reproductive and provisioning activities, potentially to wait for future breeding seasons with more favorable conditions (Russell 1999, Thompson and Ollason 2001), and (3) there is also evidence that albatrosses are unable to adjust breeding effort in response to environmental conditions (Weimerskirch et al. 2001).

Because different abiotic and biotic factors influence nestling survival and adult mortality differently, we did not correlate demographic rates within the matrix. We included demographic stochasticity for adult survival and fecundity based on projected ranges of these parameters (cf. Cousins and Cooper 2000). At each time step, adult survival and fecundity matrix elements were selected from a beta distribution of published values using stratified Monte Carlo sampling. Because the demographic parameters were based primarily on data collected in the mid-1970s, ‘‘double-dipping,’’ or counting mortality sources both within a parameter estimate and within a simulation scenario, is not likely (Brook 2000).

TABLE 2. Black-footed Albatross bycatch per unit effort based on National Marine Fisheries Service observer data from the period 1994–2000 for tuna and swordfish vessels, excluding mixed catch vessels.

Catch	Nov–Feb	Mar–Jun	Jul–Oct
Tuna	0.015 (0.014)	0.024 (0.015)	0.005 (0.004)
Swordfish	0.310 (0.061)	0.594 (0.021)	0.167 (0.052)

Notes: Values represent mean (SE) bycatch rates per 1000 hooks. For each time period, the mean number of hooks per time period are: November–February, 5928×10^3; March–June, 5906×10^3; July–October, 4297×10^3.

RESULTS

Mortality from CNP fleets

Using BPUE from NMFS observer data (Table 2), the three estimation methods provided roughly similar estimates of total BFAL mortality incurred by the Hawaii-based U.S. fleet (Fig. 3). The Pennington method typically yielded the lowest yearly estimates. This could be due to minor deviations from the lognormal distribution, an underlying assumption for this method. The two-stage estimator tended to yield the highest

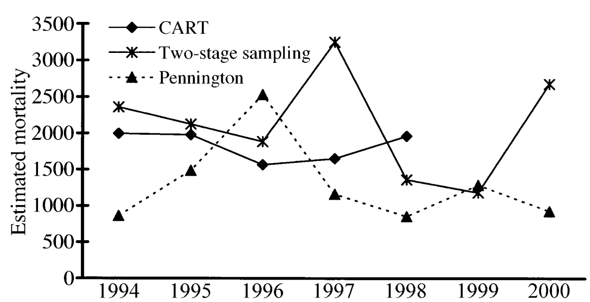

FIG. 3. Estimates of total Black-footed Albatross mortality from the U.S. pelagic longline fleet in the central North Pacific, using three analysis methods.

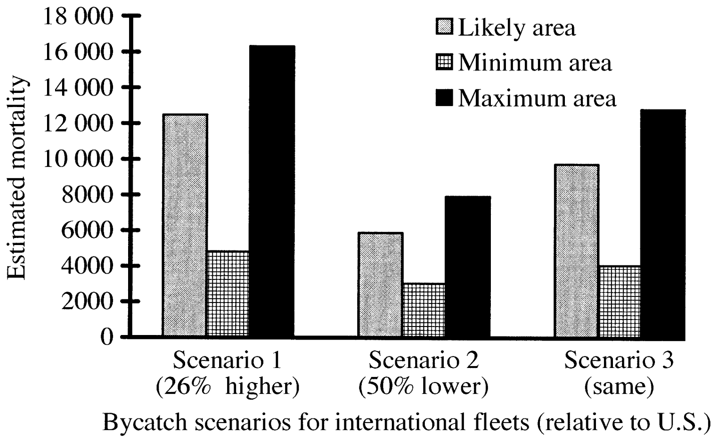

FIG. 4. Black-footed Albatross mortality estimates from international pelagic longline fleets in the central North Pacific across the three areas of co-occurrence (see Fig. 2). Bycatch rates are relative to the distribution of observed bycatch per unit effort rates for the U.S. fleet.

estimates. The variance associated with each annual estimate was high (±6000), making the confidence intervals too wide to be instructive as a means of assessing the accuracy of the extrapolated estimate within each method. This high level of variance stems from the nature of the data set; bycatch among fishing trips varies widely, with as many as 30 hooked birds observed in one trip, which can be many times higher than other trips with comparable set and hook numbers. Even within a trip, birds are often caught in abrupt peaks, with 12 birds hooked in one set and zero birds hooked in previous and subsequent sets of equal effort, i.e., number of hooks. Although the confidence intervals within the three methods were not instructive, we used the similarity of values generated across methods as an indicator of estimate stability. The mean of annual means across methods suggests that the U.S. pelagic longline fleet based in Hawaii have killed ~2000 BFAL per year (1998 ± 165; mean ± 1 SE). A bootstrap analysis of 1000 replications of each annual estimate for the three methods yielded a statistically similar mean with 95% confidence intervals ($\bar{X}$ = 1847; 1544–2286).

We then used the area of co-occurrence estimates combined with the three bycatch scenarios to generate estimates of BFAL bycatch from the international fleets (Fig. 4). Our lowest estimate is the weighted mean from the minimum area across the three bycatch scenarios; at minimum, annual mortality from international fleets is 3200 individuals. Taking the weighted mean of the intermediate area estimates across the scenarios, our moderate estimate of international bycatch is an annual mortality of 8000 individuals. The highest estimates were from the weighted mean of the maximum area; at maximum, international fleets kill 11 800 individuals annually. Summing these international estimates with the annual U.S. bycatch, we generated a bounded estimate of total BFAL bycatch from pelagic longline vessels in the CNP (Table 3). We refer to these as the best-case, the moderate, and the worst-case mortality levels.

TABLE 3. Bounded estimates of total Black-footed Albatross mortality in the central North Pacific from U.S. and international pelagic longline vessels.

Mortality level	Percentage of population killed	U.S. mortality	International mortality	No. individuals killed
Best case	1.9	2000	3200	5200
Moderate	3.7	2000	8000	10 000
Worst case	5	2000	11 800	13 800

Note: We assumed an initial population of 300 000 individuals based on recent estimates (Cousins and Cooper 2000).

Population trajectories

Using the baseline (stable population) matrix model, we evaluated the impact of the bounded estimates of adult longline mortality on population dynamics. The three mortality levels yielded a range of lambda values (Fig. 5). Our population trajectories across the three mortality levels suggest that even at the best-case mortality level, i.e., 1.9% of population killed by pelagic longlines each year, some population declines would be likely over the next 20 years (Fig. 6). For the best-case mortality level to be an accurate representation of current bycatch levels, the international fleets, which have nearly four times the effort of the U.S. fleet in the CNP, would be incurring only slightly more mortality per year (2000 U.S. + 3200 International = 5200). Our results support the IUCN assessment of greater than 20% declines from current population size over the next 60 years (assuming constant levels of bycatch mortality over the time period).

DISCUSSION

Longline bycatch in context

To put the projected mortality from pelagic longline fisheries in context, we identified other sources of mortality that impact BFAL populations (Table 4). Historically, egg and feather harvests in the early 1900s may have taken as many as 300 000 birds/yr (Rice and Kenyon 1962). Until they were banned in 1992, high seas

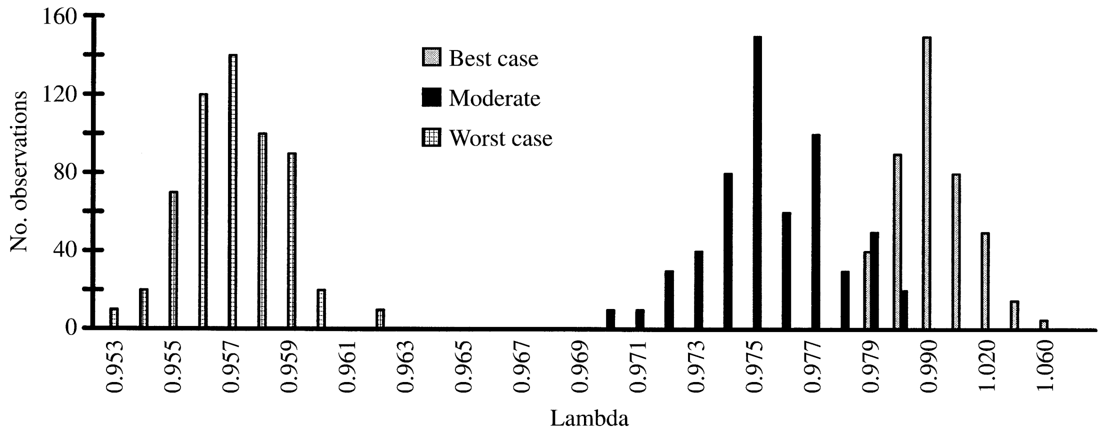

FIG. 5. Lambda values associated with the three Black-footed Albatross mortality scenarios from pelagic longline bycatch in the central North Pacific.

drift nets took an estimated 3500–4500 birds/yr (Johnson et al. 1993). Plastic ingestion by chicks and toxin contamination have been suggested to increase nestling mortality (Sievert and Sileo 1993, Ludwig et al. 1998). Besides pelagic longlines, formal bycatch estimates have been made for only one other extant fishery; U.S. demersal longline vessels in the Bering Sea and the Gulf of Alaska take an estimated 300–600 BFAL/yr (Stehn et al. 2001; NPFMC, *available online*).[3] Demersal longlining, gillnetting, and the troll fishery by U.S. and other fleets throughout the CNP may also contribute to BFAL bycatch. It is possible that the BFAL mortality from pelagic longlines may be 2–3 times higher than the mortality incurred by the high seas driftnet fishery.

Current management options

Following the 1996 IUCN Seabird Bycatch Reduction Resolution and the FAO International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries ratified in 1999 (Cooper et al. 2001), recent research (Klaer and Polacheck 1998, Brothers et al. 1999*a, b*) has focused on several types of measures to mitigate seabird bycatch including bird-scaring devices designed to discourage birds from scavenging over baited lines, line-setting devices that place baited lines in protected areas outside a ship's wake, weighting lines to increase sink rates, and modifying bait condition by thawing or dying bait to make it less visible and accessible.

This research has provided overwhelming evidence that mitigation measures can be used effectively to significantly reduce seabird bycatch, even if effective management requires a combination of measures depending on the fishing area and seabird species impacted (Klaer and Polacheck 1998, Brothers et al. 1999*a, b*, Boggs 2001, Lokkeborg 2001). The overall U.S. bycatch rate for BFAL in the North Pacific (0.18 birds/1000 hooks) is comparable to reported seabird bycatch rates in Australian and New Zealand waters (0.15 birds/1000 hooks [Gales et al. 1998]) before seabird bycatch mitigation regulations were made mandatory in 1995 and 1993, respectively (Bache and Evans 1999).

Analysis caveats

The method and analyses we present are limited by lack of data and/or poor access to data. However, despite this limitation, our method of generating bounded estimates of total mortality provides an important means of assessing the potential impact of pelagic longline fishing on a vulnerable seabird population. The method incorporates existing fisheries observer data, at-sea survey information, and available demographic rates to present a comprehensive analysis of BFAL bycatch.

Ideally, to incorporate uncertainty in an analysis, one would use a rigorous statistical technique, e.g., bootstrapping or Bayesian statistics (Hilborn and Mangel 1997). For this case study, and for many other studies of seabird species, rigorous statistical analysis is not feasible. Although a technique like bootstrapping may be instructive to quantify uncertainty when data are available, given our data limitations, this approach cannot answer the necessary question: what are the bycatch rates from the international fleets? Moreover, these techniques suggest a level of precision that is not justified based on the limited data available. Instead of a statistical technique, we use scenario analysis as a framework for our estimation exercise. Although an imperfect representation of international bycatch trends, the scenario analysis presents a means of bracketing a management problem that demands immediate attention, even with substantial gaps in the data set (Wack 1985*a*).

Despite potential uncertainty and estimation error, we believe our estimates are most likely conservative. Although our population projections include mortality

[3] URL: ⟨http://www.fakr.noaa.gov/npfmc/safes/safe.htm⟩

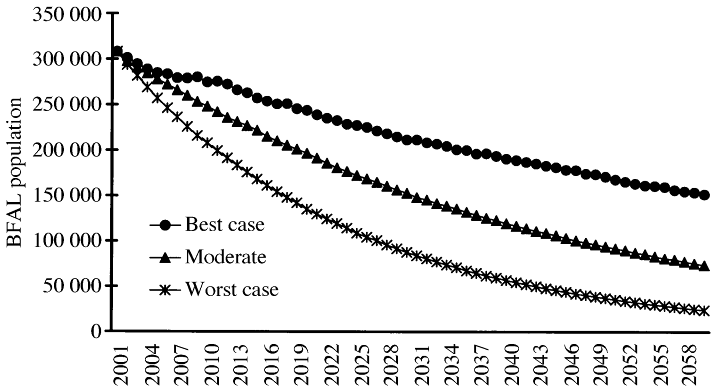

FIG. 6. Population trajectories for Black-footed Albatross (BFAL) over the next 60 years in response the three levels of estimated mortality from pelagic longlining in the North Pacific.

from pelagic longline fisheries in conjunction with natural mortality, we do not incorporate the influences of strong environmental effects, which have been shown to exert strong negative impacts on BFAL and other seabird populations (Thompson and Ollason 2001, Weimerskirch et al. 2001). Nor do we account for mortality from other fisheries, such as the U.S. demersal longline fishery and other fisheries prosecuted by other nations in the central North Pacific. In addition, despite concerted efforts by observers, bycatch data may not account for birds that have been scavenged or dislodged from the line before it is hauled at the end of a set. Previous research has suggested that as many as 30% of birds that are hooked are dislodged during the haul and thus not observed (Brothers 1991). We also do not include the additional loss of reproductive opportunities to surviving pair members from the effect of widowing (Fisher 1976). Finally, the possibility of underreporting of international fishing effort in the OFP database provides further support for the conservative nature of our projections. International reports and commissions are reliant on member nations to report their own effort per region and cannot be independently verified.

Recent changes in NMFS regulations may have substantially changed the amount of BFAL bycatch by the U.S. Pacific longline fleet. Seabird mitigation measures (line-setting devices, weighted lines, and blue, thawed bait) were implemented first as an emergency rule by NMFS in June of 2001 (NMFS 2001) and then issued as a final rule by NMFS a year later (NMFS 2002). In March 2001, NMFS also introduced a complete swordfish fishery closure north of the equator to the North Pole. Tuna fishing was prohibited for an area northwest to the breeding grounds from April to May. The mitigation measures, the closure of the swordfish fishery, and the seasonal tuna fishery closure during high bycatch months of April and May are likely to reduce U.S. BFAL bycatch. However, if U.S. tuna vessels redistribute their fishing effort in the former swordfish fishing area (adjacent to breeding grounds), U.S. bycatch levels may not decline dramatically. Moreover, given BFALs long-ranging foraging trips that extend off the coasts of Washington, Oregon, and California, it is possible that redistributed U.S. swordfish effort off the coast of California will also lead to BFAL bycatch. NMFS observer data will be needed to assess the impact of the redistribution of fishing effort in this area. It is important to note that these management actions are not likely to have any impact on international bycatch levels.

CONCLUSIONS

Based on our BFAL bycatch estimates and other known mortality sources, pelagic longlining by U.S.,

TABLE 4. Sources of Black-footed Albatross mortality in the central and North Pacific (adapted from a table in Cousins and Cooper 2000).

Mortality source†	No. birds/yr	Reference
Pelagic longline: all nations, central North Pacific‡	5000–14 000	this analysis
Demersal longline: U.S., North Pacific	300–600	Stehn et al. (2001), NPFMC (2001)
Plastic and toxin contaminants	?	Ludwig et al. (1997), Sievert and Sileo (1993)
High seas drift net: North Pacific§	3500–4500	Ogi et al. (1993), Johnson et al. (1993)
Egg and feather harvests‖	300 000	Rice and Kenyon (1962), Spennemann (1998)

† There are other fisheries that also may incur Black-footed Albatross bycatch, including demersal longlines off Canada's west coast and in other areas of the central North Pacific, coastal gillnets (drift and set nets), and a troll fishery. However, at present there are no bycatch estimates for these fisheries.

‡ Although the U.S. Hawaii-based swordfish fishery was closed in March 2001, U.S. swordfish effort has likely been distributed off the California coast. It is unclear how this redistribution will impact Black-footed Albatross bycatch levels.

§ Includes mothership and land-based salmon driftnet, flying squid driftnet, and large-mesh driftnet fishery from Japan, Korea, and Taiwan. Fishery closed in 1992.

‖ Harvests in late 1800s and early 1900s.

Japanese, and Taiwanese fleets appears to be the single largest cause of BFAL mortality at this time. Across fleets, pelagic longlining vessels likely kill at least 5000–14 000 BFAL in the North Pacific, removing 1.9–5% of the population per year. A preliminary analysis by Cousins and Cooper (2000) generated a rough estimate of potential biological removal (PBR) for BFAL, where PBR is defined as the maximum mortality a population can sustain before exhibiting declines. Calculated as the product of a maximum productivity rate and the current population estimate, these authors suggested that the PBR should not exceed 10 000 birds/yr. Although this estimate is strongly influenced by the population size used in calculations, it does provide a precautionary approach to estimating sustainable mortality levels. Our results indicate that BFAL mortality from pelagic longlining in the North Pacific, in addition to mortality from other U.S. and nations' fisheries, is likely to exceed this threshold. Our population trajectories across the range of mortality estimates suggest that population declines are likely at the 10 000 individuals (moderate) mortality level. Although declines have not been observed across all breeding colonies, BFAL bycatch rates suggest population level effects are likely. Given the evidence of likely population declines and the success from bycatch mitigation measures in other ocean regions, bycatch migitation should be mandatory for all fleets in the central North Pacific to protect this vulnerable species.

Black-footed Albatross highlight the conservation concerns for many pelagic, long-lived seabirds. As with other typical "*K*" strategist species that have delayed maturity, low reproductive output, and long lives, the complete impact of perturbations that cause declines in adult survival may not be detectable for many years. This lag in population response makes tracking population trends in response to a mortality source challenging. This lag also contributes to our uncertainty in quantifying the magnitude of human-mediated mortality on these seabird populations. However, waiting for directional declines across all local populations, an unequivocal signal of a decline in the overall population (e.g., Steller sea lion, Pascual and Adkison 1994, Calkins et al. 1999), would present a formidable challenge to the conservation of BFAL and other seabirds. Likewise, waiting for a more complete data set, with which more rigorous statistical analyses could be conducted, presents a similar conservation challenge.

Although this case study focuses on an albatross species in the North Pacific, pelagic longlines negatively impact seabirds in the Atlantic, Indian, Australasian, and Pacific regions of the Southern Ocean as well as other ocean regions (Prince et al. 1998, Belda and Sanchez 2001). Here we suggest a proactive approach of using existing information to create bounded estimates of current bycatch from pelagic fleets, accounting for a reasonable range of bycatch scenarios. The bounded estimates can then be used to project likely impacts of this mortality at the population level before catastrophic declines occur. Despite data limitations, our approach is comprehensive in that we incorporate data on at-sea seabird distribution, fisheries effort and bycatch, and population-level effects. The estimation and extrapolation method we use is clearly subject to error and uncertainty. However, our analyses provide a means to explore likely population-level effects, the first necessary step to implement needed management actions. Our analyses also emphasize the importance of assessing bycatch from a multinational perspective due to the highly vagile nature of seabirds. Even with mandatory bycatch mitigation measures for the U.S. fleet, mortality incurred by Japanese and Taiwanese vessels will need to be substantially reduced to protect the Black-footed Albatross. International coordination of bycatch mitigation will be critical for the conservation of this and other pelagic species.

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