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The Factors Influencing Albatross Interactions in the Hawaii Longline Fishery: Towards Identifying Drivers and Quantifying Impacts

Report of a workshop in Honolulu, Hawaii, 7–9 November 2017

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The Factors Influencing Albatross Interactions in the Hawaii Longline Fishery: Towards Identifying Drivers and Quantifying Impacts

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Cover: A Black-footed Albatross taking off from the sea surface in waters north of Hawaii. Photo courtesy of David Hyrenbach.

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Executive Summary

The Hawaii longline fishery has been required to use seabird mitigation measures under the Pacific Pelagic Fishery Management Plan (current Fishery Ecosystem Plan, or FEP) since 2001. In the past decade since the successful implementation of seabird mitigation measures, the fishery has seen a gradual increasing trend in Black-footed (*Phoebastria nigripes,* BFAL) and Laysan (*P. immutabilis,* LAAL*)* albatross interactions, with higher rates of Black-footed albatross interactions since 2015. A published analysis conducted by Gilman and colleagues (2016) using data from October 2004 to May 2014, indicated that albatross interaction rates significantly increased during years of higher annual mean multivariate El Niño index (MEI), suggesting that oceanographic changes may have contributed to these changes in albatross catch rates. This analysis also showed a significant increasing trend in the number of albatross attending fishing vessels which may have contributed to the increasing catch rates. Moreover, the higher interaction rates observed during the recent El Niño event (2015–2016) further underscore the potential links between ocean conditions and albatross longline interactions.

While albatross interactions in the Hawaii longline fishery remain well below pre-mitigation levels, the Western Pacific Regional Fishery Management Council, at its 166th Meeting in June 2016, recommended further research to improve understanding of interaction rates in the fishery. On 7–9 November 2017, in coordination with NMFS Pacific Islands Regional Office and Pacific Islands Fisheries Science Center, the Council convened a workshop to explore the potential drivers and implications of the higher albatross interaction rates observed in 2015–2016. These were explored in the context of longer-term oceanographic variability, shifts in fishery effort and distribution, changes in albatross at-sea distribution, and albatross demography and population trends. Specifically, the workshop focused on four objectives:

1) review recent increased interactions in the Hawaii longline fishery;

2) explore possible factors responsible for this increase;

3) evaluate albatross population impacts; and

4) provide input for future data collection, analyses, and modeling.

The workshop participants included 28 local, national, and international seabird ecologists, seabird population modelers, oceanographers, fisheries scientists, and industry representatives. The exploratory analyses and information presented at the workshop suggested that the higher BFAL interaction rates in the Hawaii deep-set longline (DSLL) fishery in 2015–2016 may be largely explained by environmental conditions associated with the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). During quarter 1 of years with positive PDO and ENSO conditions (2015, 2016), winds north of 25ºN latitude switch from trades to westerlies. This change in wind direction results in more productive surface waters in the fishing grounds during quarters 1 and 2, and an apparent eastward shift in BFAL distributions into the fishing grounds. The Transition Zone Chlorophyll Front (TZCF), an important foraging habitat for BFAL, also shifts south, bringing it into the northern edge of the fishing grounds. In summary, these oceanographic shifts increase the spatial overlap of BFAL distributions with the Hawaii DSLL fishery during years of positive PDO and ENSO conditions.

The spatial distributions of fishing effort and mitigation measures during quarters 1 and 2 of 2015 and 2016 were not anomalous in a longer-term context (2004–2016). While quarter 3 fishing effort has shifted further eastwards over the past decade, these months (July–September) are not a time of substantial albatross-fishery interactions. Because BFAL interaction rates and abundance around vessels are positively correlated, workshop participants identified factors that may influence BFAL vessel attendance, such as breeding population dynamics (e.g., reproductive success), mesoscale features (e.g., eddies), and increased albatross attraction to vessels (e.g., fishing practices, albatross learning).

Population models, updated for the workshop, indicated that the DSLL interactions in 2015–2016, if stabilized at this higher level, are likely to have an imperceptible impact on BFAL population growth. However, if these elevated bycatch rates are consistent throughout North Pacific longline fisheries with BFAL interactions, the population is projected to decline. While North Pacific-wide bycatch estimates are not available, data from Alaska fisheries suggest that the 2015–2016 increase is unlikely to be basin-wide.

As next steps, workshop participants discussed moving towards an Integrated Population Model (IPM), building upon the current BFAL demographic model by integrating the multiple available data sets and perspectives. Yet several data gaps must be addressed to develop an IPM, involving an improved understanding of at-sea distribution, bycatch rates, and survivorship of birds from different colonies. In particular, tracking studies at the main breeding sites are needed to determine the degree to which birds overlap and interact with fisheries. While tracking has occurred at three breeding sites (French Frigate Shoals, Midway Island, and Kure Atoll), birds from several sites in the Northwestern (Laysan Island) and the main Hawaiian Islands (Necker, Nihoa, and Kaula Islands) have not been tracked.

Workshop participants also stressed the need for continued population monitoring at Midway Island to update the uninterrupted time series of breeding and reproductive success data. They also indicated the importance of resuming breeding population counts at French Frigate Shoals and Laysan Island, two colonies that were historically surveyed by the U.S. Fish and Wildlife Service (USFWS) but are no longer monitored.

Introduction: Background and Objectives of the Workshop

Mortality in longline fisheries is a critical global threat to most albatross and large petrel species (Croxall and Gales 1998, Brothers et al. 1999, Gilman 2001). In the North Pacific Ocean, incidental bycatch of BFAL and LAAL in the Hawaii pelagic deep-set (DSLL) and shallow-set (SSLL) longline fisheries are of concern to fisheries managers (Cousins and Cooper 2000, Gilman and Freifeld 2003, Gilman et al. 2016). Together, these two albatross species accounted for 93% of all seabird takes in the DSLL fishery since observer coverage began in 1994 and through 2013 (Gilman et al. 2016).

This section summarizes previous efforts by the Western Pacific Regional Fishery Management Council (WPRFMC) to quantify the magnitude and population-level impacts of BFAL bycatch in the Hawaii longline fisheries over the last two decades. It briefly discusses recent findings concerning the risk factors responsible for albatross-fishery interactions, and the current population status of the species. The purpose of this background section is to provide readers with the historical context that motivated and informed the current workshop.

Overview of the 1998 Black-footed Albatross Population Biology Workshop

In 1998, the BFAL was assessed as Vulnerable by the International Union for the Conservation of Nature (IUCN), partly due to the incidental mortality in longline fisheries (Croxall and Gales 1998). In October 1998, the Western Pacific Regional Fishery Management Council (hereafter referred to as the Council) convened a workshop of international seabird and fisheries biologists to address the lack of a comprehensive understanding of BFAL population dynamics in the Northwestern Hawaiian Islands (NWHI). The activities of the three-day workshop reviewed available information and generated recommendations for conservation measures and future research. Using data made available at the workshop, the participants investigated current population parameters, examined changes in adult and juvenile survival rates, and evaluated the effects of longline mortality on the BFAL population using age-structure models. The workshop activities and findings summarized below were presented in a workshop report published by the Council (Cousins and Cooper 2000, Figure 1).

The first workshop objective was to review historical records and data sets which included 60 years of banding data, information on at-sea sightings and tracking, and seabird mortality estimates from Hawaii and Alaska longline fisheries. Workshop participants noted that a variety of methods have been used over the years to estimate the abundance of BFAL breeding in the NHWI. They assembled a detailed chronology and description of the census methods used in the NWHI. Workshop participants also discovered a major problem with the banding data—the inability to link the records of double-banded or replacement banded birds. Nevertheless, demographers analyzing 255 at-sea banding records of known-age BFAL suggested that younger, less experienced birds are more vulnerable to being caught by longlines, with 114 (44.7%) being young-of-the-year birds, 89 (34.9%) being pre-breeding (1–4 years old) after-hatch year birds, and 52 (20.4%) being breeding age birds (over 5 years old).

THE POPULATION BIOLOGY OF THE BLACK-
FOOTED ALBATROSS IN RELATION TO
MORTALITY CAUSED BY LONGLINE FISHING

Figure 1. Cover page of the report from the first Black-footed Albatross population workshop, held in 1998 and available on the Council. website: wpcouncil.org

At-sea sightings, fishery observer data sets, and satellite tracking showed that BFAL have a large marine distribution with foraging areas that shift as a function of the breeding season. During the egg-laying and incubation periods, from December through February, BFAL are concentrated near their breeding islands. During the remainder of the breeding season, from hatching and until the chicks fledge in July, birds range farther north to the Gulf of Alaska and the Aleutian Islands, and farther east, to the west coast of North America, where they remain in July and August. Their distribution shifts south and west during fall (September–November), with mature birds eventually returning to the colonies to breed.

participants highlighted the lack of seabird interaction and mortality data for those nations' fisheries.

Population modeling experiments developed to compare the effects of different removal rates of adults and juveniles suggested that when removal rates are 10 times higher for juveniles than for adults, the population declines more slowly than if the removal rates of these two age classes are equal. While these scenarios are not evident in the population trajectory initially, they result in changes in the population age structure and abundance after 5 years. The workshop participants also noted that, due to data gaps in population parameters, these modeling exercises were based on three untested assumptions: an equal population sex ratio, constant juvenile survival rate to the age of first breeding, and equal survivorship for males and females.

The following recommendations were agreed upon by the participants of the 1998 BFAL Population Biology Workshop:

Complete, develop, and manage a relational database of banding records.

Encourage further analyses of the existing banding and demographic data sets and conduct further modeling at a population dynamic modeling laboratory.

Design and implement a population-monitoring program at breeding sites to address the effects of longlining mortality.

Obtain information and make best estimates of fishing effort and mortality of birds from the Pacific Halibut and non-U.S. longline fisheries in the northern Pacific Ocean.

Design, implement, and develop a longline fishery-monitoring scheme to test mitigation measures and gather mortality data.

Undertake comparative studies with Hawaiian LAAL and with Japanese BFAL.

Hold a follow-up meeting to discuss progress with the above recommendations at the Second International Albatross Conference in Honolulu, Hawaii, in May 2000.

Since 1998, the following steps have been taken to address the recommendations of the BFAL Population Biology Workshop:

A relational banding database capable of addressing the shortcomings identified during the 1998 workshop was completed and implemented by USFWS. Thus, the band replacement issue, whereby worn-off and lost bands lead to overestimates of mortality rates, has been resolved by deploying multiple bands on the same individual birds.

Several analyses of existing BFAL demographic and bycatch data sets have been published since the 1998 workshop (Lewison and Crowder 2003, Véran et al. 2007, Lebreton and Véran 2013), including two population-level assessments (Arata et al. 2009, Bakker et al. 2018).

In addition to the ongoing counts at breeding sites (Flint and Fraiola, this report), a population-monitoring program involving demographic plots was established by USFWS (Kendall et al., this report) to quantify BFAL demographic rates and to address the effects of longlining mortality.

While several studies have estimated longline fishing effort and BFAL mortality in longline fisheries operating in the North Pacific Ocean, including demersal and non-U.S. longline fisheries (Hyrenbach and Dotson 2003, Lewison and Crowder 2003, Guy et al. 2013), this remains an unresolved issue (see Working Group 1 Summary). In particular, there are concerns about emerging issues in west coast fisheries, including trawl fisheries bycatch and line strikes (Jannot et al. 2011).

Several steps have been taken towards designing, implementing, and developing a longline fishery-monitoring scheme to test mitigation measures and gather mortality data (e.g., Gilman 2001, Gilman et al. 2005). This research continues in Hawaii (Gilman et al. 2003, 2007) and elsewhere in the North Pacific (Sato et al. 2012; Gladics et al. 2017). Additionally, these findings have stimulated changes in the best practices recommended by ACAP and WCPFC, which are sometimes not compatible with those used in the Hawaiian longline fishery.

Some comparative studies with Japanese BFAL and Hawaiian LAAL have been completed which involve tracking birds and describing their habitat use patterns (Kawakami et al. 2006) and characterizing overlap and mortality in longline fisheries (see Inoue et al., this report).

Finally, a follow-up Workshop on Albatross and Petrel Mortality from Longline Fishing was held in May 2000, as part of the Second International Albatross Conference in Honolulu, Hawaii. This workshop, attended by approximately 75 biologists, resource managers, and conservationists from many countries reviewed the effects of longlining on albatrosses and petrels on a global scale (Cooper 2000).

Trends in BFAL interactions with the Hawaii longline fishery (2001–2014)

The Hawaii longline fishery has been required to use seabird mitigation measures under the Pacific Pelagic Fishery Management Plan (current Fishery Ecosystem Plan, or FEP) since 2001. Seabird interactions are monitored through the National Marine Fisheries Service (NMFS) Pacific Islands Regional Office (PIRO) Observer Program, with the shallow-set component of the fishery monitored at 100% coverage, and the deep-set component monitored at approximately 20% coverage annually.

Research conducted aboard commercial vessels in 2002–2003 assessed the effectiveness of four methods for avoiding incidental seabird capture in the Hawaii DSLL: an underwater setting chute, placing branch line weights within 1 meter of the hook, blue-dyed bait, and side-setting (Gilman et al. 2003, 2005, 2007). These studies revealed that side-setting was the most effective seabird avoidance method and provided substantial operational benefits over the use of blue-dyed bait. Additionally, standardized protocols were developed to enable improved assessments of seabird avoidance methods and the estimation of albatross abundance during longline sets. Starting in October 2004, U.S. National Marine Fisheries Service (NMFS) fishery observers began conducting seabird scan counts during both setting and hauling operations (Gilman et al. 2016). Observers estimate the (low, medium, high) number of individuals of each seabird species within 137 m of the vessel during setting and hauling by conducting a visual scan of 360° around the vessel (NMFS, 2010).

As a result of these advances, albatross bycatch was greatly reduced by 2004 (Gilman et al. 2005, 2008). The analysis of fishery observer records from tuna-targeting DSLL sets before (May 2000–June 2001) and after (June 2001–September 2007) the regulations were implemented north of 23ºN latitude revealed a 67% (95% CI, 62 to 72) reduction in the standardized seabird catch rate after June 2001. While longline sets used four possible combinations of avoidance measures, three of them (side-setting, deploying heavier weights [60 g] attached to the branch line within 1 m of the hook, and using treated bait [thawed and dyed blue]) decreased bycatch rates. However, the seasonal (by quarter) and spatial (latitude/longitude) distribution of fishing effort, and the timing (diel cycle) of the start of the set were also significant factors affecting albatross bycatch rates, suggesting that the at-sea distribution and behavior of the birds influence their bycatch rates (Gilman et al. 2008).

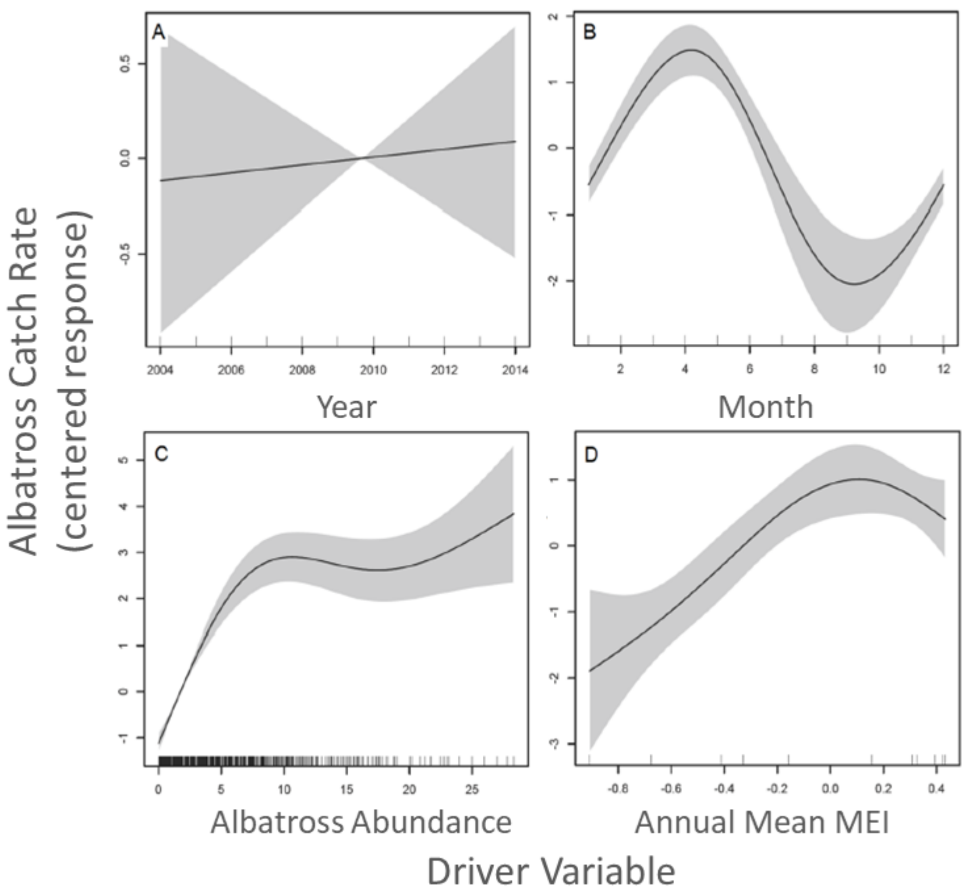
While regulations to mitigate seabird bycatch were first adopted in 2001, the most recent amendment in 2006 defined two alternative suites of seabird bycatch mitigation methods. Deep-setting vessels are required to use one of these two suites of measures when fishing north of 23° N. latitude. Vessels can set gear from the side of the vessel; set the mainline and mount a line shooter, if used, 1 m from the stern corner; deploy a bird curtain aft of the line shooter that meets regulatory design specifications; and use a minimum of 45 g weights attached within 1 m of the hook, referred to hereafter as the suite of measures that includes side setting. Alternatively, vessels can discharge fish, offal, or spent bait with all fishhooks removed, from the opposite side of the vessel where gear is being set or hauled when seabirds are present; use thawed and blue-dyed bait; use a mainline line shooter; and use a minimum of 45 g weights attached within 1 m of the hook. Overall, since seabird regulations were introduced in 2001, the seabird catch rate has declined by 74% (Gilman et al. 2016).

The observer coverage in the Hawaii DSLL tuna fishery has also increased over time; from about 4% coverage from 1994 to 2000, to about 20% since 2001. These observer data are expanded to produce annual estimates of fleet-wide seabird catch levels. A recent analysis of these data, spanning from 2004 to 2013, revealed a significant increase in the estimated raised number of seabirds caught per year, based on a linear regression model ($R^2 = 0.85$). On average, an estimated 210 seabirds (± 92, 95% C.I.) were captured by the DSLL fishery annually during this period (Gilman et al. 2016).

Further analyses to interpret this increase in bycatch revealed increasing trends in both nominal seabird catch rates (birds caught per 1000 hooks) and fishing effort (hooks deployed) between 2004 and 2013. The annual nominal seabird catch rate, which averaged 0.005 seabird captures per 1000 hooks (± 0.002, 95% C.I.) from 2004 to 2013, increased by 0.001 captures per 1000 hooks per year based on a linear regression model ($p < 0.001$, $R^2 = 0.88$). The number of hooks set per year also increased significantly, by about 1 million hooks per year, based on a linear regression model ($p < 0.001$, $R^2 = 0.84$) (Gilman et al. 2016, NMFS 2018). Together, these results suggest that the annual seabird catch levels have increased over the past decade (2004–2013) due to a combination of higher fishing effort and higher nominal seabird catch rates (Gilman et al. 2016).

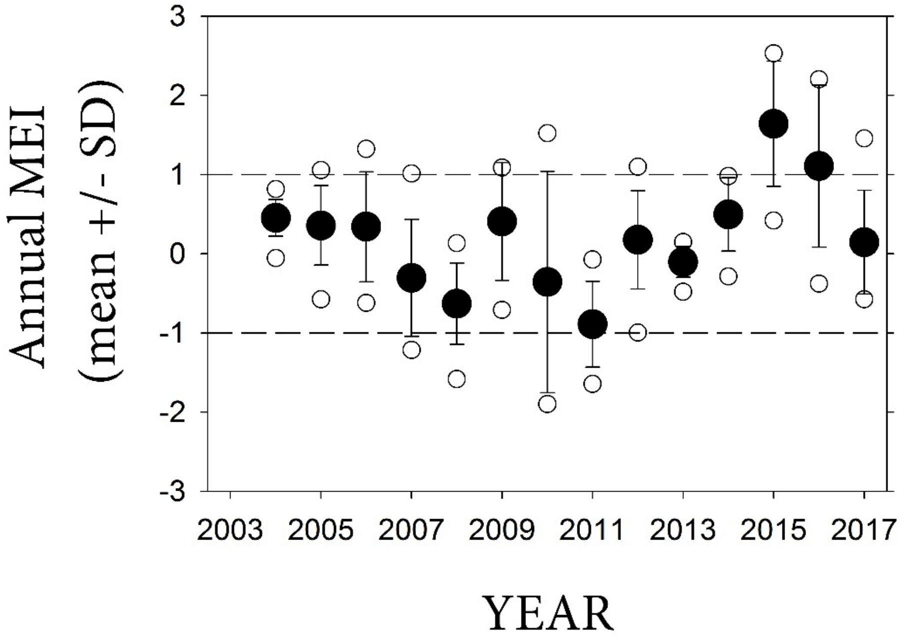
To identify the factors and covariates affecting albatross bycatch, Gilman and colleagues (2016) analyzed DSLL fishing sets between October 2004 and May 2014 and considered a broad range of temporal/spatial patterns, environmental drivers, and fishing gear/practices. Overall, eight explanatory variables had a significant effect on albatross bycatch: time (year, month), location (latitude, longitude), albatross abundance at the vessel (albatross density during setting and hauling), setting approach (side vs. stern), bait type (blue-dyed vs. untreated), and the annual average Multivariate El Niño Index (MEI), a metric of the El Niño Southern Oscillation (ENSO) (Wolter and Timlin 2011).

While the model of Gilman et al. (2016) did not find a significant increase based on the term "year," the albatross bycatch rate did increase during years of higher annual mean MEI values. Additionally, the model documented a significant seasonal trend, with higher catch rates during the first two quarters (January–June), a peak in late spring (March–May), and a minimum in late summer/early fall (August–October). The model also highlighted spatial gradients, with higher catch rates in the northwest and lower bycatch rates off the west coast of North America (east of 145ºW) and to the southwest of the main Hawaiian Islands (west of 160ºW). Albatross density had a positive non-linear influence on bycatch rates, which leveled off after a mean of 5–10 birds were sighted during setting/hauling. Finally, while both mitigation measures (treated bait and side-setting) lead to lower bycatch rates, the random effect "vessel" was also significant. Together, these results highlighted significant spatial and temporal patterns, with the highest catch rates during late spring and to the northwest of the main Hawaiian Islands.



Once these factors were accounted for, albatross capture risk was higher in three years (2007, 2008, 2010) with positive MEI conditions. Additionally, the significant trend in the number of albatross attending vessels may also have contributed to the increasing nominal catch rate (Gilman et al. 2016). This study also documented interannual spatial changes, evident as significant year interactions with latitude and longitude, and a significant random “vessel” effect.

The higher albatross interaction rates observed during 2015 and 2016 motivated the current workshop to explore the potential links between ocean conditions and albatross longline interactions and the unresolved patterns highlighted by Gilman et al. (2016). In particular, the period of positive MEI values between the fall of 2014 and the summer of 2016 provided a natural experiment to test whether the observed pattern documented by Gilman et al. (2016) persisted during a strong El Niño event (Figure 3).



BFAL population status and trends (2001–2015)

The most recent BFAL population assessment, spanning from 1923 to 2005, concluded that the species was stable or increasing, that density-dependent processes may be stabilizing the population, and that current fisheries bycatch levels were sustainable (Arata et al. 2009). While this assessment was inconsistent with population viability analyses based on limited survivorship data (Lebreton and Véran 2013), it provided the justification for IUCN's decisions to down-list the species from Endangered to Vulnerable in 2012, and to Near Threatened in 2013, where it has remained thereafter (BirdLife Datazone 2017).

Bakker and colleagues (2018) re-assessed the status of the species using a population viability approach based on a stochastic demographic matrix model to investigate: i) the potential for the skipping behavior of breeders to create apparent density dependence in nest counts, ii) the inherent limitations to assessing population trends from nest counts and the implications for evaluating impacts from fisheries bycatch, including calculating Potential Biological Removal (PBR) values, and iii) the relative importance of at-sea versus on-island threats to population viability. Overall, the results of this status assessment suggested that BFAL population growth appears to be limited by fisheries bycatch.

The demographic model of Bakker et al. (2018) recreated the BFAL population trend (2001–2015) assuming bycatch affected only after-hatch-year birds and was distributed among age classes according to their relative abundance in the population. Moreover, due to the lack of updated longline fisheries data, bycatch mortality subsequent to 2005 was assumed equal to 2005 levels (Arata et al. 2009). Additionally, the demographic model applied a range of bycatch mortality rates (x 0, 0.5, 1.0, 1.5, 2, 2.5, 3) expressed in relation to the 2005 mortality rates, ranging from a "no bycatch" scenario (x 0) to a highest bycatch scenario (x 3), where x 1 represents the estimated 2005 rate. Finally, the demographic model simulated the potential impacts of changing intensity/frequency of storm events and the benefits of eradicating the invasive plant *Verbesina encelioides* (golden crownbeard) on Midway and Kure atolls. Verbesina spread across several breeding islands in the late twentieth century and impacts albatross productivity by overgrowing their nest sites. Additionally, thick stands can lower chick survival by inhibiting their fledging or entangling them (Feenstra and Clements 2008, VanderWerf 2012).

The BFAL demographic model of Bakker et al. (2018) predicted recent count data (2001–2015) reasonably well, with the population trajectories assuming the high bycatch scenario approximating the observed trends more closely (Figure 4). Overall, the model's predicted yearly stochastic population growth rate was 2.7% (mean λ_t from 2001 through 2015 = 1.027), assuming the high bycatch scenario and the permanent *Verbesina* control scenario. For reference, the deterministic growth rate for a modelled population not experiencing any bycatch mortality, *Verbesina* impacts, or storm-related effects on reproduction was 6.5% (λ = 1.065). Overall, increasing storm effects on reproduction had only modest effects on the BFAL population, with significant increases in both the frequency and the extent of storms required to produce a large decrease in growth rates.

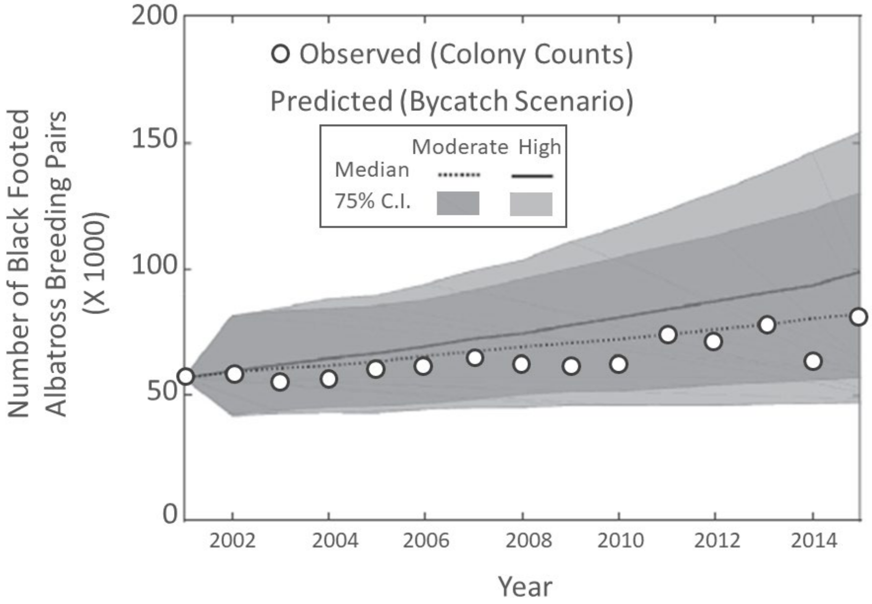


Figure 4. Observed and predicted BFAL breeding population size from yearly colony counts and a stochastic demographic model including the effects of moderate and high fisheries bycatch. Median predictions (lines) and 75% confidence intervals (shaded areas) were based on 5,000 model iterations. Figure modified from Bakker et al. 2018.

Bakker and colleagues (2018) also recommended a cautionary management approach because detecting population declines from nest counts could take decades. Ultimately, their demographic analyses highlight the inherent difficulties in assessing population status and trends in albatross species using incomplete colony-based counts and demographic data. These uncertainties further motivated the current workshop to explore the potential population-level implications of bycatch in the DSLL fishery.

Objectives and Activities of the Workshop

In response to the recent trend in albatross-fishery interactions (Gilman et al. 2016), the Council (WPRFMC), at its 166th Meeting in June 2016, recommended research on the at-sea foraging behavior of albatrosses to improve understanding of their interaction rates in the Hawaii deep-set longline (DSLL) fishery. Recognizing that the increase in albatross captures may be driven by non-fishery factors, the Council also directed its Plan Team and Protected Species Advisory Committee to continue monitoring interactions through the FEP Stock Assessment and Fishery Evaluation (SAFE) report to detect future changes in albatross interactions that may be attributed to fishing operations.

The Council convened a workshop on 7–9 November 2017, to explore the potential drivers and implications of the higher albatross-fishery interaction rates observed in 2015–2016, in the context of longer-term oceanographic variability, shifts in fishery effort and distribution, changes in albatross at-sea distribution, and albatross demography and population trends. More specifically, the workshop focused on four objectives:

1. review recent increased interactions in the Hawaii longline fishery;

2. explore possible factors responsible for this increase;

3. evaluate albatross population impacts; and

4. provide input for future data collection, analyses, and modeling.

To this end, workshop participants (Figure 5) addressed the following questions:

- Review recent conditions (2015–2016) in a longer-term context (2004–2016), concerning: (i) the oceanographic setting; (ii) longline fishing effort, distribution, and operational characteristics; (iii) albatross distributions; (iv) albatross breeding population size and success; and (v) albatross bycatch composition by age/sex.

- Investigate the influence of the following factors on albatross-fishery interactions: (i) oceanographic variability; (ii) longline fishing effort, distribution, and other operational characteristics; and (iii) albatross at-sea distributions.

- Explore how albatross demographic parameters (survivorship, breeding probability, reproductive success) vary in response to the dynamics of the marine environment and the fishery, including: (i) oceanographic changes; (ii) shifts in longline effort and distribution; and (iii) changes in albatross at-sea distributions.

- Evaluate the population-level impacts of these interactions by modeling how albatross populations respond to changes in demographic parameters, bycatch rates, and the composition of the bycatch composition by age/sex.

- Consider the creation of integrated models and assessments capable of merging the available population data (number of breeders, breeding success, capture-recapture data) with fishery-dependent information (effort and interaction rates, bycatch composition by age/sex).

Summary of Workshop Outcomes

To facilitate the workshop's activities, the steering committee devised two complementary focal areas: the risk factors affecting albatross-fisheries interactions and the potential demographic implications of those interactions for the BFAL population. While these focal areas inform each other, they rely on different data sets and analytical approaches. Thus, while this summary addresses these findings and outcomes separately, it also attempts to integrate and synthesize these perspectives.

Factors Affecting Albatross Bycatch

Exploratory analyses and information presented at the workshop suggested that the higher albatross interaction rates in 2015–2016 are largely explained by environmental conditions associated with the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). During quarter 1 of years with positive PDO and ENSO conditions (2015, 2016), winds north of 25°N latitude switch from trades to westerlies, resulting in more productive surface waters in the fishing grounds during quarters 1 and 2, and an apparent eastward shift in BFAL distributions into the fishing grounds. The Transition Zone Chlorophyll Front (TZCF), an important foraging habitat for BFAL, also shifted south into the northern edge of the fishing grounds. Together, the east-west changes in the wind field, coupled with the southward shift of the oceanographic domains, lead to greater spatial overlap between foraging BFAL and the deep-set long line fishery at a time when the birds are provisioning their chicks at breeding colonies.

Changes in the spatial distribution of the fishing effort and mitigation measures during quarters 1 and 2 were also examined, but they did not differ significantly in 2015–2016 from those observed during the earlier years (2006–2017). Interestingly, while fishing effort has shifted further east during quarter 3 in recent years, this is not the time period of high albatross-fishery interactions. Yet fleet dynamics (the latitude, longitude, and seasonality of fishing effort distributions) alone did not capture the recent increase in BFAL interactions; the peak interaction rates observed during 2015–2016 were captured by PDO and local oceanographic conditions (wind, SST, Chl a). While workshop participants discussed BFAL at-sea movements from colony-based tracking, it was impossible to analyze albatross distribution during 2015–2016 due to a lack of tracking data. Following the workshop, an analysis of GPS location data for BFAL tagged at Tern Island between 2006 and 2015 compared the amount of time birds spent traveling/foraging across different latitude bands during positive and negative PDO phases (Wren et al. 2019).[1]

Updated analyses of BFAL population trends and reproductive dynamics explored those conditions that may have increased fishery interactions during 2015–2016. Namely, a growing BFAL population could lead to a higher nominal fishery interaction rate. Additionally, fishery interactions in the vicinity of breeding colonies may increase during years with unusually large numbers of breeding birds. While these analyses were unable to analyze albatross survivorship

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[1] This analysis, which involved 130 tracks from 48 individual BFAL tagged at Tern Island between November and March (2006–2015), compared the amount of time the tagged birds spent traveling/foraging across different latitude bands during positive and negative PDO phases. It showed that BFAL spent 25% more time south of 30°N during positive PDO years (66%) compared to during negative PDO years (52%).

data from 2015–2016, there was no evidence of anomalous counts and reproductive success at Midway Island. Furthermore, despite recent data gaps at several colonies (Laysan Island, French Frigate Shoals [FFS]), the analysis of the number of breeding BFAL at the three largest colonies (Midway, Laysan, FFS), which together account for 79% of the world population, did not revealed a long-term trend (1983–2017). However, a shorter-term (2004–2017) time series from Midway Island, the only colony with demographic monitoring during 2015–2016, revealed a concurrent increase in the counts of breeding birds and a decrease in their reproductive success. While the sign and magnitude of the documented trends were influenced by the duration and timing of the analyzed time series, it is undeniable that there is substantial year-to-year variability in the number of birds attempting to breed and their reproductive success.

Finally, the analysis of the bycatch composition during the two periods with the highest number of bycaught birds revealed contrasting results during the two focal years: Immature birds were most numerous in May–July of 2015, and mature birds were most numerous in January–March of 2016. Interestingly, male bycatch consistently occurred farther east than female bycatch, suggesting a longitudinal separation of the two sexes at-sea. Yet the sex ratio of the bycaught birds, on average, did not differ from the expectation (1:1) despite seasonal and interannual variability in the proportion of males and females in the bycatch. While this analysis revealed that the demographic composition of bycatch during the two periods of peak observed interactions differed from the long-term average (2006–2016), there were no consistent biases that could explain the higher interaction rates observed during 2015–2016.

Together, the exploratory analyses presented at the workshop underscore the importance of considering short-term (year-to-year) and long-term (decadal) oceanographic variability when interpreting the magnitude and drivers of fisheries bycatch. Namely, BFAL interaction rates, which had increased gradually between 2004 and 2014 (Gilman et al. 2016), peaked during 2015–2016 due to the synergistic influence of short-term and long-term environmental conditions. Considering the phasing of PDO and ENSO, it is important to note that 2011 and 2012 were La Niña and negative PDO, while 2015 and 2016 were El Niño and positive PDO. Thus, the shift in large-scale oceanographic conditions (PDO and ENSO) from 2011 to 2016 likely contributed the observed long-term increase in BFAL bycatch. This information can help managers envision future interaction rates under varying environmental conditions. Namely, because the PDO operates on decadal time scales, the high levels of BFAL sightings at longline vessels and fishery interactions documented in 2015–2016 may persist for many years.

In the first two quarters of 2017, 73 BFAL and 38 LAAL were observed bycaught in the Hawaii DSLL fishery. Overall, 97 BFAL were bycaught in the fishery in 2017, which is the third highest observed number after 2015 and 2016 (WPRFMC 2018).

Demographic Implications of Albatross Bycatch

A critical aspect needed for linking bycatch to population-level consequences involves quantifying the demographic composition of the bycatch. To this end, the analysis of the age and sex of BFAL taken incidentally by longline vessels and sampled by fishery observers documented a significant deviation in the age composition of the bycatch, with a larger proportion (79.4%) of mature birds (age > 4 years) and a smaller proportion (20.6%) of immature birds (age ≤ 4 years), compared with the stable age distribution (SAD) derived from a Leslie matrix population model. This result contrasts with the pattern previously documented during the 1998 BFAL population workshop, where most bycaught birds were immatures. Overall, the updated model results indicate that BFAL population growth appears to be limited by fisheries bycatch.

BFAL demographic rates (survivorship, skipping) during 2015–2016 could not be analyzed due to the need to continue analyzing the resighting data through 2019 to obtain robust estimates. Thus, even though there is evidence for variability in the year-to-year demographic rates, no trends have been analyzed, to date. A stage-based Leslie matrix model based on historical demographic rates (from 1980 to 2004) and 2005 bycatch rates suggests the population is slowly growing at a rate of 3% per year ($\lambda = 1.030$). Different model scenarios explored as part of the workshop highlighted that continued high bycatch rates in the Hawaii DSLL fishery cannot reverse the BFAL positive population growth. However, if these high bycatch rates are occurring in the other international longline fisheries that operate in the North Pacific, the BFAL population will decline. This result highlights the importance of working collaboratively with other U.S. and international fisheries in the subtropical and sub-arctic North Pacific to quantify the magnitude and population-level impacts of longline fisheries bycatch on this species.

Summary of Workshop Presentations and Discussions

To facilitate in-depth discussions, the morning of Day 1 was devoted to introducing the Hawaii longline fishery, and the natural history and fishery interactions of BFAL, starting with an overview of the Hawaii longline fishery (Dalzell et al., this report), a historical perspective of albatross-fishery interactions in the DSLL fishery (Ishizaki and Ellgen, this report), a synthesis of albatross risk factors in the DSLL fishery (Gilman et al. 2016), a synthesis of NWHI albatross population trends (Flint and Fraiola, this report), and a summary of BFAL at-sea distributions (Shaffer et al., this report). Following this background section, workshop presentations and discussions were organized around two complementary focus areas: (i) the factors affecting albatross-fisheries interactions (Day 1), and (ii) the potential demographic implications of those interactions for the BFAL population (Day 2). Extended abstracts of these presentations are included in this report.

Background and Overview

The Hawaii deep-set longline fishery (DSLL) operates north and south of the Hawaii Archipelago, with the shallow-setting swordfish fishery operating predominantly to the north and east of the fishing grounds. The tuna-targeting DSLL fishery accounts for 96% of the fishing effort. The number of hooks has been increasing since 2010, with 52 million hooks set in 2016. The Hawaii longline fishery is managed under the WPRFMC Pelagic Fisheries Ecosystem Plan (FEP), which specifies the measures to reduce interactions with protected species, including seabirds (Dalzell et al., this report). Seabird interactions are monitored through the NMFS Pacific Islands Regional Office (PIRO) Observer Program, with the DSLL fishery monitored at a minimum of 20% coverage annually. The numbers of observed albatross interactions are summarized and published annually as part of PIRO Seabird Annual Reports[2] and the Pelagic FEP SAFE Report[3] (Ishizaki and Ellgen, this report).

In the last decade (2004–2014), observer records have documented an increasing trend in albatross interactions (Ishizaki and Ellgen, this report). A recent analysis conducted by Gilman and colleagues (2016) using data from October 2004 to May 2014, revealed that albatross interaction rates have significantly increased over time, especially during years of higher annual mean Multivariate El Niño Index (MEI) values, suggesting that oceanographic changes have contributed to that trend. This analysis also showed a significant increasing trend in the number of albatrosses attending fishing vessels which may have contributed to the increasing catch rates. The higher interaction rates observed during the 2015–2016 El Niño event (Ishizaki and Ellgen, this report) further underscore the potential links between ocean conditions and albatross-longline interactions.

Albatross populations are monitored using time series of the number of active nests or breeding pairs at multiple monitoring sites. Using the most recent counts from the 2017 hatch year, the world-wide BFAL population was estimated at 70,096 breeding pairs. The combined BFAL counts from the three monitored breeding sites on the NWHI (Midway Island, Laysan Island, and

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[2] https://www.fisheries.noaa.gov/resource/document/seabird-interactions-and-mitigation-efforts-hawaii-longline-fisheries-annual
[3] http://www.wpcouncil.org/annual-reports/

French Frigate Shoals), which together account for over 79% of the world-wide population, have remained stable during the 34-year period spanning from 1983 to 2017, with no statistically significant trends (Flint and Fraiola, this report).

Published tracking data of BFAL breeding at three sites in the NHWI (French Frigate Shoals, Midway Island, and Kure Atoll) suggest that BFAL at-sea distribution and movement patterns vary according to the phase of the breeding season. Longer foraging trips take place during the incubation and the chick-rearing periods, and shorter trips occur during the chick-guarding (or brooding) period. Furthermore, tagging studies in the NWHI suggest population-level differences in distribution among BFAL colonies; birds from French Frigate Shoals show the greatest spatial overlap with areas used by the DSLL fishery (Shaffer et al., this report). Nevertheless, substantial knowledge gaps remain concerning sex differences in distribution during the breeding and post-breeding periods, the distributions of juveniles, and the movements of BFAL from unstudied breeding populations (e.g., Laysan Island).

A participant asked whether the BFAL caught in the Hawaii longline fishery are associated with a particular colony or whether all colonies are represented in the bycatch proportionally to the number of breeding birds. While anecdotal banding return data suggest that most fishery returns are birds banded at French Frigate Shoals, where up to 80% of the yearly band recoveries originate (USFWS), these results are difficult to interpret due to the lack of consistent and widespread banding effort (number of birds banded at different colonies over time) (Russell et al., this report).

Albatross catch rates increased significantly when more birds were present at fishing vessels, especially during years of higher mean MEI values. This suggests that decreasing ocean productivity may have contributed to both the observed increasing trends in seabird attendance at fishing vessels and nominal seabird catch rate (Gilman et al. 2016).

Group discussions following the overview presentations focused on two broad topics: (i) the potential influence of specific practices and mitigation measures on BFAL-fisheries interactions, and (ii) the implications of changing BFAL distributions and behavior on fishery interactions. Altogether these presentations and discussions highlighted the dynamic nature of longline fisheries and albatross distributions and the importance of understanding how fishing practices, bycatch mitigation measures, and fisher behavior modulate the influence of environmental drivers on the rates of fishery interactions and bycatch.

Regarding longline fishing practices and gear, recent analyses of the DSLL fishery revealed that blue-dyed bait and side-setting lead to lower seabird bycatch rates (Gilman et al. 2016). Participants discussed whether there are real economic incentives for fishermen to use these seabird mitigation measures (e.g., reducing bait loss and therefore potentially increasing catch), or whether fishermen merely consider these seabird mitigation measures a mandate that must be adhered to. Participants also noted that, while fishermen have incentive to ensure there is bait on every hook, bait loss due to false killer whales (*Pseudorca crassidens*) is of greater concern than bait loss due to seabirds. Nevertheless, the participants suggested that some seabird mitigation measures, such as weights, may have operational benefits by reducing tangles. Moreover, shallow-set operators believe that offal discard practices are a highly effective seabird mitigation measure. Altogether these discussions highlight the importance of understanding the perception of anglers towards these mandated mitigation measures and their adoption in the fishery. Workshop participants discussed the need to consider the “human factor,” noting that the attitude and behavior of individual vessel operators and their crews may affect albatross-fishery interaction rates. In particular, the experience and awareness of individual vessel operators may influence their behavior, especially as some operators who joined the fishery recently may not be familiar with the history of litigation with protected species interactions. This topic was further explored in a working group discussion on the third day (see working group 2 summary).

Participants also discussed whether the density of albatrosses around the vessel may be related to the use of strategic offal discards. It was noted that all vessels discard offal during hauling, and the observer data indicate all vessels comply with this measure. While strategic offal discards may be effective in reducing interactions in the short term, their potential long-term impacts on bycatch rates due to albatross learning behavior is unknown. This discussion highlighted the need to understand if certain operational factors increase the attractiveness of fishing vessels to BFAL. Nevertheless, Gilman and colleagues (2016) showed that the number of BFALs attending DSLL vessels was not related to five operational variables: branch line weight amount, leader length, offal and spent bait discharge practices during setting and hauling, or hook shape and size.

Following these background talks, the workshop presentations and discussions were organized around two complementary focal areas: the risk factors affecting albatross-fishery interactions (Day 1), and the potential demographic implications of those interactions for the BFAL population (Day 2).

Factors Affecting Albatross Bycatch

Several exploratory analyses and reviews were conducted in advance of the workshop to inform discussions on possible factors influencing albatross interactions in the Hawaii deep-set longline fishery with respect to the higher number of interactions observed in the fishery since 2015. These analyses were intended to build upon earlier work by Gilman et al. (2016) with a focus on comparing BFAL interactions before and after 2015. These analyses involved the influence of oceanography and fleet dynamics on albatross interactions (Wren and Polovina, this report), the demographic characteristics of BFAL interacting with the fishery based on necropsy and banding data (Russell et al., this report), and BFAL reproductive dynamics (Hyrenbach et al., this report). Extended abstracts of these analyses are included in this report.

As part of their synthesis, presenters addressed four questions pertaining to recent conditions (2015–2016) in the context of longer-term trends (2004–2016). The findings from the review of the available information and the exploratory analyses are summarized in Table 1.

Table 1. Summary of workshop findings concerning the factors affecting BFAL interactions and bycatch in the Hawaii DSLL fishery.

Research Questions	**Conditions during 2015–2016:** *Did observations suggest that 2015 and 2016 were unusual? How?* *What factors might be responsible for these anomalies?*	**Long-term (2004–2016) Trends:** *Did observations suggest any long-term trends? Over what time period?* *What factors might be responsible for these trends?*
Oceanography	YES. Positive PDO and MEI, resulting in shift of easterlies to westerlies in Q1, producing more productive (higher chlorophyll) DSLL fishing grounds in Q1 and Q2.	YES. PDO has a decadal pattern.
Fleet Dynamics	NO. Higher interaction rates in 2015 and 2016 due to stronger and more southerly westerlies, cooler water, and higher chlorophyll (positive PDO). Fleet dynamics (latitude, longitude, seasonality) alone did not capture the recent increase in interactions (2015–2016). The peaks in 2015 and 2016 were captured by a model including PDO and local oceanographic conditions (westerlies, SST, Chl).	Interaction rates increased during 2006–2014 (Gilman et al. 2016). Gradual long-term (2006–2014) increase in interactions, followed by a larger spike (2015–2016). The analysis focused specifically on the response to PDO and ENSO. 2011 and 2012 were La Niña and negative PDO, while 2015 and 2016 were El Niño and positive PDO. The temporal shift in PDO and ENSO from 2011 to 2016 would partially contribute to this long-term trend.
Albatross Distributions from Observer Sightings	BFAL distribution shifts eastward and becomes latitudinally compressed during positive PDO/MEI conditions, compared to during negative PDO/MEI conditions and long-term climatology (2006–2016).	Long-term climatology (2006–2016) shows a broader longitudinal distribution, more northerly than in 2015–2016.

Research Questions	**Conditions during 2015–2016:** *Did observations suggest that 2015 and 2016 were unusual? How?* *What factors might be responsible for these anomalies?*	**Long-term (2004–2016) Trends:** *Did observations suggest any long-term trends? Over what time period?* *What factors might be responsible for these trends?*
Albatross Abundance at Breeding Colonies	No unusual numbers of BFALs attempting to nest in 2015. NOTE: For all 8 Laysan albatross sites counted in HY 2014–2016, the numbers in the colony increased by an average of 87% in HY 2015 and declined by an average of 31% the following year.	No long-term trend (1983–2017) in number of BFAL pairs attempting to breed at three NWHI colonies (Midway-Laysan-FFS) accounting for 79% of the world population.
Albatross Reproductive Dynamics	No anomalous reproductive success and colony counts of breeding BFAL (Midway).	Midway: • Counts of breeding BFAL have increased (2004–2017) • Reproductive Success has decreased (2004–2017) FFS: • Counts of breeding BFAL correlated with PC3 (SST, PDO) (1980–2011)
Bycatch Composition	The seasonality and composition of the bycatch was markedly different in 2015 and 2016. There was sex-based spatial segregation in both years. In 2015: Highest BFAL number caught in Q2 (May–July). Higher proportion of immature birds. Male interactions occur father east. In 2016: Highest BFAL number caught in Q1 (January–March). Higher proportion of mature birds. Male interactions occur father east.	Sex ratio of bycatch does not differ from 1:1. Maturity status ratio (mature/immature) differs from population stable age distribution (SAD). Higher proportion of mature birds (79.4%) than immature birds (20.6%) caught in Hawaii DSLL fishery. Bycatch composition (by sex and age classes) differed seasonally: • More females in Q1/Q2 • More males in Q3 • More mature birds in Q1 • More immature birds in Q3

Group discussions and clarifications regarding the presentations on the factors influencing BFAL-fisheries interactions are summarized below.

The selection of 2004–2016 as the base-period for the exploratory analyses of the influence of oceanographic variability and fleet dynamics on BFAL interactions rates was discussed in context of longer-term fishery management and interaction trends. While the beginning of the standardized BFAL scans by fishery observers in 2004 (Gilman et al. 2016) determined the start of the time series analyzed for the workshop, participants noted that the observer logs show years with high and low interaction rates before 2004.

The discussion of oceanographic drivers focused on the seasonal and longer-term dynamics of the North Pacific Transition Zone Chlorophyll Front (NPTZCF). While a long-term latitudinal shift is not evident, climate models hypothesize that the subtropical biome will shift northwards. It is likely that the shift has not yet been observed due to the shorter-term variability in the latitudinal position of the NPTZCF induced by the PDO and ENSO.

Participants also discussed the potential influence of conditions at albatross breeding colonies on the magnitude of fisheries interactions. In particular, certain oceanographic factors may be driving years of low albatross reproductive success. Two major El Niño events (1983–1984, 1997–1998) were each followed by a La Niña event and a year of anomalously low BFAL reproductive success (1984, 1999). Participants noted that El Niño years are generally more favorable for albatross breeding in the NWHI than La Niña years (Thorne et al. 2015) and remarked that 1998–1999 and 1984–1985 were strong and weak La Niña events, respectively.

Oceanographic drivers of BFAL reproductive dynamics may be associated with shifts in BFAL foraging behavior that could, in turn, influence fisheries overlap and interactions. Namely, there is evidence that the same oceanographic factors that influence BFAL reproductive success at breeding colonies also affect their at-sea distribution. Previously, Thorne et al. (2015) showed that BFAL reproductive success at FFS from 1981–2012 declined during La Niña years, as evidenced by the negative correlation with the MEI. Moreover, BFAL reproductive success declined during years of warmer SST in the central Pacific, higher North Pacific Gyre Oscillation (NPGO), and when the NPTZCF was located father north and farther away from their breeding colony. Thorne et al. (2016) also documented changes in albatross at-sea distributions associated with El Niño-driven changes in wind patterns. While these results suggest that oceanographic variability affects BFAL foraging movements (Thorne et al. 2016, 2015), it is highly likely that birds from different colonies respond differently— the magnitude of the observed correlations between BFAL reproductive performance and ENSO/PDO likely vary from colony to colony. The patterns documented at FFS may not be as evident at Midway, which is located further northwest and closer to the NPTZCF. Interestingly, Shaffer indicated that the tracking effort at Midway showed more southerly foraging distribution during 2015–2016 as compared to previous years.

Participants also wondered about the impact of breeding success on the following year's reproductive effort and success. It was noted that the timing of reproductive failure may have a bearing on the reproductive effort and success in the following year, whereby failed breeders may not attempt breeding in the following year. Therefore, the magnitude and timing of breeding failures could affect the number of breeding birds and their success during the following year.

While birds may be able to recover from an “early” failure during the incubation and the chick brooding periods (November–February), they may not be able to do so when they experience a “late” breeding failure, during the chick-rearing period (March–June). The magnitude and timing of breeding failures in a given year may also affect BFAL at-sea distribution and overlap with fisheries because failed breeders are not spatially constrained to the breeding colony.

Polovina indicated the possibility that a relationship between reproductive success and fishery interactions exists during the third quarter (July–September) when provisioning BFAL commute from Hawaii to California, where ocean productivity declines during El Niño conditions. Conversely, BFAL are expected to experience better foraging conditions in the Central Pacific Ocean during first and second quarters (January–June) in El Niño years, when the TZCF is located farther south and local ocean productivity is higher. However, it is unknown whether BFAL provisioning their chicks rely more heavily on fishing vessels than non-breeding or failed breeders or whether non-breeders and failed breeders change their at-sea distributions and overlap more with fishing vessels than breeding birds. Nevertheless, the potential link between BFAL reproductive failure and fisheries interactions should be most apparent if breeders that fail early (January–February) shift their distributions into the fishing grounds (farther from colonies and eastwards). Conversely, this mechanism may not be apparent if failed breeders abandon their nests in March–April when breeders and failed breeders are ranging as far as California and the Gulf of Alaska.

Participants discussed the higher proportion of mature birds compared to immature birds in the bycatch, noting that the 1998 workshop suggested a greater number of immature birds caught in the fishery. Based on the necropsy performed on salvaged specimens, the juvenile birds appear to be pre-breeders rather than fledglings, evidenced by their plumage and bursa characteristics (Russell et al., this report). The degree to which juvenile BFAL distributions overlap with the DSLL fishing grounds is unknown due to the limited information on at-sea distributions of fledging chicks and juveniles. Participants noted that findings from the 1998 workshop, which showed a larger number of immature birds, were based on band recoveries, suggesting these finding may have been reflective of banding effort rather than the demographics of the albatrosses prone to bycatch.

In addition to the short-term influence of ENSO on reproductive success, some participants wondered whether BFAL may track other long-term environmental factors, such as the increase in sea surface temperature (SST) and the deepening thermocline. Locally, the expansion of the oligotrophic domain north of Hawaii and the warming of the Central Pacific spatially overlap the longline fishing grounds and the BFAL foraging range (Polovina et al. 2008, Di Lorenzo et al. 2010).

Additionally, given the influence of large-scale environmental variability and the interplay between ocean conditions and BFAL at-sea distribution, these discussions highlighted the importance of considering basin-wide fishery interactions. It is essential to recognize that, because the Hawaii longline fleet is a small portion of a much larger international fleet, observations made in this fishery (e.g., trends and anomalies) represent a small sample of a larger longline fishery. Reconciling these observed patterns and trends across multiple domestic longline fisheries (e.g., pelagic vs demersal) and international pelagic fisheries is essential to interpret these patterns and their potential population-level implications.

Case Studies from Other Fisheries

A presentation examined the factors affecting seabird bycatch in the Japanese longline fishery in the southern and northern hemispheres (Inoue et al., this report). Factors affecting bycatch rates in the southern hemisphere included longitude, latitude, the calendar date (interactions higher in January–March, coinciding with the breeding season), and SST (interactions increased between 9–11°C; related to the polar front, currents, and other oceanographic fronts).

The North Pacific analysis used observer data from longline vessels between 2014 and 2016; the results suggested that BFAL interactions are strongly affected by their preference for warmer SST along the southern part of the Kuroshio extension. Conversely, LAAL interactions occurred in colder water and showed seasonal differences between winter and summer (Inoue et al., this report). The North Pacific analysis was preliminary as the observer program being initiated in 2013, and future work will consider additional operational and environmental factors.

Emerging Conceptual Model and Hypothesis

The exploratory analyses and information presented at the workshop suggested that the higher BFAL interaction rates in 2015–2016, which are correlated with BFAL sightings around Hawaii DSLL vessels, may be largely explained by environmental conditions driven by short-term (ENSO) and long-term (PDO) environmental variability. During years with positive PDO and ENSO conditions (2015, 2016), winds north of 25°N latitude switched from trades to westerlies, resulting in cooler and more productive surface waters in the central North Pacific (150–165°W, 23–30°N) during quarter 1 and quarter 2, and an apparent eastward shift in BFAL distribution into the fishing grounds. Additionally, the concurrent southward shift of the Transition Zone Chlorophyll Front (TZCF), an important foraging habitat for BFAL, into the northern edge of the fishing grounds further mediates the overlap of foraging BFAL with the DSLL fishery. While exploratory analyses also investigated potential changes in the spatial distribution of fishing effort and mitigation measures, they did not differ significantly during quarter 1 and quarter 2 of the two focal years (2015, 2016) compared to the long-term conditions (2004–2016). Moreover, while fishing effort has shifted further east during quarter 3 (July – September) of recent years, this is not a time period of high fishery interactions in the DSLL fishery.

While the oceanographic indices (MEI, PDO) and fleet dynamics, defined by the spatial distribution (latitude, longitude) over time (months, years), showed relatively high explanatory power (74%) of BFAL sightings around DSLL vessels, these factors do not fully explain the higher interaction numbers and rates observed in 2015 and 2016 (Wren and Polovina, this report). Therefore, workshop participants discussed other factors that may influence BFAL abundance around fishing vessels and highlighted three potential drivers: (i) increased BFAL attraction and reliance on vessels (e.g., vessel fishing and mitigation practices, albatross learning behavior), (ii) BFAL aggregation at mesoscale oceanographic features targeted by the DSLL fishery (e.g., eddies, fronts) not included in the exploratory analysis, and (iii) changes in BFAL behavior and distribution driven by breeding population dynamics (e.g., reproductive effort and success). Workshop participants also noted that other factors relating to fishing practices and operations may further drive interactions by changing albatross attraction towards and behavior around vessels.

Discussions regarding potential drivers of BFAL abundance at DSLL vessels highlighted the following key points:

- Previous analysis of albatross interactions with Hawaii DSLL vessels by Gilman et al. (2016) revealed that albatross catch rate increases non-linearly as the density of birds around the vessel increased. While the average albatross density around the vessel during setting and hauling ranged from 0 to 30 birds, there was no significant increase in the catch rate beyond a threshold of 10 birds. This finding suggests that albatross density affects catch rates, likely due to its influence on catchability, but that the influence of local abundance becomes saturated at high albatross densities, possibly caused by changes in the scavenging behavior as a result of intense competition (Gilman et al. 2016). Nevertheless, it is worth noting that BFAL are often not present or occur in low numbers at DSLL vessels. The number of interactions per set varies temporally, with most of the interactions in 2015 occurring in clusters (3–4 per set), while the majority of interactions in 2016 involved up to 2 birds per set (Wren and Polovina, this report).

- Because BFAL and DSLL vessels may be targeting other mesoscale oceanographic features, like eddies and fronts, additional explanatory variables could be used to investigate environmental drivers of BFAL abundance and bycatch. Several metrics could be used to explore the influence of the TZCF, a permanent frontal system which shifts latitude seasonally and in response to ENSO (Wren and Polovina, this report). For instance, the distance to the TZCF, the strength of the TZCF, and the interplay of the TZCF and the 18ºC SST could further explain BFAL abundance and catch rates. Future models could include local wind speed and direction during fishing operations, two environmental factors which likely influence BFAL distribution and foraging behavior by mitigating their local abundance and their ability to target the bait.

- Workshop participants also wondered whether the presence and abundance of other species during longline sets, either target fish (e.g., mahi-mahi in the catch) or other seabirds (e.g., shearwaters in the observer scans), may influence interaction rates. These potential associations may be caused by aggregations at similar oceanographic features (e.g., convergence zones) or interspecific interactions whereby diving shearwaters maintain the sinking baited hooks closer to the surface and within reach of the albatross. This would require quantifying the relationships between BFAL interaction rates and other target and non-target species.

- In addition to local conditions at DSLL vessels, other population-wide factors may influence BFAL abundance/behavior and interaction rates. In particular, BFAL breeding dynamics (number of breeding birds, reproductive success) likely mediate their abundance and distribution at sea. Nevertheless, workshop participants noted that caution should be taken when making predictions regarding breeding sites and overlap with the fishery due to the information gaps concerning the movements of birds from a large NWHI colony (Laysan Island with 24,565 breeding pairs; Flint and Fraiola, this report). Additionally, there is no information about the movements of BFAL from two small MHI colonies (Lehua and Kaula Rock, with 43 breeding pairs; Flint and Fraiola, this report) located farther east and closer to the DSLL longline fishing grounds (Shaffer et al., this report). Furthermore, “poor food” years could be associated not only with low reproductive success, but also with higher albatross attraction to vessels, as birds may rely more heavily on longline bait and discards. Testing this prediction would require quantifying the spatial overlap of BFAL movements with the DSLL fishery during several years of contrasting oceanographic conditions.

- Workshop participants discussed the potential factors influencing BFAL reliance on the Hawaii DSLL fishery and the degree of variability in the attractiveness of individual vessels within the fishery. Because BFAL interact with vessels from many fisheries and countries at-sea, BFAL interactions and catch rates in different fisheries are likely not independent but do influence each other. Thus, BFAL reliance on the Hawaii DSLL fishery is potentially influenced by changes in the operations (effort/distribution/fishing practices/mitigation measures) of all other longline fisheries operating within their range. Therefore, any observed changes in BFAL catch rates in the Hawaii DSLL fishery need to be evaluated within a larger, multi-fishery context. Namely, BFAL interactions in the Hawaii longline fishery may change if, for instance, other fisheries introduce mitigation measures.

- Other management factors may also influence albatross interactions in the Hawaii DSLL longline fishery. For instance, a participant questioned whether the expansion of the Papahānaumokuākea National Marine Monument may have led to higher spatial aggregation of the fishery which in turn may have affected BFAL attendance at longline vessels and interaction rates. The discussion highlighted the difficulty of interpreting the implications of fishery redistributions whereby the number of interactions would be expected to increase if the vessels moved into areas with higher-than-average interaction rates. While the implications of these redistributions are unknown, there is evidence of long-term shifts in fishing effort distributions. In particular, the participants noted that the Hawaii longline fishery is increasingly becoming a high-seas fishery, with a shift of effort outside of the U.S. Exclusive Economic Zone. Moreover, the Hawaii longline bigeye tuna quota closures in the western and central Pacific Ocean have resulted in effort shifting to the eastern Pacific Ocean during the closures, adding to the increasing Hawaii longline effort east of 150°W in recent years.

- Characterizing the degree of individual variability in fishing practices and the application of mitigation measures within the Hawaii DSLL fishery may further help explain the observed variability in albatross interaction rates. The workshop participants highlighted the need to understand whether vessel operators' practices (e.g., setting in areas with large numbers of birds) and experience (e.g., using mitigation measures) influence BFAL catch rates. They specifically questioned whether the use of strategic offal discards as a mitigation measure leads to higher interaction rates in the long term.

- The workshop elicited a discussion regarding the potential for albatross learning behavior associated with longline vessels. The extent to which individual birds specialize in foraging around vessels or learn from positive and negative interactions with vessels is unknown. Field observations during controlled fishing experiments revealed that albatrosses change their vessel-attendance around mitigated/unmitigated sets (Boggs 2001). Moreover, dietary studies using stable isotopes suggested a great deal of individual variability in LAAL, with some individuals having high $\delta^{15}N$ ratios, consistent with a high degree of reliance on fishery association (Edwards et al. 2015). Because similar data are not available for BFAL, additional diet and isotopic studies would help understand the degree to which foraging strategies are a function of season, breeding status, and multi-annual breeding success, factors that likely affect the probability of association with fisheries. Additionally, because BFALs that feed around vessels may have higher reproductive success, the number of birds around vessels may change over time.

Discussions concerning other drivers of BFAL interactions highlighted the following key points:

- Following the discussions about the changing albatross abundance at Hawaii DSLL vessels, workshop participants discussed the potential change in albatross reliance on and foraging behavior at vessels. They noted that the number of seabirds around the vessels could increase competition for access to the bait, leading to more aggressive behavior and higher interaction rates.

- The need to develop approaches for evaluating BFAL foraging behavior and to quantify the degree of individual specialization on attending fishing vessels was reiterated. Participants raised the question of whether diet signatures could be detected in feathers or other tissues using chemical analyses. While trophic level may not provide sufficient specificity due to the high degree of variability in the observed $\delta^{15}N$ ratios, several lines of evidence suggest that birds with higher multi-annual reproductive success were less likely to associate with Hawaii and Alaska longline fisheries (Edwards et al. 2015). Additionally, quantitative fatty acid signature analysis (QFASA) revealed that fisheries-associated diet occurred in both Hawaiian albatross species during the incubation and chick-brood stages. However, while fisheries were not the dominant BFAL food source (contributing < 10% of the total pooled diet), the diets of a few individuals consisted almost entirely of fisheries-derived food, revealing that some birds specialize on foraging at longline vessels (Conners et al. 2018).

- The demographic composition of BFAL bycatch (2006–2016) was characterized by a higher proportion of mature birds compared to immature birds. Necropsies of the retrieved BFAL specimens revealed that the juvenile birds were pre-breeders rather than fledglings, as evidenced by their plumage and bursa characteristics (Russell et al., this report). The participants noted that these findings contrast with the 1998 workshop results which suggested that a greater number of immature birds were caught in the Hawaii longline fishery; this may be more reflective of the banding effort than the demography of the birds prone to bycatch.

- Participants also considered the potential effects of the recent changes in mitigation measures in the DSLL fishery (offal discharge, blue-dyed bait, side-setting) and stressed the need to consider all variables known to influence seabird bycatch rates, including environmental variables and seabird-specific mitigation measures (e.g., time of day of fishing, leader length) in future analyses of BFAL interaction rates.

- At various points in the workshop discussions, participants questioned the effectiveness of seabird bycatch mitigation measures. These discussions focused on strategic offal discards and tori (bird-scaring) lines. Tori lines are not required in the Hawaii longline fishery, which operates in an area with few diving seabirds (e.g., shearwaters), because they are considered impractical and unsuitable due to their tendency to tangle while side-setting. Nevertheless, gear testing in other areas (e.g., Japan), has shown that tori lines are suitable for stern setting (Melvin et al. 2004; Sato et al. 2012).

- The "human factor," previously discussed as a potential driver of BFAL attraction to DSLL vessels, was also considered since the variability in operator experience using mitigation measures may influence BFAL interaction rates. This factor is particularly relevant because the size of the fleet has increased over time, with many new operators joining the fishery. Approximately 20% of captains have only 3–4 years of experience in the Hawaii fishery and, therefore, less experience with seabird interactions compared to more experienced captains. The newer captains may not fully understand the broader population-level consequences of higher interactions. Thus, understanding the changing level of experience of vessel operators was considered a key knowledge gap. While the information from the mandatory Protected Species Workshop may provide some measure of operator experience, quantifying operator awareness may require questionnaires and focus groups.

Demographic Implications of Albatross Bycatch

The second focus area of the workshop entailed quantifying BFAL demographic rates (adult survivorship, probability of skipping breeding) and investigating the potential demographic impacts of the documented fisheries interactions in a broader population-level context. To this end, several presentations on albatross demographic rates (Kendall et al., this report) and BFAL demographic modelling (Bakker and Finkelstein, this report) informed discussions on the potential population-level impacts of the higher fishery interactions in 2015 and 2016 in the Hawaii longline fishery. Presenters providing information on albatross demographic rates and models addressed several questions pertaining to conditions during 2015–2016 and long-term trends as part of their synthesis (Table 2).

Survival and breeding probabilities of BFAL and LAAL at Midway Atoll and Laysan Island were estimated based on a systematic sampling of nesting birds initiated in 2005. Survival, generally high for both species, is slightly higher for LAAL. Nevertheless, LAAL tend to skip breeding more frequently than BFAL, but return to breed the following year with higher probability (Kendall et al., this report).

A recently published demographic model (Bakker et al. 2018) provided the first updated status assessment of BFAL and LAAL since 2009 (Arata et al. 2009). The BFAL demographic model incorporated new data but used historical bycatch estimates from Arata et al. (2009). Overall, the updated model results indicated that BFAL population growth appears to be limited by fisheries bycatch (Bakker and Finkelstein, this report).

BFAL demographic rates (survivorship, skipping) during 2015–2016 could not be analyzed due to the need to continue analyzing the resighting data through 2019 to obtain robust estimates. Thus, even though there is evidence for variability in the year-to-year demographic rates, no trends have been established to date. A stage-based Leslie matrix model based on historical demographic rates (estimated from1980 to 2004) and 2005 bycatch rates suggests the population is slowly growing (with a population growth rate λ= 1.030) (3% population growth per year) (Bakker et al. 2018).

The published BFAL population model was updated in advance of the workshop to incorporate bycatch data from the Hawaii DSLL fishery through 2016. Using the Arata et al. (2009) bycatch estimates for non-Hawaii fisheries and the most recent survival and skipping rates, the updated population model suggests a population that is stable. In fact, the effect of the Hawaii DSLL fishery on the population growth rate (λ) is negligible, even after applying the revised bycatch maturity ratio, with an excess of mature birds. Moreover, assuming the elevated interaction rates observed in 2015–2016 continue in the future, this increase would likely have an imperceptible effect on the population growth if this impact were limited to the Hawaii DSLL fishery. If these elevated interaction rates are applied consistently throughout North Pacific longline fisheries with BFAL bycatch, the population is projected to decline by as much as 95% by 2040. These modeling results highlight the value of updated demographic data from colonies and fisheries and the need for reliable North Pacific-wide bycatch estimates. While these data are not available for international fisheries operating in the central and western North Pacific, observations from Alaska fisheries bycatch suggest that the increase in 2015–2016 is unlikely to be basin-wide (see Working Group 1 Summary). This discussion underscores the need for reliable North Pacific-wide BFAL bycatch estimates.

Table 2. Summary of workshop findings concerning the population-level impacts of Black-footed Albatross Bycatch in the Hawaii DSLL fishery.

Research Questions	**Conditions during 2015–2016:** *Did analyses suggest that higher fishery interactions in 2015 and 2016 had a population-level impact?* *What observations and analyses would be needed to quantify these impacts?*	**Long-term (2004–2016) Trends:** *Did analyses suggest any long-term trends in population abundance, productivity, or demographic rates? What are they? Over what time period?* *What observations and analyses would be needed to quantify these impacts?*
BFAL Survivorship and probability of skipping breeding	No basis for evaluation. Need to continue analysis of resighting data through 2019.	Variability in year-to-year rates; did not analyze for a trend.
BFAL Population Model	NO—If this is a localized event and DSLL 2015–2016 bycatch rates do not continue. YES—If DSLL bycatch rates continue at or above the 2015–2016 level. **Note:** Population impacts increase when sustained bycatch rates from Hawaii DSLL fishery are applied to foreign longline fisheries.	Population growing 3% per year based on 1980–2004 demographic rates and 2005 bycatch rates. More recent survival rate estimates (2012–2014) suggest a population that is stable, not growing. Applying the revised bycatch maturity ratio only to the Hawaii DSLL fishery leads to an imperceptible change. The scenario where the revised bycatch maturity ratio is applied to all longline fisheries results in a larger population decline.

Integrated Population Modeling

The workshop presented a keynote talk on integrated population modeling (IPM) and its application to a variety of seabird populations impacted by climatic variability and fisheries bycatch (Barbraud, this report). IPMs combine multiple data sources into a single framework and provide an approach for investigating links between vital rates and environmental factors. While IPMs offer a number of advantages, including the ability to estimate vital rates in data-poor settings, they are relatively complex to build. Several examples of IPMs applied to seabird populations were showcased in the presentation.

Participants agreed on the need for integrative modeling approaches to explore and evaluate the influence of multiple oceanographic factors and fisheries bycatch on BFAL reproductive dynamics and population trends. Incorporating these drivers into an integrated modelling framework would allow the evaluation of the relative importance of these potential population drivers and their synergistic interactions.

Data for North Pacific albatross are still fairly limited compared to the information used to develop rigorous IPMs for other species (Barbraud, this report). More specifically, the development of a BFAL IPM is inhibited by the paucity of age-specific demographic and at-sea distribution data and will require fishery bycatch data throughout the North Pacific.

Workshop participants discussed the next steps required to move towards an IPM capable of building upon the current BFAL population model and incorporating fisheries data. To this end, several key data gaps must be filled, including improved age-specific data on BFAL demographic rates, distributions and overlap with fisheries, and North Pacific-wide fishery bycatch data. Continued population monitoring remains particularly important, especially at those sites with long-term monitoring (French Frigate Shoals and Laysan Island), to update the existing reproductive success and survivorship data.

Working Group Summaries

Four working groups were convened on the morning of day 3 to explore specific topics in further detail. A summary of each of the working group discussions is included below.

Working Group 1: Dynamics and Bycatch Rates of Other Longline Fisheries

Karen Baird, Myra Finkelstein, Yukiko Inoue, Asuka Ishizaki, MiAe Kim, Daisuke Ochi, Neville Smith

General Discussion

This working group discussed general North Pacific fishery trends to inform the bycatch scenarios used in Bakker and Finkelstein's model update, as well as approaches to estimating North Pacific-wide albatross bycatch levels.

Because Bakker and Finkelstein (this report) used the bycatch estimates in Arata et al. (2009) for non-Hawaii fisheries in the updated model scenarios, the working group discussed these original bycatch data. Arata et al. (2009) included BFAL bycatch estimates in driftnet, pelagic longline, and demersal longline fisheries. Of those, the pelagic longline fishery was the primary fishery contributing to BFAL bycatch in the North Pacific. The working group focused on identifying general pelagic longline fishery trends in the North Pacific Ocean after 2005.

Working group members identified publicly available international pelagic longline data from various sources, including the following:

- WCPFC country reports (seabird bycatch data since 2013; public domain effort data available in 5×5 grids);
- WCPFC public domain bycatch data[4];
- Tuna Fishery Yearbook;
- ISC data;
- U.S. non-Hawaii observer data reports[5].

While not comprehensive, this review of available information on the North Pacific Ocean pelagic longline fisheries operating north of 20 °N suggested that Bakker and Finkelstein's use of Arata et al. (2009) as a baseline for the non-Hawaii longline bycatch may be reasonable. Specifically:

- International longline catch (albacore, bluefin, bigeye) north of 20 °N has generally remained stable since 2005.

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[4] https://www.wcpfc.int/node/29966

[5] https://www.fisheries.noaa.gov/alaska/bycatch/seabird-bycatch-alaska

- WCPFC seabird measures have been required since 2007, with changes in 2012 and thereafter. Small vessel requirements became effective in January 2017. However, implementation at country-level and actual uptake level are unknown.
- WCPFC Japan small vessel observer coverage started in 2013.
- Other uncertainties include:
    - Chinese fleet fishing effort and bycatch; and
    - IATTC fishing effort and bycatch.

Regarding the 2015–2016 BFAL bycatch increase in the Hawaii fishery and whether this spike was consistent across the North Pacific:

- Working group members reviewed recent Alaska fishery observer data and found that there were no substantial changes in 2015–2016 compared to previous years.
- International data are only available since 2013, and do not provide a reliable indication of changes in recent years.

Data Needs and Future Analyses

This working group also discussed steps for estimating North Pacific-wide albatross bycatch using new data and analyses. The main discussion points involved the following:

- Temporal estimation could account for seasonality in bycatch rates. However, seasonality may differ by geographic location and by fishery, depending on the birds' movements and the shifts in fishing effort distributions.
- Information on albatross distributions during the non-breeding season is limited.
- If BFAL (and LAAL) sightings from at-sea surveys are available, they can be used in conjunction with the scan data from fishery observers to model their distributions.
- A working group member inquired about analytical approaches for quantifying bycatch in undocumented fisheries. While group members recognized the inherent difficulties in developing these estimates, they recognized that IPMs could be used to estimate unknown mortality sources, which may include undocumented bycatch.

Next Steps

This working group finished by outlining some key principles and next steps for estimating BFAL bycatch rates in other fisheries:

- A risk assessment approach would allow multiple species to be analyzed using a common framework. Despite the data gaps, key data sets are available to start applying this approach to North Pacific albatrosses.
- Identifying those species for which bycatch estimates are needed is critical for defining the assessment area and for identifying which fisheries to include. Depending on the assessment area, domestic fisheries should be considered in addition to high seas fisheries. To this end, the use of FAO effort statistics is suggested in addition to RFMO effort data.

- Defining the precision of the required bycatch estimates is also critical because it determines the effort needed to generate these estimates and helps to prioritize the research needs.

Working Group 2: Fishing Practices, Gear, and Mitigation; Quantifying the "Human Factor"

Melanie Abecassis, Chris Boggs, Paul Dalzell, Sarah Ellgen, Eric Gilman, Sean Martin, John Peschon, Johanna Wren

This working group discussed those fishing gear and practices that may impact seabird bycatch in the Hawaii DSLL and the potential influence of the "human factor" (the variability in experience or skill amongst vessel operators and crews) on the effectiveness of mitigation measures. These discussions focused on four areas:

- Offal discharge;
- Outreach to Hawaii DSLL fishery crews and captains;
- The relevant experience of captain and crew in the Hawaii DSLL fishery and
- Changes in fishing practices over time that may impact seabird bycatch.

Strategic Offal Discharge

This mitigation measure is practiced in Alaska. The fish are headed and gutted, and the offal is thrown over the opposite side of the boat from where the gear is deployed, attracting birds to the side away from the hooks. Because the Hawaii DSLL fishery does not retain the offal, the working group believes that this does not warrant further investigation.

Outreach to Crews and Captains

The working group members highlighted the need to engage and improve relations with vessel crews and captains regarding seabird bycatch mitigation. It is essential to provide trainings about fishing regulations and mitigation measures, to educate captains about the consequences of bycatch, to determine the resources required for effective communication to the fleet, and to build trust with vessel captains and crews. The working group identified the following next steps:

- Develop translated materials and outreach efforts targeting different ethnic groups engaged in the fishery;
- Deliver protected species workshops to captains and crews;
- Engage the fleet from the Pier 38 NOAA Fisheries office;
- Work with the Hawaii Longline Association to develop a training program for crews.

Evaluate the Experience of Crews and Captains Regarding Seabird Bycatch Mitigation

A better understanding of the relevant experience of captains and crews will help determine whether this factor can impact the effectiveness of mitigation measures and BFAL bycatch.

The working group participants agreed that assessing the knowledge and experience of the operators participating in the Hawaii DSLL fishery and other longline fisheries that use seabird mitigation measures would provide managers with valuable insights. Information for this assessment could come from:

- Logbook data;
- PSW records;
- State fishing licenses;
- Surveying fishermen on their awareness and experience regarding seabirds;
- Engaging vessel operators when records indicate anomalous seabird interactions (several BFAL bycaught in one set) to understand the specific circumstances.

Changes in Fishing Practices Over Time that May Impact Seabird Bycatch

While there may have been few changes in fishing practices and gear between 2014 and 2016, these shifts could influence seabird interactions and bycatch and may warrant further assessment. Future analyses could assess trends in the following fishing practices as potential bycatch drivers:

- The time a set starts in relation to the time of day and diel cycles (twilight) using fishery observer records;
- The duration of the set from fishery observer records;
- The enhanced BFAL attraction to vessels fishing near each other using VMS data. Observer seabird scans could be used to look for higher BFAL densities around clustered vessels.

Working Group 3: Albatross Distribution and Behavior

Jessie Beck, Melanie Brown, Rachael Orben, Jeff Polovina, Tamara Russell, Scott Shaffer

This working group discussed analyses of existing data sets, data needs, and next steps concerning albatross distributions and behavior.

Analyses of Existing Data sets

- In some years, nesting sites may experience trade winds; in other years they may experience westerlies. Analyzing tracking data with fine-scale wind data can reveal whether the bird trajectories change under the two different wind patterns, with a particular focus on the time spent in the Hawaii longline fishing grounds.
- Integrate BFAL sighting and interaction data from fishery observers with vessel monitoring system (VMS) data from fishery vessel locations to investigate the influence of vessel aggregations.
- Merge BFAL tracking data sets with vessel positions to calculate encounter rates. Determine if the birds are moving from vessel to vessel.

- Integrate BFAL sighting, tracking, and interaction data to create a spatial density map and develop a movement model with environmental drivers.
- Develop habitat modelling to fill in gaps of at-sea distributions.
- Compare banding data records with tracked bird movements.
- Analyze tracking data to identify high-use features (e.g., fronts, eddies).
- Use existing data on fatty acids with longline-associated signatures to map locations where tracked birds interacted with vessels. We have movement data from telemetry tracks and diet information from Conner's work.
- Analyze fatty acid signatures from necropsied bycaught birds to test if they had a history of successful fishery interactions before they were caught.

Data Needs

- Collect data on BFAL spatial use and movements. Focus on:
    - Birds from colonies in the Main Hawaiian Islands;
    - Birds from French Frigate Shoals (FFS);
    - Birds that failed during breeding and abandoned (failed breeders);
    - Birds of different age/sex/behavioral states;
    - Colony visitation and foraging behavior of non-breeders (especially fledglings) at colonies and how they overlap with fisheries and with adult distributions.
- Return rates of juveniles to breeding colonies to quantify their survivorship;
- Foraging signature associated with fishery feeding. Are there two foraging modes: birds that rely on fisheries vs. birds that do not rely on fisheries?

Next Steps

- Study BFAL distribution using the following approaches:
    - Use eBird to enhance the understanding of at-sea distributions.
    - Tag birds on the main Hawaiian Islands with metal and colored (darvic) bands.
    - Tag birds that interact with fishing vessels to investigate if they repeated this behavior.
    - Fishery observers can record color-banded birds at fishing vessels. Can cryptic mortality be tracked (injured birds that fly away)?
    - Analyze tracking and diet (isotopic/fatty acid) data to find potential foraging signatures with birds feeding at fishing vessels.
    - Develop spatial models of BFAL movements (by sex, age, behavioral state) in relation to oceanographic conditions.
    - Merge distribution model with bycatch interactions and sightings; use these integrated layers to investigate how the abundance of BFALs influences the interaction and bycatch rates.

  - Combine these data sets to find hotspots of potential interaction zones by mapping probabilities of interactions.
  - Tag FFS birds before they relocate to other colonies.
- Compile information needed for developing an Integrated Population Model:
  - Time spent by BFAL (by sex/age and behavioral state) within specific areas in relation to fishery distributions;
  - Fishing fleet distribution and BFAL overlap;
  - The degree of individual BFAL reliance on fishing vessels to understand potential feeding specialization and bycatch interaction risks.

Working Group 4: Albatross Population Status and Trends

Vickie Bakker, Christophe Barbraud, Milani Chaloupka, Beth Flint, David Hyrenbach, Bill Kendall, Roberta Swift

This working group discussed improvements for monitoring albatross populations and trends in colonies and at-sea.

- *At Colonies:* Improving and augmenting data collection approaches.
  - Colony counts:
    - Use new technologies, like drones, to mitigate impacts on burrowing species (e.g., Bonin Petrel) and to survey inaccessible colonies.
    - Employ repeated surveys to determine the timing of the breeding failure and the loss of nests. This is only feasible during the brooding period when chicks do not move around.
    - Use drone surveys to distinguish between walkers and nesters.
    - Use satellite imagery to obtain counts from inaccessible colonies (e.g., Laysan Island, Tern Island).
    - Study changes in the ratio of breeders to walkers attending colonies throughout the breeding season.
    - Use resighting data to understand the colony visitation behavior of non-breeders (especially fledglings).
    - Develop an Integrated Population Model to improve the total population size estimates, including skipping breeders.
  - Demography plots:
    - Maintain existing demography plots, increase band reading efforts, and document short-term variability using photo quadrats.
    - Continue monitoring yearly survivorship and skipping through the 2018-2019 breeding season to ascertain the rates for the 2015–2016 breeding season.

        - Investigate how representative the demographic plots are of the broader loss of nests and chicks elsewhere in breeding colonies due to storms. Because storm inundation affects chicks, counts before/after storm events could be used to quantify this impact.
        - Consider the environmental variability across plots, regarding exposure to waves, inundation, and the influence of the cooling breeze. Compare nest counts and breeding success in inundation prone areas to plots with high/low wave exposure.
        - Similarly, compare nest counts and breeding success in areas of high heat exposure and in plots without breeze, where birds have died due to over-heating. There is evidence that adult birds have died sitting in nests from heat exposure when the cooling breeze was blocked.
        - Investigate the interannual variability in skipping rates and the observed variation in the number of birds attempting to breed from year to year. Skipping rates, which address the probability of breeding, may depend on oceanographic variability and may respond to lagged conditions. Moreover, skipping rates, which appear to be higher in younger birds, may vary by age and sex.
        - Explore whether BFAL are susceptible to carrying capacity at breeding colonies. While nesting space is not necessarily limiting currently, will that change in the future? Moreover, would higher nesting densities reduce reproductive success?
- *At Sea:* Improving and augmenting the collection of demographic data.
    - Tracking survivorship: There was great interest in developing fishery-independent methods, such as color band resighting and tracking, that do not rely on sightings from fishing vessels or the recovery of bycaught banded birds. These methods can help to: (i) identify the component of the population not susceptible to the fishery based on their at-sea distributions, (ii) document unknown anthropogenic mortality sources, and (iii) calculate demographic rates (e.g., survivorship, skipping) during the prolonged pre-breeding (juveniles) and non-breeding (adults) dispersal at sea.
    - For juveniles, another key approach would entail quantifying survivorship before the birds recruit to breeding colonies to help anticipate population changes. This would involve quantifying the ratio of juvenile: adult birds and band returns (via recaptures/photos).
    - For adults, these observations would help determine whether birds not resighted at colonies are really skipping breeding or have died.

The working group also considered several factors involved in detecting population trends.

- *Confounding Factors*
    - Because other impacts, including contaminants disrupting reproduction, disease (e.g., avian malaria and pox), and plastic ingestion, could inhibit the detection of a

bycatch signal, these potential sources of mortality should be monitored. Several steps are currently being taken to address these impacts:

    - Screening of diseases whenever there are mortality events on colonies by the U.S. Geological Survey (USGS);
    - Bycaught specimen collection and sampling for fat, plastics, and isotopes;
    - Collection of abandoned LAAL eggs by the National Institute of Standards and Technology (NIST) for analysis of pollutants as part of the Seabird Tissue Archival and Monitoring Project (STAMP).

- Additionally, episodic events like storm and tsunami inundation need to be quantified using monitoring and adaptive measures:
    - Photo and satellite quadrats of likely inundation zones could be used to document bird densities early in the breeding season, and these baselines could be used to compare conditions before and after winter storms.
    - Because these events can impact many breeding sites, satellite imagery or airplane overflights could be used to survey colonies after severe inundation events.
- Oceanographic factors, like inter-annual and longer-term changes in ocean productivity and climate, may also affect BFAL demography with built-in temporal lags. In particular, the winter survivorship, the skipping rate, and the reproductive success may vary in response to this oceanographic forcing.
- Because BFAL are susceptible to bycatch in other pelagic/demersal longline and trawl fisheries, a comprehensive assessment will need to incorporate these mortality sources. Some key data gaps and needs involve:
    - Total bycatch mortality: would it be useful to update figure 4 in the Arata et al. (2009) status assessment?
    - Understanding to what extent increased mortality in the Hawaii DSLL fishery may be offset by reductions in other fisheries:
        - Taiwan and Korea dominate effort in the albacore fishery;
        - Kure BFAL overlap with Japanese fisheries in the NW Pacific;
        - Tern Island BFAL commute to the west coast and overlap with demersal fisheries;
        - Midway BFAL likely overlap with fisheries in NW and NE Pacific.
    - Mapping fishing effort distributions across fisheries:
        - Taiwan has published several papers.
        - Japan is sharing data and information.
        - Korea has not provided information.
        - A global composite of 2004 data provided a coarse (5×5 degree grids) snapshot; a North Pacific update would be very useful.

    - IATTC developed summaries during the 1980s for the Eastern Pacific Ocean (EPO), but fisheries distributions have shifted.

Data and Analysis Needs and Next Steps

Workshop discussions identified the following data and analysis needs:

- Determine the relative contribution to overall bycatch from the colonies of banded BFAL. Is FFS disproportionately over-represented in the bycatch?
- Update breeding and reproductive success data from FFS—there may be a disproportionate impact on FFS breeding population from the fishery.
- Long-term population counts need to continue, especially at Midway, where the time series has not been interrupted.
- Continue analysis of albatross demographic data to assess annual survivorship and skipping in 2015–2016, and thereafter.
- Analyze the spatial overlap of BFAL tracked from FFS during the breeding season with Hawaii longline fishing effort;
- Expand satellite tracking to other age classes (fledging birds and pre-breeders);
- Expand satellite tracking to other breeding sites in the NWHI (Laysan Island) and the MHI (Lehua and Kaula Rock).
- Examine albatross tracking data for overlap with fishing vessels (using VMS data).
- Examine whether any of the albatross taken in the longline fishery and necropsied had been previously tracked with satellite tags.
- Examine whether the magnitude and timing of breeding failures at colonies affect BFAL at-sea distribution and overlap with fisheries.
- Examine whether non-breeders and failed breeders change their at-sea distributions and overlap more with fishing vessels than breeding birds.
- To understand the nonlinear response of BFAL bycatch rates to albatross density, investigate the local factors that lead to BFAL aggregation at DSLL vessels and how density influences behavior and fishery interactions.
- Examine how local wind speed and direction during fishing operations influence BFAL abundance, foraging behavior, and interactions at longline vessels.
- Examine whether the presence/abundance of other target and non-target species in the catch influences BFAL interaction rates.
- Examine BFAL interactions and catch rates in different fisheries operating in the North Pacific, including the Hawaii DSLL and SSLL.
- Examine secondary interactions by analyzing shearwater numbers around vessels from observer scan counts to investigate whether changes in their presence/abundance are correlated with higher albatross interaction years.

- Perform dietary and isotopic studies to understand the degree to which BFAL foraging strategies (and association with fisheries) are a function of season, breeding status, and multi-annual breeding success.
- Quantify the degree of crew awareness and perception of seabird bycatch and mitigation measures compared to other bycatch issues, like false killer whales.

Workshop discussions identified the following next steps:

- Develop a meta-database listing what data are available (by colony) and who is responsible for collecting and curating these data.
- Improve colony counts using new technologies (drones, satellites) and expand data collection to currently inaccessible islands (Laysan, French Frigate Shoals).
- Continue collecting demographic data (survivorship, skipping, reproductive success) using demographic plots at colonies.
- Augment inter-plot and inter-colony comparisons to evaluate impacts from winter storms and inundation events.
- Build upon the current population model to develop an Integrated Population Model (IPM) using available spatially explicit data sets.
- Conceptualize an IPM able to address total population size, including non-breeders and juveniles, based on adult counts at multiple breeding colonies over time (e.g., years of contrasting oceanographic conditions). This model would allow the assessment of the fishery impacts (e.g., effect of fishery takes on the population) in a broader ecological context.
- Developing a rigorous IPM model would require filling in substantial data gaps:
    - BFAL distribution and fishery interaction data for different age-classes (breeders, juveniles, fledging chicks) from all breeding colonies during multiple years of contrasting oceanographic conditions (e.g., ENSO, PDO);
    - Fishing effort distributions and BFAL bycatch data for the Hawaii DSLL and SSLL fisheries and other North Pacific longline fisheries;
    - Characterize the degree of individual variability in BFAL association and reliance on fisheries. Are there bold (attracted) and shy (avoiding) birds?
    - Determine whether BFAL provisioning their chicks rely more heavily on fishing vessels than non-breeding or failed breeders.
- Collaborate with the Hawaii Longline Association to engage DSLL captains and crews to better understand fishing practices and seabird mitigation practices:
    - Investigate how operators respond to seabird interactions and determine which variables may be contributing to individual vessel differences in bycatch rates.
    - Study how the level of experience and awareness of vessel operators to seabird bycatch mitigation has changed over time using questionnaires, trainings, and focal groups.

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Extended Abstracts from Workshop Presentations

Figure 5. Workshop participants meeting at the Council office in Honolulu.

Introduction to the Workshop on the Factors Influencing Albatross Interactions in the Hawaii Longline Fishery: Towards Identifying Drivers and Quantifying Impacts

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Purpose of the workshop

The Hawaii longline fishery has been required to use seabird mitigation measures under the Pacific Pelagic Fishery Management Plan (current Fishery Ecosystem Plan, or FEP) since 2001. Since the implementation of seabird mitigation measures, the fishery has seen an increasing trend in Laysan and Black-footed Albatross interactions. A recent analysis conducted by Gilman and colleagues (2016) using data from October 2004 to May 2014, indicated that albatross interaction rates significantly increased during years of higher annual mean multivariate El Niño index (MEI), suggesting that oceanographic changes may have contributed to the increasing trend in albatross catch rates. This analysis also showed a significant increasing trend in the number of albatrosses attending fishing vessels, which may have contributed to the increasing catch rates. Moreover, the higher interaction rates observed during the recent (2015–2016) El Niño event further underscore the potential links between ocean conditions and albatross longline interactions.

In response to the recent trend in albatross interactions, the Western Pacific Regional Fishery Management Council (Council), at its 166th Meeting in June 2016, recommended research on the at-sea foraging behavior of albatrosses to improve understanding of their interaction rates in the Hawaii longline fishery. Recognizing that the increase in albatross captures may be driven by fishery factors, the Council also directed its Plan Team and Protected Species Advisory Committee to continue monitoring interactions through the FEP Stock Assessment and Fishery Evaluation (SAFE) report to detect future changes in albatross interactions that may be attributed to fishing operations.

Additionally, the Council and NMFS are in the process of developing a data integration chapter for the SAFE report that would assess policy-relevant fishery ecosystem relationships. The relationship between albatross interaction trends, fishing operation characteristics, and oceanographic factors has been identified as a high importance focus for the Pelagic FEP SAFE report data integration chapter.

This workshop will explore the potential drivers and implications of the higher interaction rates observed in 2015–2016 in the context of longer-term oceanographic variability, shifts in fishery effort and distribution, changes in albatross at-sea distribution, and albatross demography and population trends. The workshop will focus on addressing four key objectives:

1. Review recent increased albatross interactions in the Hawaii longline fishery;
2. Explore possible factors responsible for this increase:
3. Evaluate albatross population impacts; and
4. Provide input for future data collection, analysis, and models.

The Workshop's approach is summarized in a conceptual diagram (Figure 6).

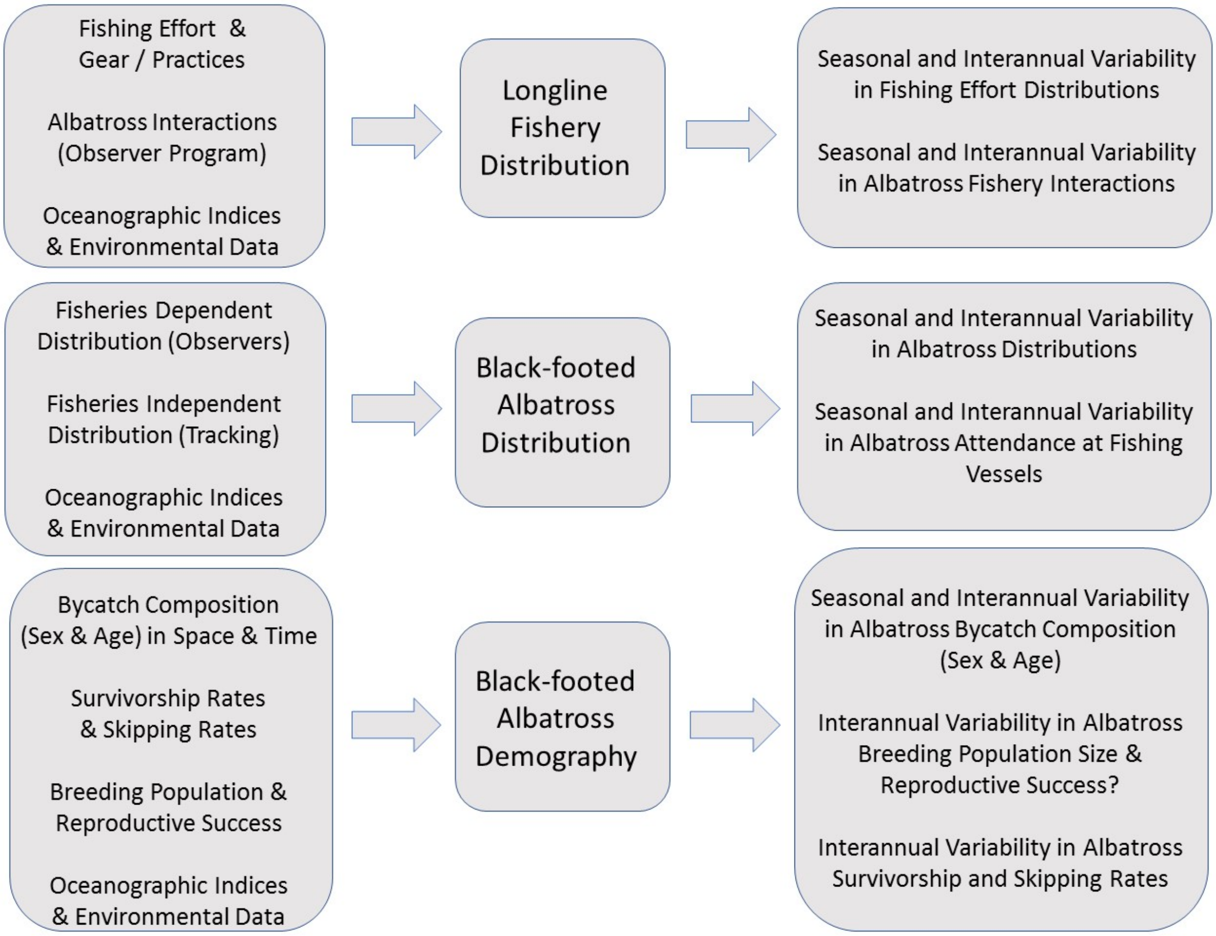
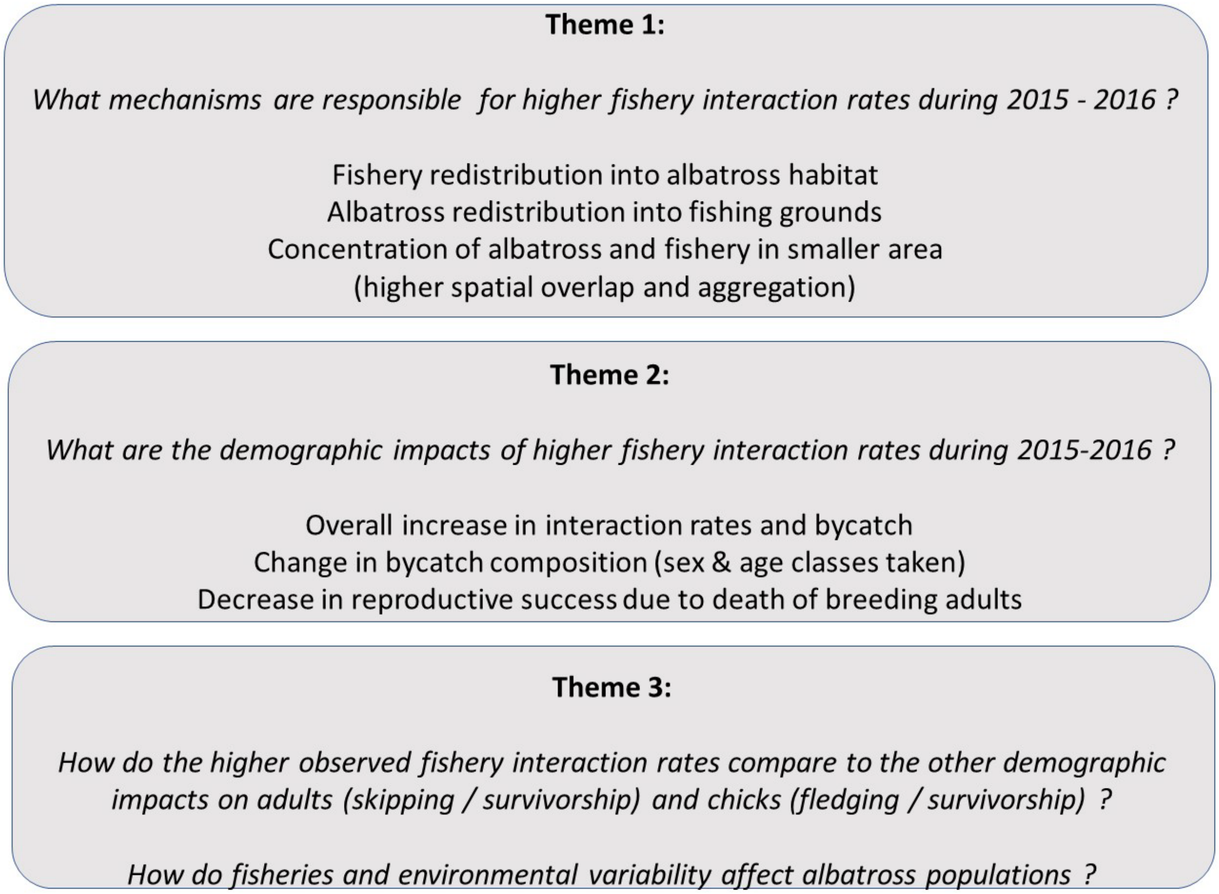


Figure 6. Conceptual diagram for the workshop.

While the ultimate discussions and conclusions from these exploratory analyses will be defined adaptively, based on the results presented at the workshop, we anticipate the discussions on the following topics, integrated into three overarching themes (Figure 7):

- Review recent conditions during 2015–2016 in the context of a longer-term reference period (2004–2016), concerning: (i) the oceanographic setting; (ii) longline fishing effort, distribution, and other operational characteristics; (iii) albatross at-sea distribution; (iv) albatross breeding population size and success; and (v) albatross bycatch composition by age/sex.

- Investigate the influence of the following factors on albatross interactions: (i) oceanographic variability; (ii) longline fishing effort, distribution, and other operational characteristics; and (iii) albatross at-sea distribution.
- Explore how albatross demographic parameters (adult survivorship and breeding probability, reproductive success) vary from year to year in relation to covariates designed to capture the dynamics of the marine environment and the fishery, including: (i) changes in the oceanography of the central North Pacific; (ii) shifts in longline effort and distribution; and (iii) changes in albatross at-sea distribution.
- Evaluate the population-level impacts of these interactions by modeling how albatross populations respond to changes in demographic parameters, bycatch rates, and the composition of the bycatch composition by age/sex.
- Provide input towards the creation of integrated models and assessments capable of merging the available population data (number of breeders, breeding success, capture-recapture data) with fishery-dependent information (effort and interaction rates, bycatch composition by age/sex).



Theme 1:

What mechanisms are responsible for higher fishery interaction rates during 2015 - 2016 ?

Fishery redistribution into albatross habitat
Albatross redistribution into fishing grounds
Concentration of albatross and fishery in smaller area
(higher spatial overlap and aggregation)

Theme 2:

What are the demographic impacts of higher fishery interaction rates during 2015-2016 ?

Overall increase in interaction rates and bycatch
Change in bycatch composition (sex & age classes taken)
Decrease in reproductive success due to death of breeding adults

Theme 3:

How do the higher observed fishery interaction rates compare to the other demographic impacts on adults (skipping / survivorship) and chicks (fledging / survivorship) ?

How do fisheries and environmental variability affect albatross populations ?

Figure 7. Conceptual diagram of the workshop's focal areas for discussion.

1998 Black-footed Albatross Population Biology Workshop Findings

The Council hosted the Workshop on the Population Biology of the Black-footed Albatross in Relation to Mortality Caused by Longline Fishing in October 1998 (Cousins and Cooper 2000). The workshop brought together seabird and fisheries biologists and population modelers to characterize the population biology of the Black-footed Albatross and to evaluate the species' resilience to the effects of mortality due to longline fisheries interactions.

Key findings from the 1998 Population Biology Workshop relevant to the discussions of the current workshop are summarized below. Additionally, the full workshop report is available at the Council web-site[6]

Banding Data

- Banding data from longline-caught birds suggested that younger and less experienced birds are more vulnerable to bycatch. The great majority (77%) of albatross captured at sea was taken during the six-month period (March–August) spanning from the chick-rearing period to the post-breeding dispersal.
    - Analysis of 255 known-age at-sea Black-footed Albatross banding records showed that 114 (44.7%) were young-of-the-year, 40 were 2-year-olds (5.7%), 25 were 3-year-olds (9.8%), and 52 were over five years (20.4%).
    - Band returns were not distributed uniformly throughout the year: monthly proportions ranged from a low in November (1.8%) to a high in July (20.3%). Overall, band returns varied by quarter, (18.0%, 33.7%, 38.5%, and 9.8%), with most band returns from summer (July–September) and spring (April–June).

Population Modeling

- Population modeling experiments were developed at the workshop to compare the effects of different removal rates of adults and juveniles.
- Due to the lack of population parameters, the models assumed equal sex ratio (1:1), equal survival rate for males and females, and constant juvenile survival rate to the age of first breeding.
    - The modal age of first breeding is seven years.
    - Some of the population parameters used in the modeling experiments (e.g., adult survival rate of 0.923 with a range of 0.810–0.994) were based on data collected in the 1960s, prior to the development of the modern Hawaii longline fleet.
- Modeling conclusions:
    - If the total number of birds killed in the longline fishery each year is of the order of one percent of the total population, then the growth rate of the population (lambda) will be reduced by slightly more than one percent.

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[6] http://www.wpcouncil.org

- A total population of 300,000 birds could withstand, at the very most, a loss of 10,000 birds per year to all mortality sources including combined natural and anthropogenic sources.
- When removal rates are 10 times higher for juveniles than for adults, the population declines more slowly than if removal rates are equal.

Workshop Recommendations

1. Complete, develop, and manage a relational database for banding records.
2. Encourage further analyses of the existing data sets and conduct further modeling at a population dynamic modeling laboratory.
3. Design and implement a population-monitoring program at breeding sites to address the effects of longlining mortality.
4. Obtain information and make best estimates of fishing effort and mortality of birds from the Pacific halibut and non-U.S. longline fisheries in the Northern Pacific Ocean.
5. Design, implement, and develop a longline fishery-monitoring scheme to test mitigation measures and to gather mortality data.
6. Undertake comparative studies with Laysan and Japanese Black-footed Albatross.
7. Hold a follow-up meeting to discuss progress with the above recommendations at the Second International Albatross Conference in Honolulu, Hawaii, 8–12 May 2000.

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Overview of the Hawaii Longline Fishery

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Characteristics of the Hawaii Longline Fishery

Longline fishing in Hawaii dates from 1917 using wooden style sampans off the Waianae coast of Oahu. Changes in fishing methods and greater amounts of fishing gear characterized the expansion of the longline fleet over the ensuing decades. In the mid-1980s, longliners began exploring fishing grounds up to 800 nmi from the main Hawaiian Islands, and distant-water fishing gradually became more common in the 1990s. Boggs and Ito (1993) give a comprehensive account of the history of the Hawaii longline fishery up to the early 1990s. The Pelagics SAFE Report (WPRFMC 2017), from which most of this abstract is freely adapted, contains contemporary descriptions of the fishery.

All Hawaii longline vessels fish for bigeye tuna; some vessels still opt to seasonally fish for swordfish out of Hawaii. Vessels now deploy continuous nylon monofilament main lines stored on spools with snap-on monofilament branch lines. The fleet size ranged between 120 and 130 vessels during the 1990s, but more recently has increased to between 135 and 140 vessels, and the number of hooks deployed has increased 50%–70% since the mid-2000s.

Conflicts with other fisheries and interactions with protected species led to the exclusion of the longline fishery from the nearshore waters of the Hawaii Archipelago in 1990 and 1991. Longline fishing was prohibited within a radius of 50 nmi off the Northwestern Hawaiian Islands (NWHI) to prevent interactions with Hawaiian monk seals. In 1991, the Council established a buffer zone prohibiting longline fishing within a radius of 75 nmi off Kauai and Oahu and 50 nmi of the coasts of Maui, Molokai, Lanai, Kahoolawe, and Hawaii to prevent conflicts with small-boat fisheries operating in those areas.

Type and Quantity of Fishing Gear

In this fishery, longline gear is comprised of monofilament mainline stored on a hydraulically operated drum. Typically, between 30–50 nmi of mainline are deployed in a “set.” This line is suspended by surface floats to form a series of catenary curves in the water column to which the branch lines are attached and suspended.

When targeting bigeye tuna, fishermen deploy 15–30 hooks between the line floats, with enough sag to reach as deep as 400 m (referred to as “deep-set”). A line shooter is required to place this sag. In targeting swordfish, only a few hooks are deployed between floats and the line is kept relatively taut so that it stays in the upper 30–90 m of water (referred to as “shallow-set”). Night fishing employs luminescent "light sticks" which attract broadbill swordfish or their prey. Imported squid were first used for bait in the shallow-set fishery, but fishermen switched to fish bait in 2004 in response to management measures to reduce sea turtle interactions (WPRFMC

2004). Longline operators are required to declare whether they will be deep-setting or shallow-setting prior to every trip, and do not switch gear type or target during a trip.

Fishing Areas

The deep-set fishery operates north and south of the Hawaii Archipelago, and on occasion may range as far south as equatorial latitudes around Palmyra Atoll (Figure 8). The shallow-set swordfish fishery operates predominantly to the north and east of the Hawaiian Archipelago (Figure 8). A small portion of the vessels operating under the Hawaii longline limited entry permit start and/or complete fishing trips at ports along the California coast.

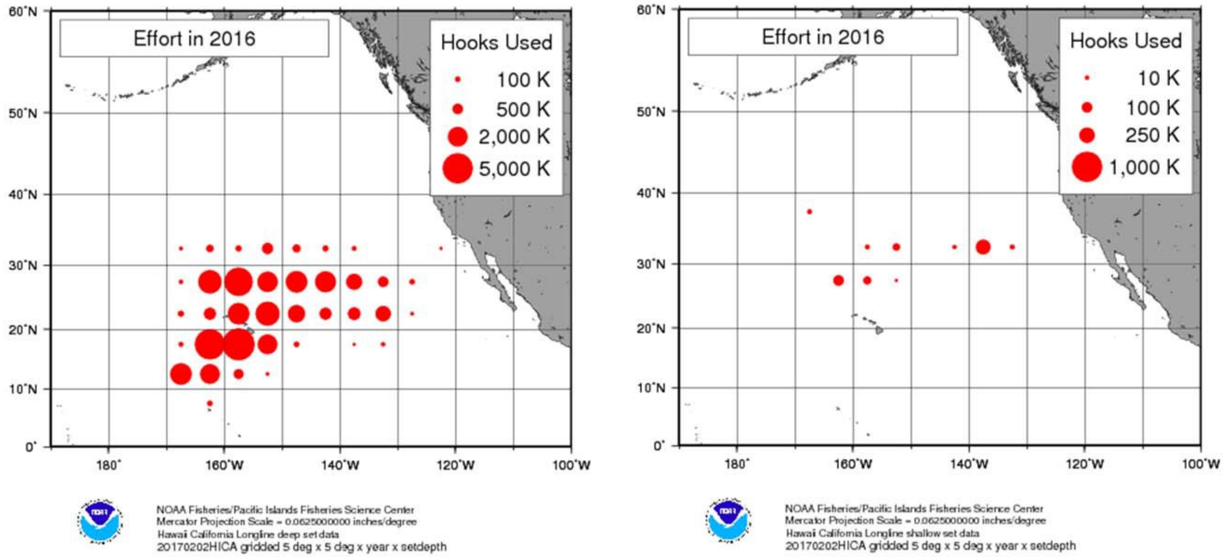


Figure 8. Distribution of deep-set (left) and shallow-set (right) longline fishing effort in 2016. Source: NMFS PIFSC unpublished data.

Catch in Numbers and Weight

From 2006 to 2016, the total catch by the Hawaii longline fleet increased from about 400,000 fish to about 600,000 fish per year, driven primarily by the expansion of the deep-set tuna fishery (Figure 9). The shallow-set swordfish fishery has remained relatively static since 2005, landing on average between 25,000 and 40,000 fish per year.

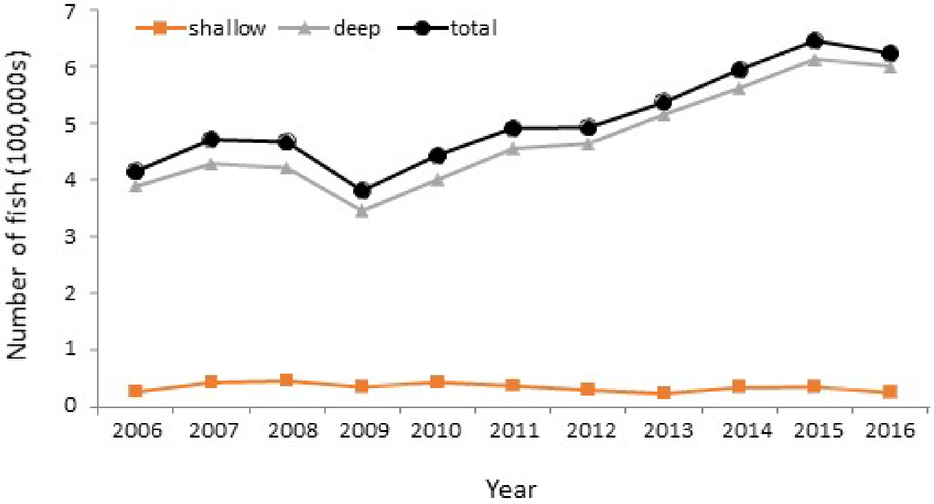


Figure 9. Landings in number of fish for the Hawaii deep-set and shallow-set longline fisheries. Source: WPRFMC (2017).

The deep-set fishery landed 32 million pounds worth $93 million in 2015 and 31 million pounds in 2016 worth $99 million. The shallow-set longline fishery landed 2.8 million lb in 2015, worth $2.9 million and 1.8 million lb in 2016, worth $2.5 million. The species composition of the deep-set and shallow-set sectors of the Hawaii longline fishery are shown in Figure 10.

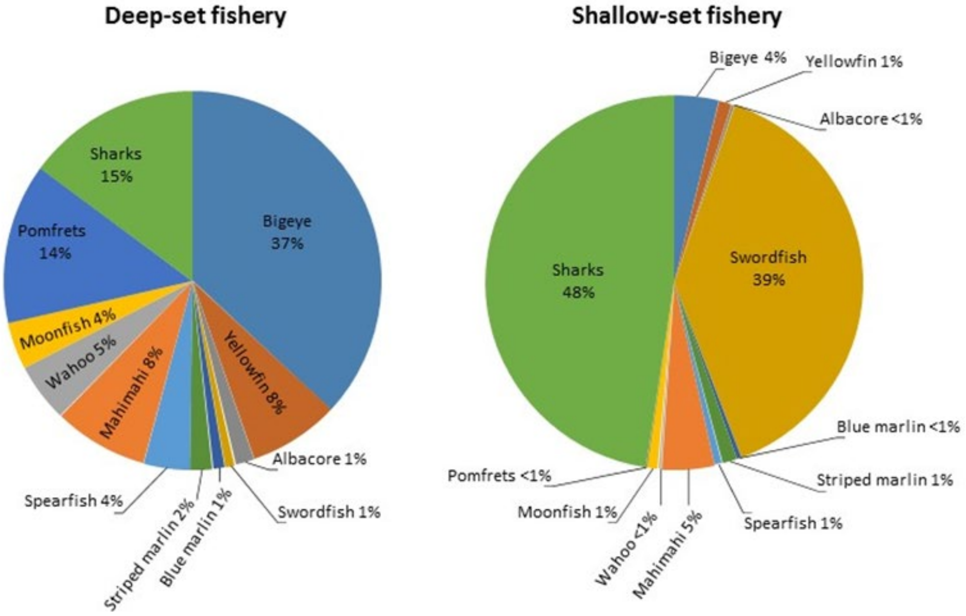


Figure 10. Species composition of total catch (kept and discarded) in the deep-set (left) and shallow-set (right) sectors of the Hawaii longline fishery in 2016. Source: WPRFMC (2017).

Fishing Operations

Fishermen shallow-setting for swordfish are required by regulations to begin gear deployment at least an hour after local sunset and to complete the deployment no later than local sunrise, unless using side-setting as the primary seabird mitigation measure. Such time constraints for deep-set tuna longlining are not proscribed in regulation, but fishing usually starts at dawn, with the set retrieved by the late afternoon. Hauling may continue to midnight or so.

The number of sets and volume of hooks set are shown in Figure 11. The number of shallow sets since 2004 has ranged between 850 and 1,833, with an average of about 1,400. The number of hooks deployed by this segment of the fishery has remained relatively static with just over a million hooks set annually for swordfish. In the deep-set fishery, the trend in the number of sets rose between 2001 and 2007, where it levels off at around 17,000–18,000. The number of hooks set by the deep-set fishery has been on a rising trend since 2010, with about 40 million hooks set in 2010, and 52 million hooks set in 2016. The average number of hooks deployed by the deep-set fishery over the 2006–2016 period was 42 million hooks, or about 96% of the total.

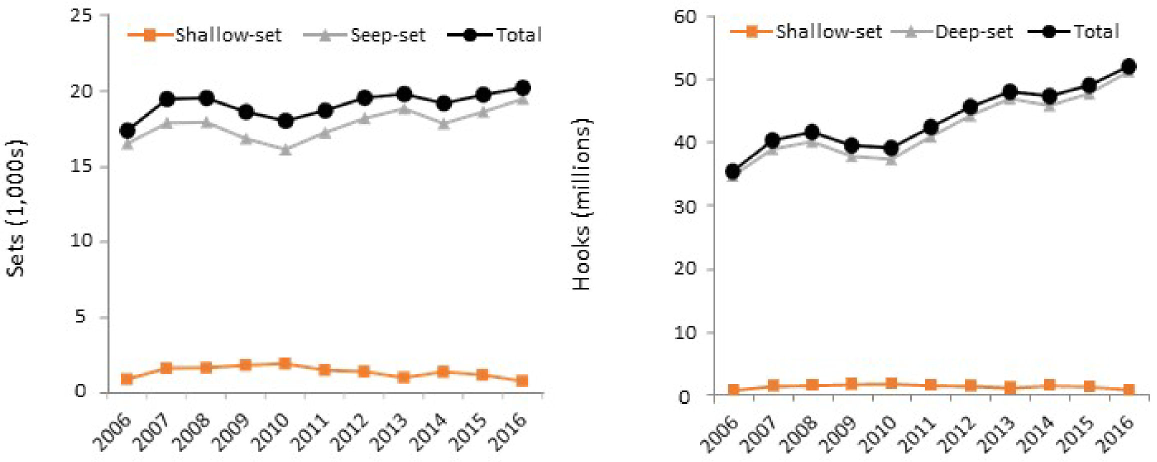


Figure 11. Effort trends in deep, shallow, and total sets (left) and hooks (right) by the Hawaii longline fishery, 2006–2016. Source: WPRFMC (2017).

Economics

The most valuable tuna per pound is Pacific bluefin, though landings of this species are negligible in the Hawaii longline fisheries. Bigeye tuna accounts for about 60% of the deep-set fishery landings and over 70% of the landed value. Swordfish comprise about 90% of the shallow-set longline fishery and between 70–80% of the landed value. The average direct revenue from the longline fishery (deep-set and shallow-set) between 2006 and 2016 was $79 million, with a high of $99 million (2016) and a low of $59 million (2009).

Management Structure and Seabird Bycatch Mitigation in the Hawaii Longline Fishery

The Hawaii longline fishery is managed under the Western Pacific Regional Fishery Management Council (WPRFMC) Pelagic Fisheries Ecosystem Plan (FEP). The Pelagic FEP specifies the maximum number of permits in the longline fleet (164), maximum vessel size (101 ft), Vessel Monitoring System requirements, spatial management areas, observer placement, and measures to reduce interactions with protected species including seabirds.

The entire suite of regulations for both the deep-set and shallow-set fishery can be found at: http://www.fpir.noaa.gov/SFD/pdfs/hawaii-longline-reg-summary.pdf.

Seabird measures in the Hawaii longline fishery were first implemented in 2001 as an emergency rule, and later implemented through the Pelagic Fishery Management Plan (FMP; currently the FEP) in 2002. The original plan required a suite of measures including blue-dyed bait, weighted hooks, and strategic offal discharge and applied to all Hawaii longline vessels operating north of 23°N. The shallow-set component of the fishery was closed at the time due to sea turtle interactions. When the shallow-set longline fishery reopened in 2004, the night setting requirement for was also implemented for this fishery. Additional changes to the seabird measure were implemented in 2006, allowing vessels to use side-setting as an alternative to blue-dyed bait and expanding the seabird mitigation requirements for the shallow-set fishery to all areas north of the equator. The current requirements for the deep-set and shallow-set fisheries are summarized in Figure 12.

The Hawaii longline fishery is also subject to the conservation and management measures of two international tuna fishery management commissions, namely the Western and Central Pacific Fishery Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IAATC). The boundary between the two commissions north of the equator is the 150°W line of longitude, about 200 miles to the east of Hawaii. The Hawaii longline fleet operates in waters under the jurisdiction of both commissions and is subject to the conservation measures for seabirds. These are based largely on the Council's measures and currently do not conflict with the Council's seabird mitigation requirements for the Hawaii longline fleet.

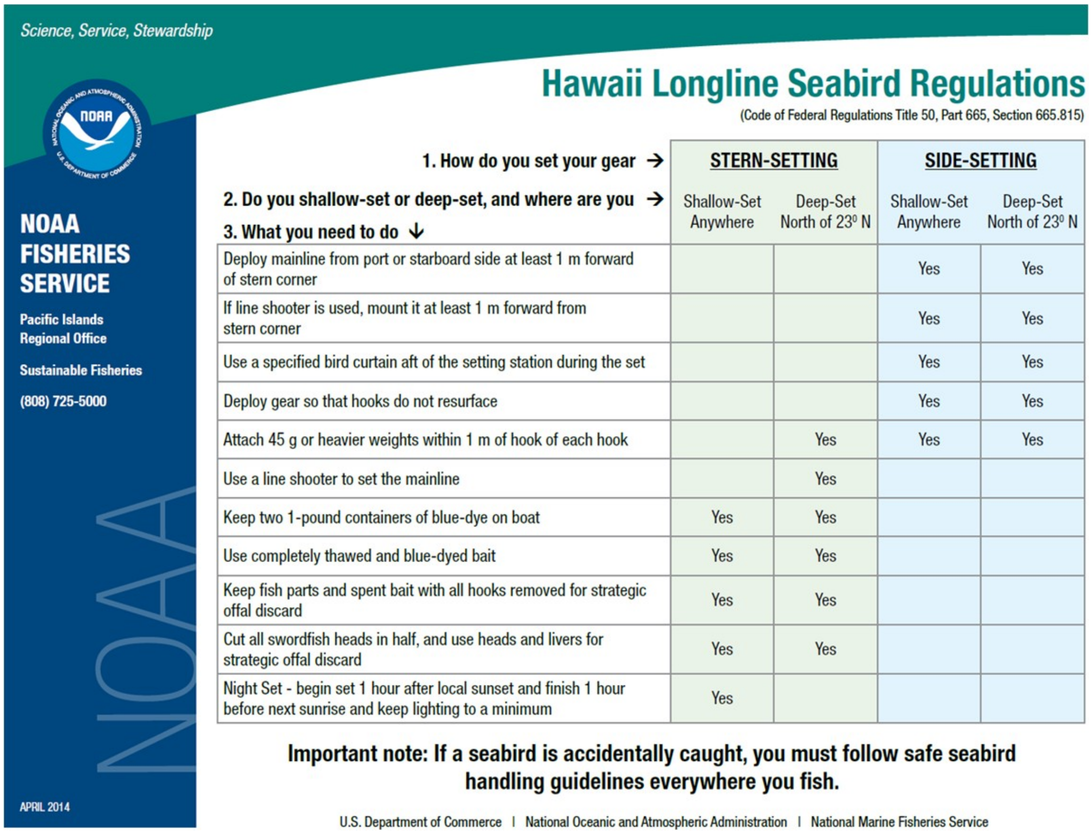
Data Collection

Logbook Data

All Hawaii longline permit holders must fill out a daily operational logbook on their fishing operations. A sample is available the Pacific Islands Fisheries Science Center website at: https://www.pifsc.noaa.gov/fmb/fmap/federal_forms/pacific_islands_daily_longline_fishing_log.pdf.

The logbook requires detailed information on the start of the longline set and its completion on the haul back. This includes fishing positions, number of hooks set, number of hooks between floats, use of light-sticks, bait type and the principal target species.

The logbooks also require information on the numbers of fish caught on each haul including tunas, billfish, other pelagics, and sharks. The catch is divided into the numbers caught and kept and the numbers discarded. Protected species interactions are also included in the daily logbook and cover marine mammals, turtles, and seabirds. If an interaction with one of these species occurs, the number released uninjured, injured, or dead must be provided.



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Hawaii Longline Seabird Regulations

(Code of Federal Regulations Title 50, Part 665, Section 665.815)

1. How do you set your gear →	STERN-SETTING		SIDE-SETTING	
2. Do you shallow-set or deep-set, and where are you →	Shallow-Set Anywhere	Deep-Set North of 23° N	Shallow-Set Anywhere	Deep-Set North of 23° N
3. What you need to do ↓				
Deploy mainline from port or starboard side at least 1 m forward of stern corner			Yes	Yes
If line shooter is used, mount it at least 1 m forward from stern corner			Yes	Yes
Use a specified bird curtain aft of the setting station during the set			Yes	Yes
Deploy gear so that hooks do not resurface			Yes	Yes
Attach 45 g or heavier weights within 1 m of hook of each hook		Yes	Yes	Yes
Use a line shooter to set the mainline		Yes		
Keep two 1-pound containers of blue-dye on boat	Yes	Yes		
Use completely thawed and blue-dyed bait	Yes	Yes		
Keep fish parts and spent bait with all hooks removed for strategic offal discard	Yes	Yes		
Cut all swordfish heads in half, and use heads and livers for strategic offal discard	Yes	Yes		
Night Set - begin set 1 hour after local sunset and finish 1 hour before next sunrise and keep lighting to a minimum	Yes			

Important note: If a seabird is accidentally caught, you must follow safe seabird handling guidelines everywhere you fish.

U.S. Department of Commerce | National Oceanic and Atmospheric Administration | National Marine Fisheries Service

Figure 12. Summary of current seabird regulations for the Hawaii longline fishery. Source: NMFS PIRO Seabird Compliance Guide, July 2014.

Observer Data

The Hawaii longline fishery has been monitored through the NMFS Pacific Islands Regional Office (PIRO) Observer Program since 1994. Observer coverage ranged between 3% and 5% for the entire fleet from 1994 through 1999 and increased to 10% in 2000. The deep-set longline fishery has been consistently monitored at a minimum of 20% coverage annually since 2002, and the shallow-set fishery has been monitored at 100% coverage since 2004. Hawaii longline operators are required to call in 72 hours prior to departure and declare their trip type so that observer placement can be arranged. The 20% observer coverage for the deep-set fishery is sampled using a two-stage probability sampling design (McCracken 2014).

The observers on the Hawaii longline fishery collect data on general operational characteristics (e.g., fishing location and gear characteristics), target and non-target catch, and protected species interactions. For each longline set, the observers record the beginning and end set date and time, location (latitude and longitude), weather, Beaufort scale, and sea surface temperature. The observers also record whether there are seabirds present during set and haul. For each seabird interaction, the observer records species, capture and release date and time, capture and release location (latitude and longitude), any presence of tags, hooking and/or entanglement details (hooking location, gear removal, remaining gear), morphology of the bird caught, and any light devices used. Dead seabirds are typically collected and brought back to port for necropsy.

Additionally, observers conduct seabird scan counts. Currently, counts are conducted during a 5-minute window at the start of setting and again at 30 minutes after the start of set for another 5 minutes. Scan counts are also conducted during a 5-minute window at the start of the haul. Some modifications to the seabird scan protocol have been introduced over time.

The observer manual and forms are available on the PIRO Observer Program website at: https://www.fpir.noaa.gov/OBS/obs_observer_manual_forms.html.

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Time Series of Albatross Interactions in the Hawaii Longline Fishery

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Albatross Interaction Time Series

Seabird interactions in the Hawaii longline fishery are monitored through the NMFS Pacific Islands Regional Office (PIRO) Observer Program, with the swordfish-targeting shallow-set longline fishery monitored at 100% coverage and the bigeye tuna-targeting deep-set longline fishery monitored at a minimum of 20% coverage annually.

Black-footed (*Phoebastria nigripes*) and Laysan (*P. immutabilis*) Albatross interaction data for the Hawaii shallow-set and deep-set longline fisheries are summarized in Table 3 and Table 4. The data are based on the summaries published by the PIRO Observer Program, which compiles the number of annual interactions using the vessel arrival date rather than the interaction date due to the quarterly sampling timeframe for the deep-set longline fishery. Because longline trips typically last several weeks, observed interactions from a trip beginning in December and ending in January are counted as January interactions for the purpose of PIRO Observer Program summaries. The annual summaries are compiled in a time series starting in 2004 for the shallow-set fishery and 2002 for the deep-set fishery in the Pelagic FEP SAFE Report (WPRFMC 2017).

Additionally, NMFS PIRO annually publishes the Seabird Interactions and Mitigation Efforts in Hawai`i Longline Fisheries (Seabird Annual Report). The Seabird Annual Report summarizes the annual numbers of observed interactions based on the date and time of the beginning of the haul (equivalent to the interaction date).

Table 3. Observed number of interactions and released dead, and interactions per 1,000 hooks for Laysan, Black-footed, and Short-tailed Albatrosses in the Hawaii shallow-set longline fishery, 2004–2016.[a]

				Laysan Albatross			Black-footed Albatross			Short-tailed Albatross
Year	Obs. Cov. (%)	Obs. Sets	Obs. Hooks	Total observed interactions	Released dead	Interactions / 1,000 hooks	Total observed interactions	Released dead	Interactions / 1,000 hooks	Total observed interactions
2004	100	88	76,750	1	0	0.013	0	0	0.000	0
2005	100	1,604	1,328,806	62	18	0.047	7	4	0.005	0
2006	100	939	745,125	8	3	0.011	3	3	0.004	0
2007[b]	100	1,496	1,292,036	39	6	0.030	8	2	0.006	0
2008	100	1,487	1,350,127	33	11	0.024	6	4	0.004	0
2009	100	1,833	1,767,128	81	17	0.046	29	7	0.016	0
2010	100	1,879	1,828,529	40	7	0.022	39	11	0.021	0
2011	100	1,579	1,611,395	49	10	0.030	19	5	0.012	0
2012	100	1,307	1,418,843	61	11	0.043	37	10	0.026	0
2013	100	912	1,000,084	46	10	0.046	28	17	0.028	0
2014	100	1,349	1,509,727	36	2	0.024	29	14	0.019	0
2015	100	1,178	1,286,628	45	6	0.035	41	10	0.032	0
2016	100	778	849,681	26	3	0.031	40	12	0.047	0

[a] Take data are based on vessel arrival dates.

[b] Due to vessel confidentiality rules, data for the fourth quarter in 2007 are combined with data for 2008. Take data for 2007 reflect those from first, second, and third quarters. Sources: 2004-2016 PIRO Observer Program Annual and quarterly Status Reports

Table 4. Observed number of interactions and released dead, interactions per 1,000 hooks, and estimated total interactions for Laysan, Black-footed, and Short-tailed Albatrosses in the Hawaii deep-set longline fishery, 2004–2016.[a]

				Laysan albatross				Black-footed Albatross				Short-tailed Albatross
				Observed			Estimated total interactions[b]	Observed			Estimated total interactions[b]	Total observed interactions
Year	Obs. Cov. (%)	Obs. Sets	Obs. Hooks	Total observed interactions	Released dead	Takes/ 1,000 hooks		Total observed interactions	Released dead	Takes/ 1,000 hooks		
2004	24.6	3,958	7,900,681	2	2	0.000	10	4	4	0.001	16	0
2005	26.1	4,602	9,360,671	6	6	0.001	43	12	12	0.001	82	0
2006	21.2	3,605	7,540,286	1	1	0.000	7	17	17	0.002	70	0
2007	20.1	3,506	7,620,083	7	7	0.001	44	14	14	0.002	77	0
2008	21.7	3,915	8,775,951	14	13	0.002	55	34	33	0.004	118	0
2009	20.6	3,520	7,877,861	18	18	0.002	60	23	23	0.003	110	0
2010	21.1	3,580	8,184,127	39	38	0.005	155	17	17	0.002	65	0
2011	20.3	3,540	8,260,092	32	31	0.004	187	13	12	0.002	73	0
2012	20.4	3,659	8,768,728	30	25	0.003	136	35	35	0.004	167	0
2013	20.4	3,830	9,278,133	48	46	0.005	236	50	47	0.005	257	0
2014	20.8	3,831	9,608,244	13	10	0.001	77	32	29	0.003	175	0
2015	20.6	3,728	9,393,234	24	22	0.003	119	107	92	0.011	541	0
2016	20.1	3,880	9,872,439	34	32	0.003	166	104	99	0.011	485	0

[a] Take data are based on vessel arrival dates.

[b] Estimated interactions for 2004–16 are point estimates generated by NMFS Pacific Islands Fisheries Science Center (McCracken, various years)

Sources: Observed interaction data—2004-2016 PIRO Observer Program Annual and quarterly Status Reports

Estimated total interactions, 2004–2016—McCracken 2005; McCracken 2006; McCracken 2007; McCracken 2008; McCracken 2009; McCracken 2010; McCracken 2011b; McCracken 2012; McCracken 2013; McCracken 2014; McCracken 2017a, McCracken 2017b.

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Status and Trends of Albatross Populations in the Northwestern Hawaiian Islands

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Introduction

Breeding populations of all three Northern hemisphere albatross species, Black-footed Albatross (*Phoebastria nigripes*), Laysan Albatross (*P. immutabilis*), and Short-tailed Albatross (*P. albatrus*) are monitored over a large portion of their range to assess the status of these species. While many aspects of their lives at sea are poorly understood, they are easily counted and observed in the breeding colonies and have been censused at all sites biologists can access during the winter months when they are breeding. Population sizes and trends have been tracked for these species since 1897 when the earliest recorded large-scale exploitation of their populations, the feather harvests, started (Spenneman 1998). By 1914, more than 3.5 million birds were harvested in the central tropical Pacific; a large proportion were these 3 species of albatrosses. Underlying trends may reflect recovery from those events, disturbances, and habitat loss due to activities at breeding sites in WWII and during the Cold War, and from the 1950s on, commercial fishing, including high seas drift nets, pelagic and demersal longlines (Arata et al. 2009). Bakker et al. (2018) have recently summarized the difficulties inherent in assessing population status and trends using annual nest count data for species such as albatrosses. They demonstrate that those nest count data quantify a varying fraction of the population, and this fraction tends to be negatively autocorrelated through time, giving the illusion of negative density dependence. Current status is also no guarantee of future status. The IUCN Red List process now acknowledges that some threatening processes such as sea level rise that will eliminate nesting habitat may not currently be manifested in population trajectories, but they may be predicted to affect population persistence in the future (Reynolds et al. 2016).

Based on this understanding, analyses of recent data for Black-footed and Laysan Albatrosses suggest that while these species' populations are not undergoing rapid declines as once thought and are either stable or increasing. However, modelling the likely effects of mortality caused by longline fishing fleets, combined with potential losses to breeding colonies from sea-level rise and storm surges, suggests it is appropriate to precautionarily predict a moderately rapid population decline over the next three generations (56 years); hence their classification as Near Threatened rather than Least Concern (Birdlife 2017a, b).

Methods

The most stable and repeatable metric for population time series is active nests or breeding pairs. Both Laysan (LAAL) and Black-footed (BFAL) Albatross are strongly synchronous and initiate breeding within a short window in the boreal winter. Counts at sites with field stations occupied year-round are initiated as soon as all eggs have been laid (mid-December), and all counting is done before 7 January to minimize the effects of egg loss. Colonies without winter access are counted opportunistically and an error factor using best available reproductive performance data is used.

A loglinear Poisson regression method was used to analyze time series of count data. The method produces yearly indices and trend estimates. The method can also deal with several difficulties inherent to monitoring data, especially missing values, over- and undersampling of certain strata, serial correlation, and deviations from Poisson distribution. A computer program, called rTRIM, was used to apply the method (Van Strien et al. 2004).

Results

Black-Footed Albatross Distribution

Black-footed Albatross are known to exist at 17 active colonies and have been extirpated at an additional 12 sites (Figure 13). These colonies span the entire North Pacific and are found in the Izu, Ogasawara, and Senkaku Islands in East Asia, the Hawaiian Islands, and until recently in Mexico on Isla Guadalupe and in the Revillagigedos. Historically, this species was found breeding further south than it now occurs.

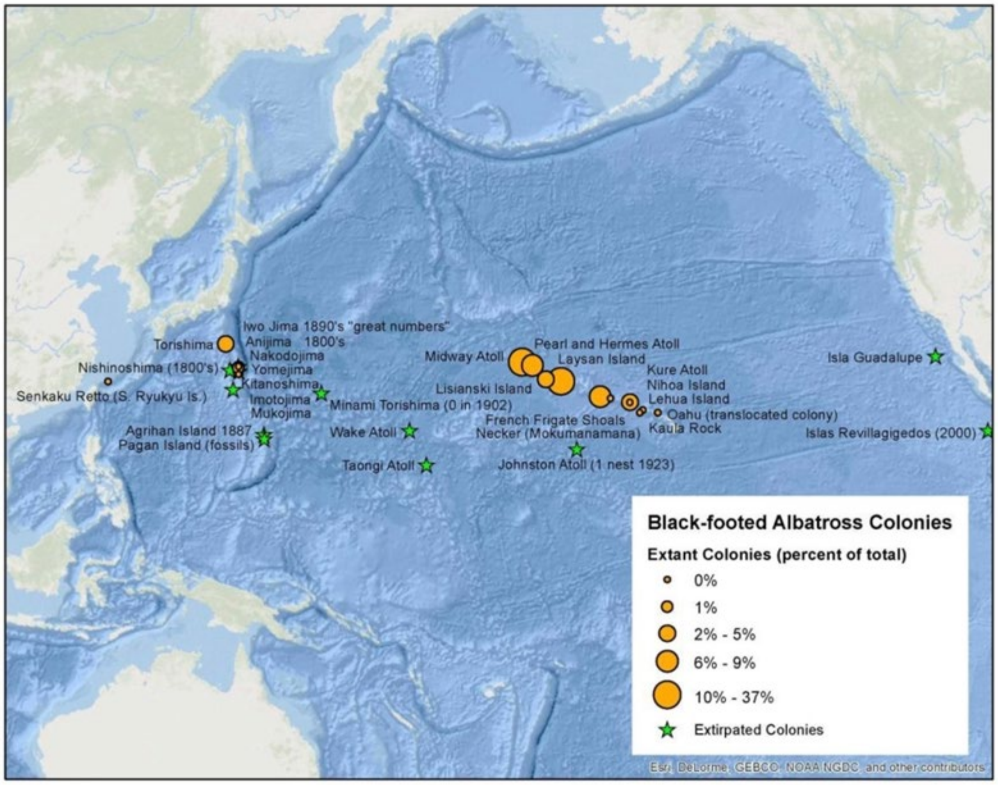

Figure 13. Distribution of extant Black-footed Albatross colonies and those that have been extirpated.

Black-Footed Albatross Population Size

Total world population using the most recent count for each site adds up to 70,096 pairs (Table 5).

Table 5. Estimate of BFAL world population size (number of breeding pairs, #bp) in 2017, based on the most recent data. Black font indicates the counts are from the 2017 breeding season. Red font indicates that the latest count data pre-date 2017.

Extirpated sites (date)	Latitude - Longitude	# Bp
Agrihan Island (1887)	18° 46' N 145° 45' E	0
Anijima (1800's)	27° 07' N 142° 12' E	0
Isla Guadalupe	29° 02' N 118° 17' W	0
Iwo Jima 1890's "great numbers"	24° 47' N 141° 19' E	0
Kitanoshima	27° 43' N 142° 06' E	0
Minami Torishima (0 in 1902)	24° 18' N 153° 58' E	0
Nishinoshima (1800's)	27° 15' N 140° 54' E	0
Pagan Island (fossils)	18° 09' N 145° 48' E	0
Islas Revillagigedos (2000)	19° 19' N 110° 48' W	0
Johnston Atoll (1 nest 1923)	16° 45' N 169° 32' W	0
Taongi Atoll	14° 36' N 169° 00' E	0
Wake Atoll	19° 18' N 166° 35' E	0
Active colonies		
French Frigate Shoals	23° 45' N 166° 10' W	4,944
Imotojima	26° 39' N 142° 10' E	9
Kaula Rock	21° 39' N 160° 32' W	4
Kure Atoll	23° 03' N 161° 56' W	3,398
Laysan Island	25° 46' N 171° 45' W	24,565
Lehua Island	22° 01' N 160° 06' W	39
Lisianski Island	26° 04' N 173° 58' W	2,126
Midway Atoll	28° 15' N 177° 20' W	25,615
Mukojima	27° 41' 24" N 142° 11' E	190
Oahu (translocated colony)	21° 41' N 157° 57' W	9
Nakodojima	27° 37' N 142° 10' E	468
Necker (Mokumanamana)	23° 35' N 164° 42' W	112
Nihoa Island	23° 03' N 161° 56' W	1
Pearl and Hermes Atoll	27° 50' N 175° 50' W	6,116
Senkaku Retto (S. Ryukyu Is.)	25° 45' N 123° 30' E	56
Torishima	30° 29' N 140° 19' E	2,060
Yomejima	27° 30' N 142° 06' E	384
		70,096

Black-Footed Albatross Trend

The trend of the total counts of BFAL from the Midway-FFS-Laysan populations (which represents 79% of the total world population) was stable in the 34 years from 1983 to 2017 (Figure 14). No statistically significant trends in BFAL populations from 1983 to 2017 were detected (Wald = 1.47, df = 1, p = 0.226). In 1995 (Wald = 6.32, df = 1, p = 0.0120), there was a statistically significant changepoint in terms of the trend (i.e., slope). However, the model using this changepoint was less sparse (AIC ≃ 9,000) than the base model 2 (AIC ≃ 7,170).

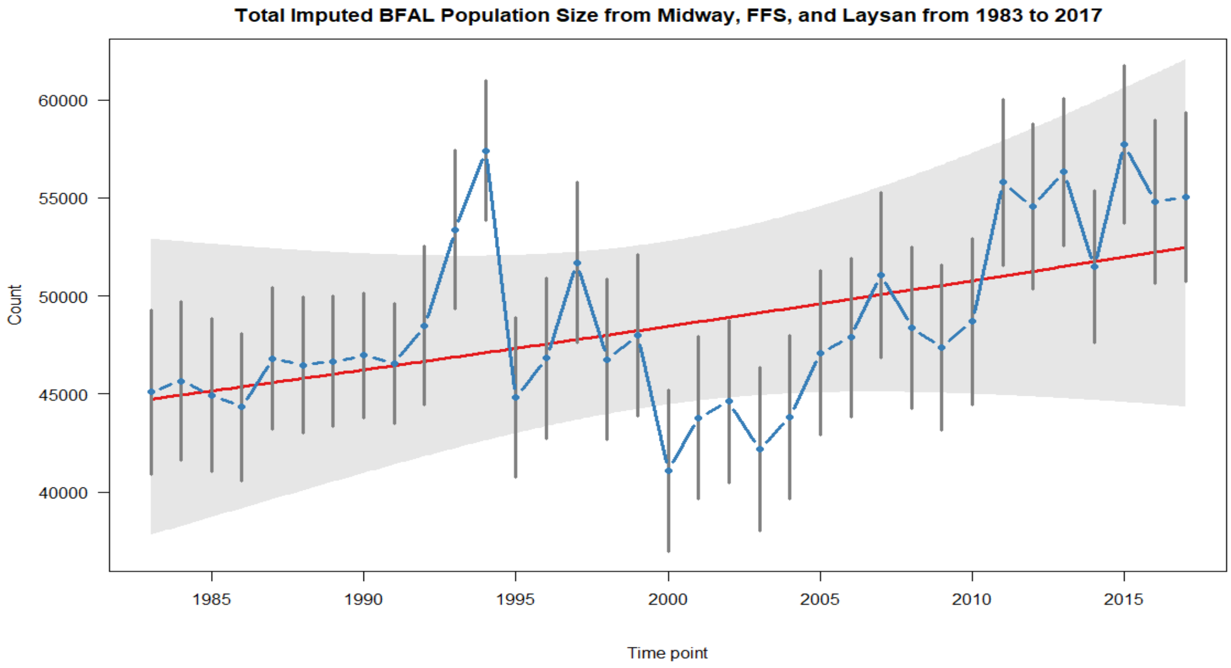

Figure 14. rTRIM analysis of Black-footed Albatross data 1983 to 2017 from Midway, FFS, and Laysan Island. Total imputed counts (± SE bars) of BFAL across all three sites (Midway, French Frigate Shoals, and Laysan) from years 1983 to 2017, as computed by Model 2 where time point 1 is also the only possible change point. The overall trend (red line) and its 95% confidence interval (gray shaded area) are plotted. R code for rTRIM analysis: trim(count ~ site + time, data=BFAL, model=2, serialcor=TRUE, overdisp=TRUE).

Laysan Albatross Distribution

Laysan Albatross are found in 18 colonies now and known to have originated from three additional former colonies (Figure 15). They are distributed across the North Pacific, but a large proportion of the world's population occurs in the Hawaiian Islands.

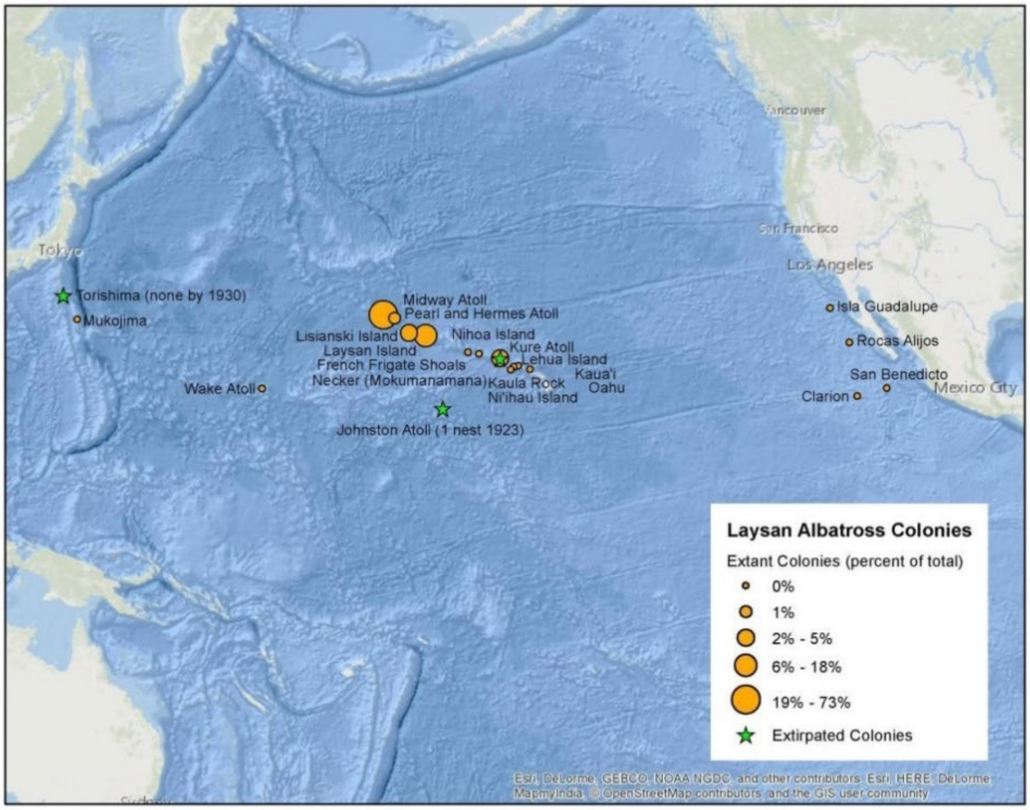

Figure 15. Distribution of extant and extirpated LAAL colonies.

Laysan Albatross Population Size

Laysan Albatross have a world population of an order of magnitude larger than Black-footed Albatross, estimated at 768,895 breeding pairs (Table 6).

Laysan Albatross Trend

The Conservation of Albatrosses and Petrels (ACAP) data managers have used the rTRIM model on Laysan Albatross and found that the population is stable.

Table 6. Estimate of LAAL world population size (number of breeding pairs, #bp) in 2017, based on the most recent data. Black font indicates the counts are from the 2017 breeding season. Red font indicates that the latest count data pre-date 2017.

Extirpated sites (date)	Latitude-Longitude	# Bp pairs
Johnston Atoll (1 nest 1923)	16° 45' N 169° 32' W	0
Nihoa Island	23° 03' N 161° 56' W	0
Torishima (none by 1930)	30° 29' N 140° 19' E	0
Active colonies		
Clarion	18° 21' N 114° 43' W	46
French Frigate Shoals	166° 10' W 166° 10' W	2,892
Isla Guadalupe	29° 02' N 118° 17' W	1,131
Kaua'i	22° 05' N 159° 30' W	319
Kaula Rock	21° 39' N 160° 32' W	10
Kure Atoll	23° 03' N 161° 56' W	35,538
Laysan Island	25° 46' N 171° 45' W	134,835
Lehua Island	22° 01' N 160° 06' W	47
Lisianski Island	26° 04' N 173° 58' W	26,500
Midway Atoll	28° 15' N 177° 20' W	559,862
Mukojima	27° 41' 24" N 142° 11' E	18
Necker (Mokumanamana)	23° 35' N 164° 42' W	500
Ni'ihau Island	21° 54' N 160° 10' W	190
O'ahu	21° 41' N 157° 57' W	85
Pearl and Hermes Atoll	27° 50' N 175° 50' W	6,900
Rocas Alijos	24° 58' N 115° 45' W	4
San Benedicto	19° 19' N 110° 48' W	17
Wake Atoll	19° 18' N 166° 35' E	1
		768,895

Conclusions

The populations of the two most numerous of the three North Pacific albatrosses appear to be stable for the time being but have been listed by the IUCN as Near Threatened (NT) because of the high likelihood of catastrophic habitat loss in the future due to anthropogenic climate change. Fishery interactions have been identified as an ongoing concern, especially for Black-footed Albatross. This concern will be amplified if the judgement changes regarding the genetic work that triggered a review of the taxonomic status of the Japanese population of Black-footed Albatross by the Taxonomy Working Group of ACAP. A molecular study by Walsh and Edwards (2005) showed significant population genetic differentiation between Hawaiian and Japanese colonies. These data suggest the Japanese and Hawaiian colonies are significantly differentiated at this locus, but there was no differentiation within the Hawaiian Islands. Eda et al. (2008) expanded the Walsh and Edwards study to include 50 samples from Japan's Bonin Islands (western North Pacific). The authors suggested that these islands may be more representative of the western Pacific colonies as those birds from the Izu Islands are likely to be the "result of relatively recent re-colonization or have increased following a severe population bottleneck." This study found the haplotype common on Izu was also common in the Bonin colonies (0.9) and therefore were also strongly differentiated from the Hawaiian colonies.

Although these two studies report strong population genetic differentiation between Japanese and Hawaiian colonies, the two groups do share some haplotypes suggesting that genetic separation is relatively recent. Ando et al. (2011) studied eleven polymorphic microsatellites in Black-footed Albatross from the Bonin Islands and found no genetic differentiation among the sub-populations of those islands. To date, there have been no studies of other mitochondrial regions, genomic markers (such as microsatellites), or formal studies of morphological differences between birds from the western and eastern Pacific. Anecdotal references suggest Japanese birds tend to be smaller than Hawaiian birds (see Walsh and Edwards 2005). The taxonomy working group found no other differences in functionally independent characters, so they determined that while the genetic data suggest strong population genetic differentiation between the Japanese and Hawaiian Island colonies of Black-footed Albatross there is insufficient information to support any taxonomic revision of Black-footed Albatross even at the subspecific level. Indeed, the genetic differentiation revealed by the studies summarized above could have been elevated by the severe and recent population bottlenecks in the Japanese colonies (from intense feather collecting), thus it would be premature to act on these data alone. Further genetic and morphological studies are required before a taxonomic amendment could be justified. If the groups were separated, the Japanese population (3,167 pairs) would immediately have its concern level increased because of a small population size.

Acknowledgements

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Population-Level Assessment of Black-Footed Albatross Foraging Distributions and Habitat Use in the North Pacific

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Introduction

Black-footed Albatross (*Phoebastria nigripes,* BFAL) are wide-ranging, large pelagic seabirds that breed on 17 subtropical islands in the central and western North Pacific (see Flint and Fraiola, this report). Albatross spend 90% of their lives at sea but become central place foragers when tied to a colony for breeding (Warham 1990; Tickell 2000). This facet of their life history has facilitated our understanding of their at-sea distribution and behavior by deploying a suite of telemetry devices to record their movement and activity. Together, these perspectives provide valuable ecological insights into their distribution and habitat use patterns. Multiple visits to the colony while breeding have ensured high recapture rates (> 90% recovery) for recovery of deployed tracking devices. To date, BFAL have been tracked from Tern Island, French Frigate Shoals (23.9°N, 166.2°W), Midway Atoll (28.2°N, 177.4°W), Kure Atoll (28.4°N, 178.3°W), and several at-sea locations off California and Alaska. These studies have characterized movement patterns during 1) each phase of the breeding season (incubation, chick guard, and chick rearing), 2) the post-breeding dispersal of breeders, and 3) the year-round movements of non-breeders. Additionally, complementary analyses of tissue samples (blood, feathers) diet samples, morphometric data (e.g., body mass and skeletal dimensions), and demographic information (breeding success, breeding history, age, and sex) have facilitated the interpretation of the tracking data. Our results highlight differences in foraging distributions associated with distinct breeding phases within a given colony and colony-based differences in at-sea distribution during the breeding and post-breeding periods. These patterns provide an ecological and life-history context for the examination of BFAL interactions with the Hawaii longline fishery.

Methods

Over the last 20 years, BFAL have been tracked using a variety of tracking devices, each with different limitations on battery life, accuracy, and types of data provided. Between 1997 and1999, adult BFAL were tracked at Tern Island using conventional satellite platform terminal transmitters (PTTs) attached to feathers on the dorsal region between the scapula (Fernández et al. 2001; Hyrenbach et al. 2002). On average, these devices yield 12 locations per day, with an accuracy ranging from 150 m to several km. Additional tag deployments were conducted on adult BFAL at Tern Island from 2002 through 2011, using either satellite PTTs, geolocation loggers, GPS data loggers, or a combination of these tags (Shaffer et al. 2005; Kappes et al. 2010, 2015; Conners et al. 2015; Thorne et al. 2015, 2016; Žydelis et al. 2011). Geolocation loggers (hereafter GLS–global location sensor) yielded only 2 locations per day, with an accuracy of approximately 200 km (Phillips et al. 2004; Shaffer et al. 2005). However, these tags are ideal for recording continuous long term (several years) movements because they are mounted on field readable plastic bands and do not fall off during molt. More recently, GPS loggers, first deployed on adult BFAL at Tern Island in 2006 and then 2008–2011, have an accuracy of 3 m and a sampling frequency between 10 seconds and 10 minutes, yielding high resolution spatiotemporal data to delineate fine-scale foraging behavior (e.g., Conners et al. 2015). Both GLS and GPS loggers have been used to study the long range (GLS) and fine-scale (GPS) movements of adult BFAL at Midway (2012–2016, Gutowsky et al. 2014a, 2015) and Kure Atoll (2012–2013, Hester et al. in prep). Satellite PTTs were also used to study the movements of post-breeding adult BFAL captured and released at sea, off the coasts of California (Hyrenbach and Dotson 2001, 2003; Hyrenbach 2008) and the Aleutian Islands in Alaska (Fischer et al. 2009). Finally, satellite PTTs were deployed on fledgling BFAL at Midway Atoll from 2006 to 2008 (Gutowsky et al. 2014b).

Tracking data have been combined with satellite remotely-sensed environmental data to examine the movement patterns and distribution of BFAL in relation to oceanographic features, like sea surface temperature (SST), sea surface height (SSH), chlorophyll a concentration (chl-a), bathymetry, wind stress curl, eddy kinetic energy (EKE), and distance to transition zone chlorophyll front (distTZCF). Overall, these features partially explain (in part or in combination) the observed distributions and patterns of area restricted searching of BFAL (e.g., Hyrenbach et al. 2002; Kappes et al. 2010: Thorne et al. 2015). Finally, tracking data and oceanographic correlates have been used to examine linkages between BFAL distributions and fisheries (Fischer et al. 2009: Žydelis et al. 2011).

Key findings

The published tracking studies underscore two patterns of at-sea distribution related to the timing of their breeding cycle and the location of the breeding colonies.

1) BFAL distribution and movement patterns vary according to breeding phase. During the incubation phase, foraging trips frequently extend beyond 10 days in duration and range over 2,000 km from the colony to pelagic waters northeast of Tern Island (Kappes et al. 2010, 2015). After hatching, BFAL parents brood their chicks for about 3 weeks and are most constrained because chicks require frequent, small meals. Therefore, foraging excursions are typically less than 3 days in duration and occur within 300–400 km of the colony (Table 7). As parents' transition to rearing larger chicks, both male and female BFAL often travel to productive waters off the continental U.S. and Canada, extending their foraging ranges to nearly 3,000 km for durations of two weeks. Although foraging behavior varies widely across breeding phases, BFAL from Tern Island forage within or transit through the fishing grounds of the Hawaii deep-set longline fishery (see Wren and Polovina, this report). On the other hand, BFAL from Kure Atoll venture into the NW Pacific and may overlap with Japanese and Taiwanese longline fisheries (Hyrenbach et al. 2017).

2) Population-level differences in distribution exist among BFAL colonies of the Northwest Hawaiian Islands. Tracking studies reveal population-level differences in foraging distribution among the three BFAL colonies where birds have been tracked: Tern Island, Midway Atoll, and Kure Atoll. GPS tracking data collected during the late incubation and chick-brooding periods at Tern and Midway reveal spatial segregation of birds from these two colonies at-sea (Figure 16). Nevertheless, this result needs to be interpreted with caution since the number of tracked individuals is quite small relative to the total population at each colony. Thus, more tracking information is needed to fully evaluate whether fine-scale segregation occurs for these and other colonies.

Nevertheless, the GPS tracking data suggest that BFAL from Tern Island likely overlap more with the core fishing grounds of the Hawaiian deep-set longline fishery (25–30 ° N, 150–165 ° W) (Table 7). Population-level differences in core habitat and home ranges of BFAL from multiple colonies are also evident throughout the year (Figure 16). Long-range movement patterns show minimal overlap of core habitats during 3 of the 4 quarters, whereby Tern Island birds exhibit a distinct easterly bias from the colony and Midway birds exhibit a westerly bias. The greatest overlap in distribution occurs during Quarter 3, when birds have completed breeding and are no longer tied to the colony (Figure 16).

Table 7. Distributional ranges of foraging Black-footed Albatross from Tern Island and French Frigate Shoals during the breeding phases (Kappes et al. 2015). In addition to foraging ranges, geographic coordinates of core habitat, trip durations, trip duration and range, and azimuth (Az) to the maximum distance location from the colony are also displayed. Means ± SDs are reported.

Phase of Breeding	Dates	Max. Range Latitude Longitude	Core Habitat Latitude Longitude	Trip Duration (days)	Trip Range from Colony (km)	Az to Maximum Distance Location (deg)
Incubation	early Dec – late Jan	17°N–52°N	21°N–41°N	13.30	2,045	22.8
		166°E–121°W	175°W–155°W	± 5.07	± 1,035	± 32.5
Brooding	late Jan – late Feb	22°N–27°N	23°N–25°N	2.67	313	47.4
		170°W–158°W	169°W–165°W	± 0.87	± 144	± 65.7
Rearing	early Mar – late Jun	17°N–60°N	22°N–52°N	14.40	2,883	31.9
		165°E–130°W	169°W–138°W	± 5.14	± 998	± 35

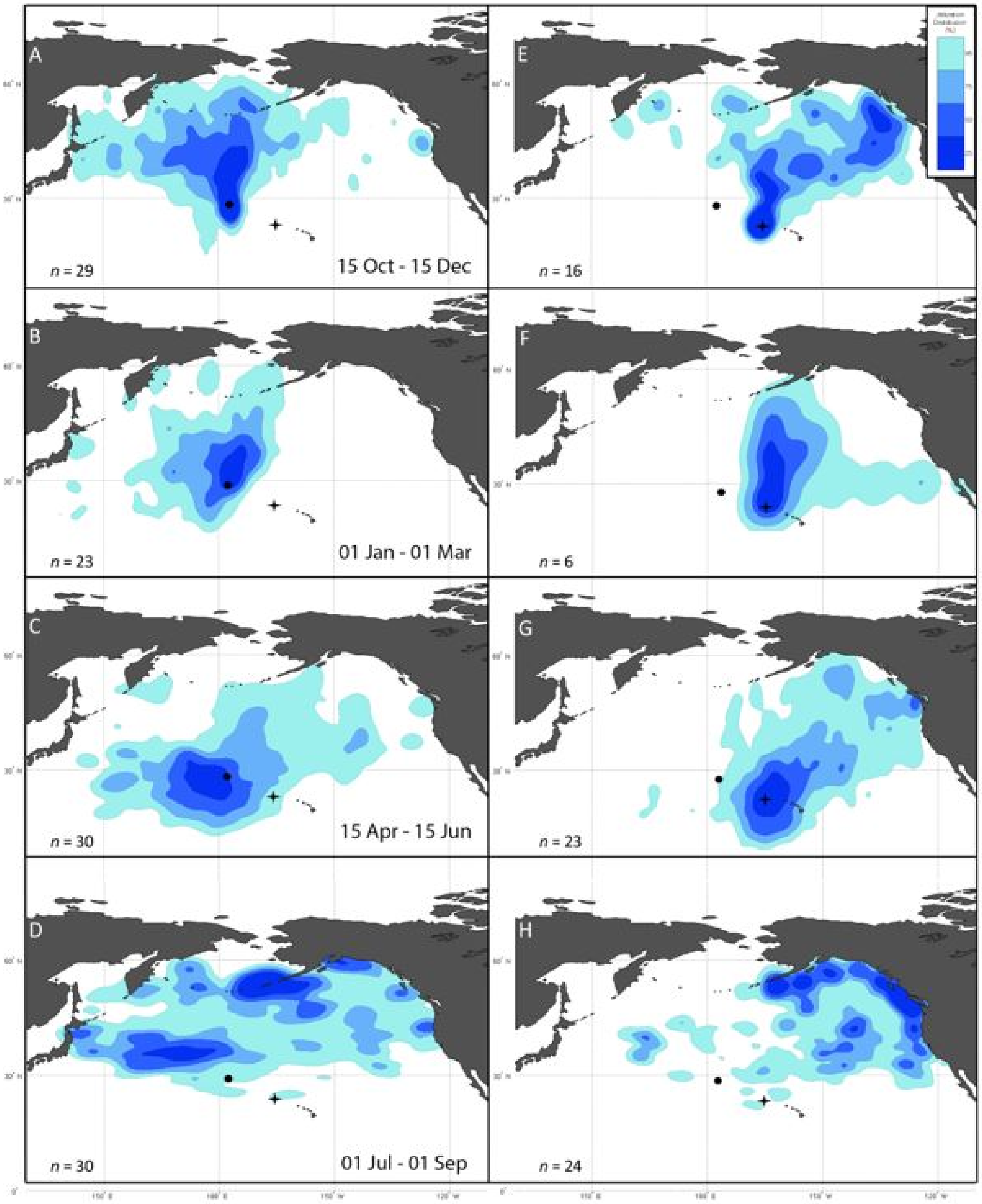

Figure 16. Colony-level differences in at-sea distribution of BFAL from Midway Atoll (panels A–D) and Tern Island (panels E–H). Panels for each population represent quarters of the calendar year, beginning when birds first return to their colony in October. BFAL were tracked throughout the year using GLS loggers deployed on birds attending a nest at Midway (2008–2013) and Tern (2008–2010). Each panel shows four kernel utilization distributions (95%, 7. Each panel shows four kernel utilization distributions (95%, 75%, 50%, 25%) based on the legend in panel E.

Next steps

The patterns documented by tracking BFAL at three sites (French Frigate Shoals, Midway Island, Kure Atoll) account for 48.4% of the global breeding population. However, additional tracking studies are needed to assess the spatial distribution of BFAL from other major breeding sites, which account for a substantial proportion of the BFAL global population. In particular, Laysan Island, Pearl and Hermes, and Lisianski Island are key sites; they comprise 35.0%, 8.7%, and 3.0% of the global population, respectively (see Flint and Fraiola, this report). Thus, a comparative multi-colony study spanning the entire breeding season and the post-breeding dispersal would allow analysis of inter-colony segregation and overlap with the Hawaii deep-set longline fishery (Figure 17).

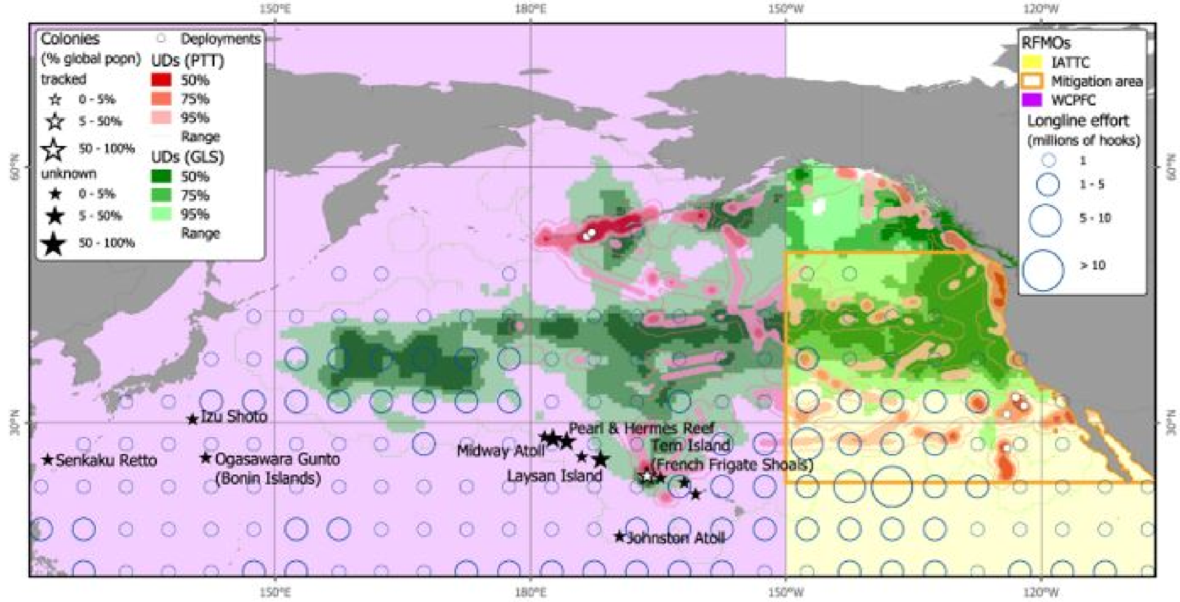

Figure 17. At-sea distribution of BFAL overlaid on longline fishing effort across the North Pacific. Shown are kernel utilization distributions from a combination of tracking data from multiple research programs (e.g., Shaffer, Hyrenbach, and Suryan labs). The data are not parsed by colony origin, sex, or temporal period (i.e., year or quarter). Instead, they show BFAL distributions and hotspots overlaid on fishing effort. Image courtesy of BirdLife International.

Two other ancillary analyses would further inform population-level impacts of longline fisheries mortality on BFAL. First, due to the potential impacts of differential age-specific and sex-specific mortality on population-level impacts, investigating the at-sea distribution of birds of different age classes and sexes would inform the observed demographic composition of the bycatch (see Russell et al., this report). While some age- and sex-specific differences in at-sea distribution have been observed, more data are needed to fully resolve these observations.

Additionally, another key area of research entails quantifying the degree to which BFAL rely on the longline fishery in terms of their aggregation at vessels and their ingestion of bait and discards. New analyses using biochemical assays of diet samples from tracked BFAL confirm the consumption of longline associated prey. Analysis of wet diet from BFAL has not been performed since Harrison et al. (1983). Thus, more than 30 years have passed without any comprehensive analysis of albatross diets from the Northwest Hawaiian Islands. Conners et al. (2018) recently analyzed stomach oil samples collected from BFAL adults tracked at Tern Island. Each bird was tracked using GPS loggers prior to sampling stomach oil so behavior and diet were collected simultaneously. Stomach oil was analyzed using quantitative fatty acid signature analysis (QFASA) and compared to the QFASA of a known prey library. The analysis revealed that overall, < 10% of pooled diets contained fisheries associated prey. However, the incidence of fisheries-associated resources was highest during the 2009–10 breeding season when there was a moderately strong central Pacific El Niño. The diets from a few individual birds contained almost entirely fisheries-associated resources, suggesting some specialization.

Together with the tracking data, these dietary analyses can be used to explore individual-level, sex-based, and age-based variability in the degree of BFAL overlap and reliance on the longline fishery. These metrics could then inform the demographic composition of the BFAL bycatch (see Russell et al., this report) and survivorship rates (see Kendall et al., this report)

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Oceanographic Variation During Winter and Spring in the Hawaii-Based Deep-Set Longline Fishing Grounds North of 25° N Latitude

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Introduction

An analysis of Black-footed Albatross interactions with the Hawaii deep-set longline fishery based on data from 2004 to 2014 suggested that interactions were higher during El Niño periods (Gilman et al. 2016). Gilman et al. (2016) did not look specifically at oceanographic conditions or factors that might result in higher interactions. In 2015 and 2016, interaction rates reached higher levels prompting this look at the role oceanographic variation may play in Black-footed Albatross interaction. Typically, Black-footed Albatross interactions with the Hawaii-based deep-set longline fishery are highest north of 25° N latitude and during the first two quarters of the year so this was the spatial and temporal focus of our oceanographic analysis.

There are two dominant modes of oceanographic and atmospheric variation in the North Pacific Ocean, the Pacific Decadal Oscillation (PDO) (Mantua and Hare 2002) and the El Niño and Southern Oscillation (ENSO) (Figure 18). Both modes have similar mid-latitude and equatorial oceanographic responses, but the PDO response typically occurs on a decadal scale with a greater mid-latitude impact while the ENSO events typically occur on an inter-annual scale with a greater equatorial response (Figure 18).

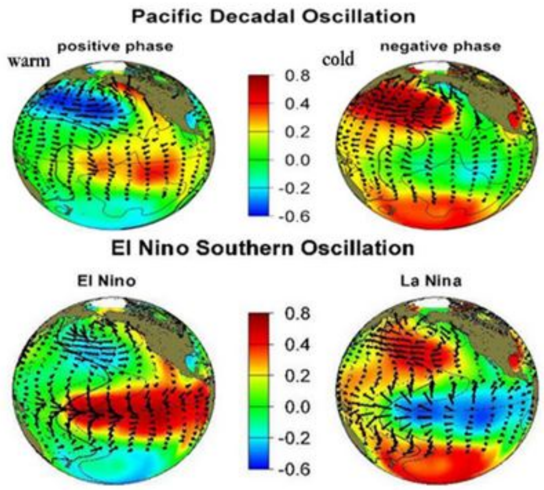

Figure 18. Positive and negative phases of PDO (top) and ENSO (bottom) with arrows indicating surface wind speed and direction anomalies and color scale indicating sea surface temperature anomalies. Image courtesy of JISAO (joint institute for the study of the atmosphere and ocean).

In the mid-latitudes during the positive phase of PDO and El Niño, the Aleutian low pressure system intensifies, westerly winds strengthen and expand southward resulting in cooler mid-latitude sea surface temperature (SST) (Figure 18). In contrast, during the negative phase of the PDO or La Niña, the Aleutian Low weakens, westerlies weaken and shift northward replaced by trade winds resulting in warmer mid-latitude SST (Figure18). When the PDO is positive and an El Niño occurs, or when the PDO phase is negative and a La Niña occurs, the two modes are "in phase," potentially amplifying their respective responses.

Methods

We used satellite remotely-sensed surface wind, sea surface temperature, and surface chlorophyll a to describe how ENSO and PDO impact the oceanography north of 25ºN latitude and between 165º–150º W longitude during the first two quarters of the years 2006–2017 (Figure 19). This spatial and temporal box covers the area and season where the great majority of the Black-footed Albatross interactions have occurred. In 2011 and 2012, quarters 1 and 2 were characterized as both La Niña and negative PDO periods (Figure 20). Quarters 1 and 2 of 2015 and 2016 were both positive PDO and El Niño periods (Figure 20). Quarter 1 of 2010 was an El Niño period and quarter 1 of 2017 was a marginally positive PDO period (Figure 20). Thus, using oceanographic data from these recent years covering alternate PDO and ENSO periods enables us to explore how these modes of climate variation may alter the oceanography in the region of deep-set fishing grounds where interactions occur.

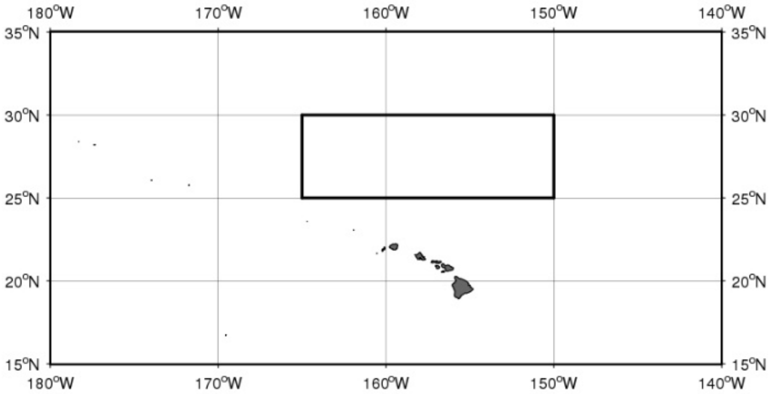

Figure 19. Map of the Hawaiian Archipelago with a box showing the area fished by the Hawaii deep-set fishery north of 25o N latitude during winter and spring.

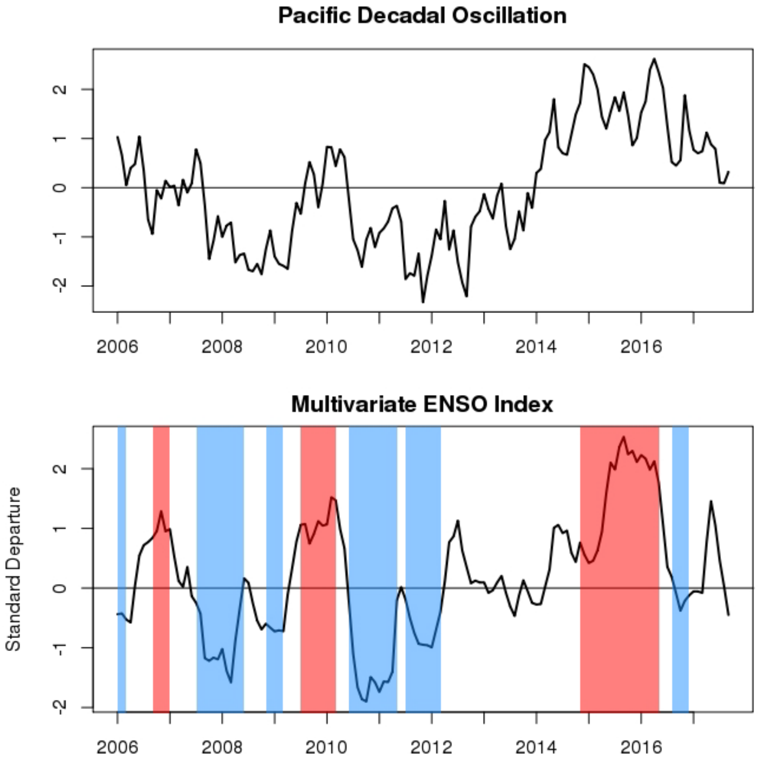

Figure 20. Time series (2006–2017) of PDO (top) and Multivariate ENSO Index (MEI) (bottom). El Niño and La Niña periods are shaded in red and blue, respectively.

Results

During quarter 1 of most years, including La Niña and negative PDO years (2011, 2012), the east-west component of the wind in the Hawaii deep-set fishing ground north of 25º N latitude is generally trade winds, blowing from the east to the to the west and shown as negative speeds (Figure 21). However, during quarter 1 of El Niño and positive PDO periods (2010, 2015, 2016), the east-west component of the winds is westerlies, blowing from the west to the east and shown as positive speeds (Figure 21).

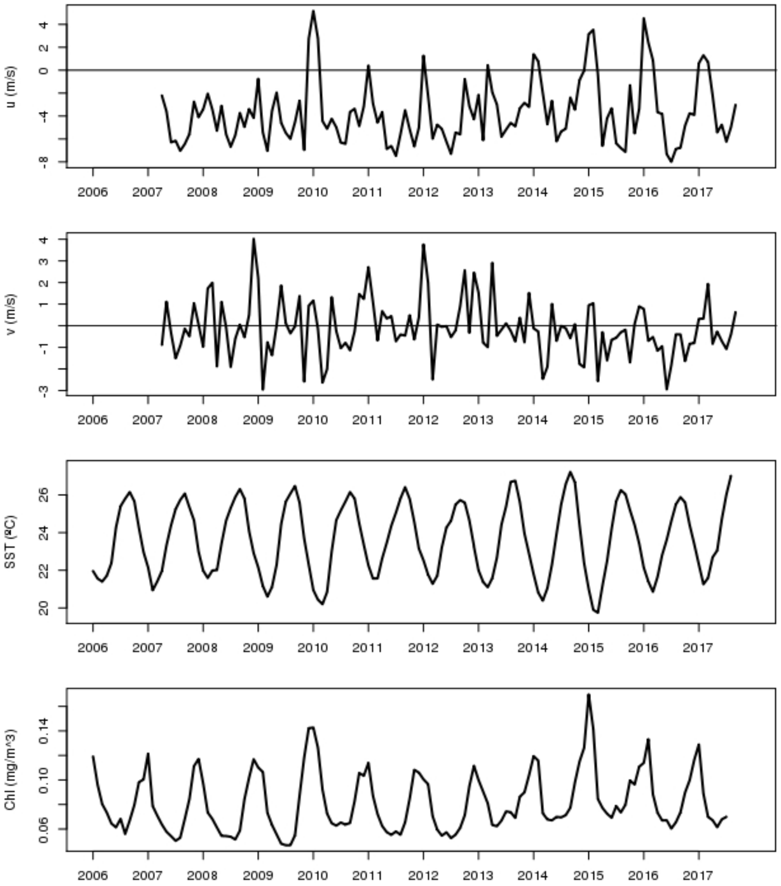

Figure 21. Time-series (2006–2017) of mean monthly east-west wind (U), north-south wind (V), SST, and chlorophyll (Chl) in box 165º–150ºW, 25º–30º N.

The north-south component of the wind is generally weaker than the east-west component and more variable. When blowing to the south, (i.e., during El Niño and positive PDO periods (2010, 2015, 2016)), wind speed is depicted as negative; when blowing to the north, (i.e., during La Niña and negative PDO quarters 1 and 2 (years 2011, 2012)), wind speed is depicted as positive. (Figure 21). The east-west direction of the winds, trades vs. westerlies, largely determines the temperature and chlorophyll a anomalies in the region. Transport of surface water moves to the right of the direction of the prevailing wind as defined by the Ekman spiral (Chereskin 1995). Specifically, the transport of water from the surface to 100 m is at a right angle to the prevailing wind direction.

Given the strong latitudinal gradient associated with colder and higher chlorophyll a water to the north, westerlies result in the southward transport of these waters into the region. Trade winds in contrast result in northward transport of warmer, low surface chlorophyll a water into the region. Thus, sea surface temperature (SST) is colder and surface chlorophyll a higher in the region during the first 2 quarters of El Niño and positive PDO years (2010, 2015, 2016) compared the first 2 quarters of La Niña and negative PDO years (2011, 2012) (Figures 21, 22).

The Transition Zone Chlorophyll Front (TZCF) (Polovina et al. 2001) is a prominent basin-wide zonal chlorophyll front located at approximately 32º N latitude north of Hawaii during the winter and serves as an important forage habitat for Black-footed Albatross (Thorne et al. 2015; Bograd et al. 2004). Its latitude is a function of wind-driven Ekman transport. During positive PDO and El Niño years, this front can shift south to 28º N latitude bringing it inside the deep-set longline fishing grounds while during negative PDO and La Niña years it can shift north of the fishing ground to 33º N latitude (Bograd et al. 2004).

Not only is the mean SST in the region colder during quarters 1 and 2 of El Niño and positive PDO, but the quarters are also characterized by stronger horizontal gradients between colder and warmer water and enhanced chlorophyll a (2016 Q1, Figure 22). The stronger horizontal temperature gradients (fronts) together with higher chlorophyll suggest an increase in productive surface fronts that may provide forage habitat for Black-footed Albatross. During La Niña and negative PDO, surface chlorophyll a in reduced and surface temperature gradients are weaker (2011–2012 Q2, Figure 22).

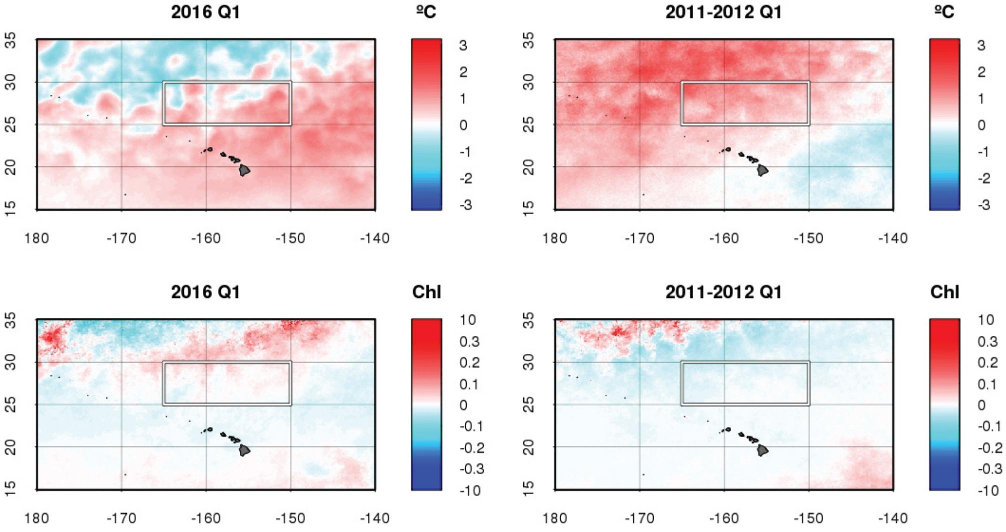

Figure 22. Monthly SST (ºC) (top) and chlorophyll a (Chl) (bottom) anomalies during quarter 1 (January–March) with the box indicating the deep-set fishing ground north of 25ºN latitude. Warmer sea surface temperatures and higher chlorophyll a concentrations are shown by the red shading, respectively

The El Niño and positive PDO result in oceanographic conditions characterized by more productive waters, more fronts, and the southward-shifted TZCF—all conditions that may enhance the foraging habitat in the deep-set fishing grounds. These conditions may attract more foraging Black-footed Albatross resulting in increased interactions with the fishery.

Conclusions

ENSO and PDO are the dominant modes of climate variation in the North Pacific, and both impact the winter and spring mid-latitude oceanography. An El Niño (La Niña) and the positive (negative) phase of the PDO have similar mid-latitude oceanographic impacts. During an El Niño or positive phase of the PDO, winds during quarter 1 in the deep-set longline fishing ground north of 25° N latitude shift from trades to westerlies and from a slight northward component to southward. Westerlies transport colder, higher surface chlorophyll a water, including the TZCF, southward potentially creating more productive surface fronts and hence forage habitat for Black-footed Albatross during quarters 1 and 2 in the deep-set fishing ground.

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Evaluation of Fleet Dynamics and Oceanography as Factors Accounting for Variations in Black-Footed Albatross Interactions in the Hawaii-Based Deep-Set Longline Fishery 2006–2017

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Introduction

The Hawaii-based deep-set longline fishery targets bigeye tuna *(Thunnus obesus)* but occasionally seabirds go after baited hooks, get hooked, and drown as the gear sinks. While mitigation efforts to reduce seabird bycatch have been successful (Gilman et al. 2016), Black-footed Albatross (*Phoebastria nigripes*) interactions have increased in the past three years from an average of 0.005 birds per 1,000 hooks in 2004–2014 (Gilman et al. 2016), to an average 0.016 birds per 1,000 hooks in 2015–2017.

The Black-footed Albatross (henceforth BFAL) nests in the Northwestern Hawaiian Islands from November through June. The birds incubate the eggs from November to January, during which time they routinely take foraging trips of 7 to 20 days. Once the chick hatches, its high energy demand limits adult foraging trips to 1–3 days, reducing the area over which the adults can forage (Hyrenback et al. 2002; Shaffer et al. 2003).

Possible factors responsible for the recent increase in interactions with the fishery include changes in fishing ground location or fishing season, changes in oceanography, or increased black-albatross population size. We will use generalized additive models (GAMs) to explore these factors.

In particular, we explore the relationship between BFAL sightings in the Hawaii-based deep-set longline fishery and fleet dynamics, oceanographic factors, including both large-scale climate variability due to the Pacific Decadal Oscillation (PDO) and El Niño–Southern Oscillation (ENSO), as well as local oceanographic and biological drivers, such as sea surface temperature and wind patterns. We also examine impacts from variations in the size of the breeding albatross population.

Methods

Data

We used data collected by the Hawaii-based deep-set longline fishery observer program. The observer program covers approximately 20% of the deep-set fleet and records data on targeted and incidental catch for each set during a vessel trip. Additionally, observers conduct a seabird scan at the start and end of each set in which they record the species and count of all birds present in a 137 m radius of the boat (NMFS 2010). Each data record contains information on the species and number of birds sighted during the scan along with the species, count, time, date, and location of any seabird interactions.

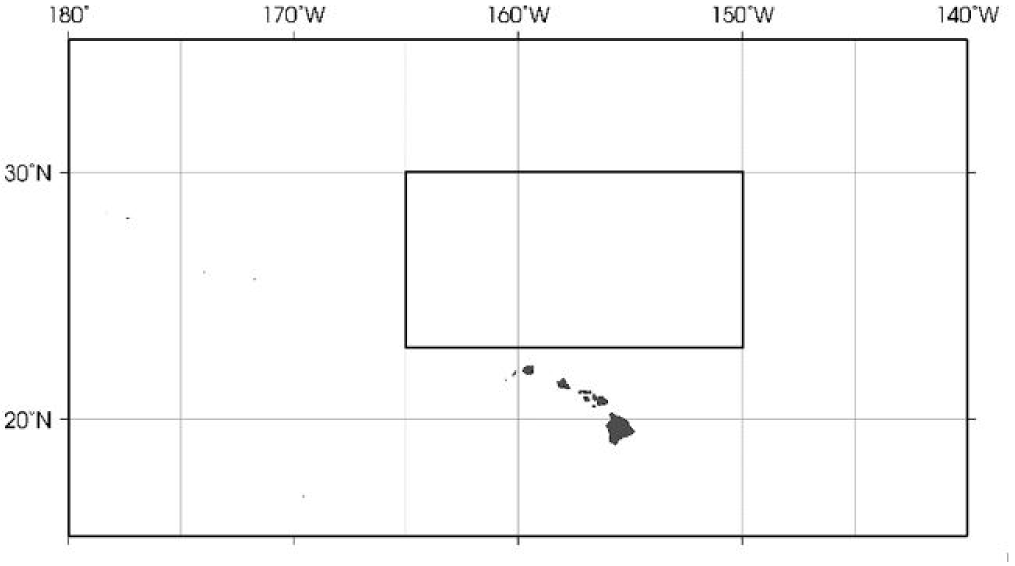

Figure 23. Map of the Hawaiian Archipelago with a box showing the area of high Black-footed Albatross interaction with the Hawaii deep-set longline fishery.

We used these data to generate models for BFAL sightings and catches from January 2006 until July 2017, as a function of 13 potentially important explanatory variables, including temporal and spatial fishing effort distribution (month, latitude and longitude), environmental drivers (chlorophyll a, standard deviation of sea surface temperature, wind stress curl, zonal and meridional wind velocities), biological drivers (number of BFAL nests and reproductive success at French Frigate Shoals), and climate drivers (Multivariate ENSO Index [MEI] and PDO). The environmental variables used were monthly remotely sensed data, accessed through OceanWatch (http://oceanwatch.pifsc.noaa.gov) and CoastWatch (http://coastwatch.pfeg.noaa.gov), and the data were averaged over the core interaction area spanning 23–30°N and 150–165°W (Figure 23).

Statistical analysis

To investigate the effect of fleet behavior on BFAL sightings, we built a GAM using independent variables of factorial month, with smoothers for hooks set (proxy for effort), and longitude and latitude. Additionally, a GAM using environmental independent variables along with season (month) and location of the sightings was constructed to evaluate the effects of environmental, biological, and climate variables. Before the GAM's were built, the independent variables were tested for collinearity, and only variables that were not collinear were used. Because the data were overdispersed, we used a negative binomial GAM with a log-link function.

Because of the low interaction rates of BFAL in the deep-set longline fishery, there were not enough data to build a GAM for the interactions as a function of environmental variables. Therefore, we calculated a linear correlation between BFAL sightings and interactions.

To evaluate the performance of the GAMs, we predicted the BFAL using set location and mean monthly values of the biological and environmental variables from the core area described above. We then calculated the correlation between the observed and predicted BFAL sightings.

Results

Fleet dynamics

The fleet dynamic GAM (using month, latitude, and longitude as independent variables) was the poorest performing GAM (Table 8), and when used to predict sightings, had one of the lowest correlations with observed sightings ($r = 0.8$, $p = 1.80\times10^{-31}$). The GAM smoother showed strong monthly, latitudinal, and longitudinal components. Sightings were highest in the first six months of the year and increased going northward and eastward. The predicted sightings captured the seasonal variability well but did not capture the increase in sightings during the first two quarters of 2015–2017 (Figure 24). Additionally, the predicted sightings overestimated the sightings in the beginning of the time series.

Table 8. Table showing GAM performance for the eight models built. These models are ranked by performance based on percent deviance explained, and the correlation between the observed and GAM predicted Black-footed Albatross sightings. All variables were highly significant with $p < 2\times10^{-16}$.

	Predicted Sightings		GAM performance	
Variable	r	rank	% deviance explained	rank
U velocity	0.866	1	42.5	5
PDO	0.860	2	44.9	1
SST S.D.	0.848	3	42.3	6
Chl a	0.824	4	42.9	3
MEI	0.816	5	43.9	2
Fleet	0.798	6	41.2	8
Curl	0.792	7	42.7	4
V velocity	0.785	8	41.5	7

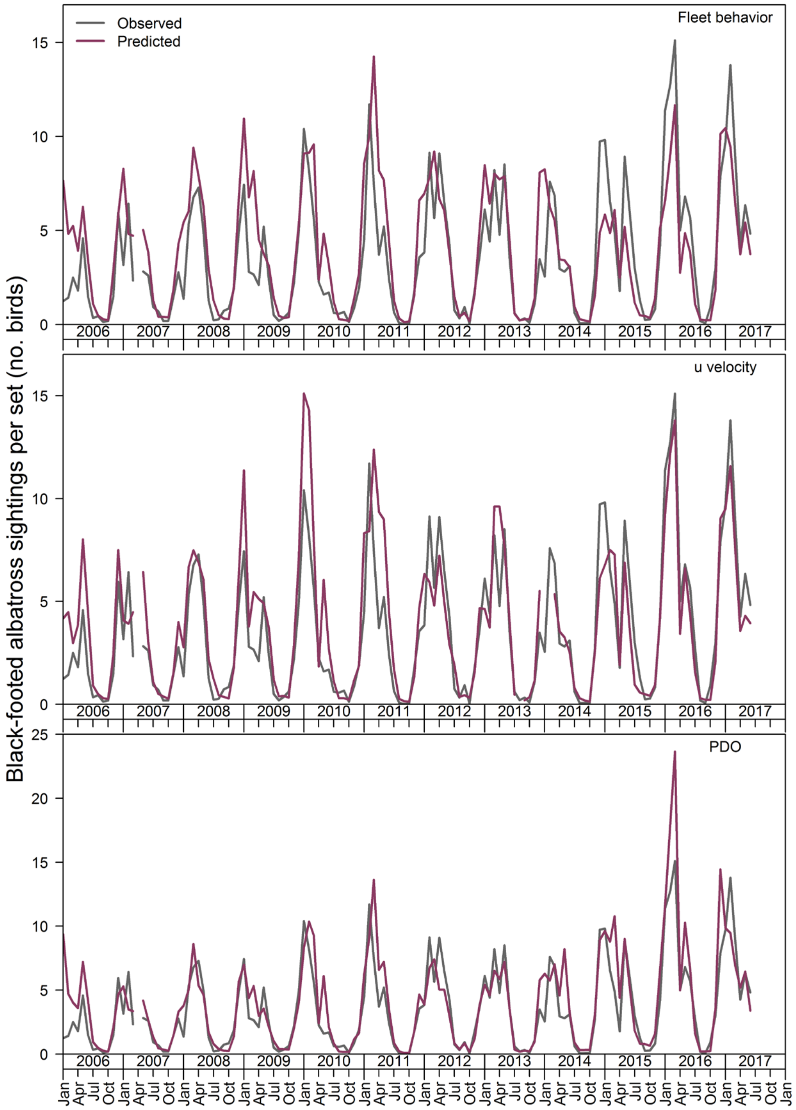

Figure 24. Observed (gray) and GAM predicted (purple) mean monthly Black-footed Albatross sightings per set from January 2006 until July 2017 for three conceptual models: a) fleet behavior, b) local oceanography, and c) larger-scale climate variability. The annual cycle in sightings coincide with the albatross breeding season.

Local oceanography

Local oceanographic variables used to drive five different GAM models are the standard deviation of sea surface temperature (SST S.D.), which is an indicator for frontal strength, chlorophyll a concentrations, wind stress curl, and the zonal (u) and meridional (v) wind velocities. These variables all describe the local oceanography in the region and indicate how productive the waters are. The best performing GAM using local oceanographic variables was the chlorophyll a GAM, followed by the wind stress curl, u component of the wind velocity, SST S.D., and v component of the wind velocity (Table 8).

When GAMs were used to predict BFAL sightings, u wind velocity had the highest correlation, followed by SST S.D., chlorophyll a, wind stress curl, and v wind velocity. The u wind velocity GAM improved the fit to the observed sightings compared with the fleet dynamic GAM and captured the seasonality and increase in sightings during 2016 and 2017 (Figure 24, top). However, it underestimated the sightings in 2012 and 2015, and overestimated sightings by 50% in 2010. The zonal (u) wind velocity smoothing term shows that there is a positive linear relationship between westerly winds and sightings; however, trade (easterly) winds have a non-linear relationship and the lowest observed sightings, suggesting that strong westerlies lead to more birds foraging in the fishing grounds, but trade winds result in few BFAL sightings.

Large-scale climate variability

For larger-scale climate variability, the GAM that used PDO as an independent variable was the best fit model and explained 44.9% of the deviance, followed by MEI, which explained 43.9% of the deviance (Table 8). When comparing predicted and observed sightings, the PDO model had the second strongest correlation, while the MEI model ranked lower and below many of the local oceanography variables.

The observed BFAL sightings and the PDO GAM predicted sightings are highly correlated (Table 8, Figure 24. bottom). Though the GAM captures the inter-annual variability, it overestimates February and March 2016 sightings by 41% and 56%, respectively.

The PDO smoother from the GAM is similar to the smoother for the u component of the wind velocity. Positive PDO has a positive linear relationship with BFAL sightings, while negative PDO is associated nonlinearly with the lowest sightings. GAM models fit with nesting population size and reproductive success failed to produce biologically realistic results and were not considered further.

Interactions

There is a strong positive linear relationship between average monthly BFAL sightings and catches during the 11-year time series ($p < 0.001$, $R^2 = 0.63$; Figure 25), suggesting the sightings are representative of the interactions. The interactions during June 2015 were anomalous, with two boats hooking 40% of the BFAL; thus, June 2015 was excluded from the linear correlation.

Conclusions

The recent increase in Black-footed Albatross interactions is not explained by fleet dynamics alone; it requires oceanographic interactions as well. Both large-scale and local climate variables explain the recent increase in BFAL interactions, namely positive PDO, strong westerly winds, high chlorophyll *a*, and cooler temperatures. PDO has a stronger response in mid-latitude compared with ENSO variability (Mantua and Hare 2002), so it is not surprising that PDO is a better predictor over MEI of BLAL interactions. The local oceanographic variables capture the positive PDO conditions and show that strong westerly winds and temperature fronts lead to high BFAL interactions. The connection to the PDO rather than ENSO explains why BFAL interactions remain high in the first half of 2017, a normal state ENSO year, but a positive PDO year.

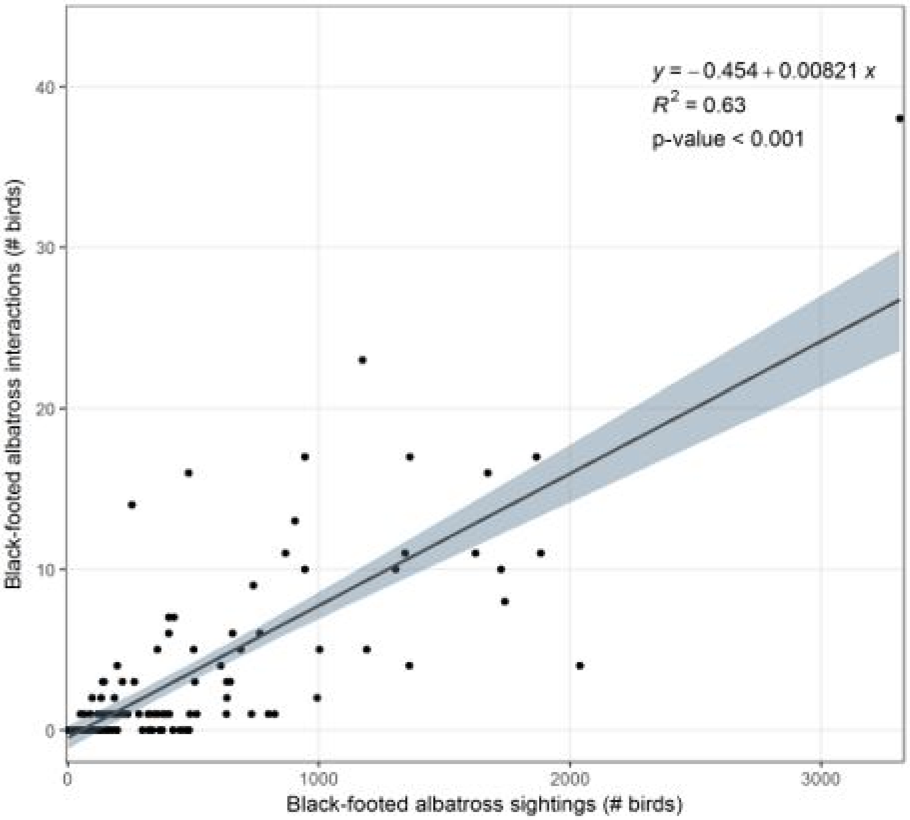

Figure 25. Linear regression between monthly Black-footed Albatross sightings and interactions north of 23°N latitude from January 2006 to July 2017. The gray shading represents ± two standard errors.

Albatrosses are more successful foragers and have higher chick rearing success during strong wind regimes (Thorne et al. 2015). While the increase in wind fields during El Niño/+PDO years leads to a greater fitness of the albatross, it also leads to greater interaction rates with the Hawaii longline fishing fleet. Conversely, during La Niña/-PDO periods, BFAL are forced to forage further to the north due to the northward displacement of the productive fronts, thus spending less time in the fishing grounds, resulting in lower sightings and interactions.

The recent increase in BFAL interactions with the Hawaii-based deep-set longline fishery can be attributed to increased overlap of BFALs' preferred foraging habitat with the fishing grounds. Gilman et al. (2016) showed a positive relationship between ENSO and BFAL interactions in the Hawaii-based longline fleet, and Thorne et al. (2016) found that BFAL are more successful foragers and have better chick rearing success during El Niño conditions. We found that BFAL interactions are primarily driven by PDO patterns and to a lesser extent ENSO, an important distinction because the PDO has a longer cycle (20–30 years) compared with ENSO (8–18 months). Therefore, the high levels of sightings and interactions may persist for many years rather than being a short episodic event.

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Demographics of Black-footed Albatross Caught in the Hawaii Deep-Set Longline Fishery

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Introduction

Black-footed (*Phoebastria nigripes*, BFAL) and Laysan (*P. immutabilis*, LAAL) albatross forage throughout the North Pacific, overlapping and, on occasion, interacting with the Hawaii longline fisheries (Gilman et al. 2016; Hyrenbach and Dotson 2003; Žydelis et al. 2011). The National Marine Fisheries Service (NMFS) documented higher interactions in the Hawaii deep-set longline fishery during 2015 and 2016, the drivers and implications of which remain unexplained (Ishizaki et al., this report).

Population models, which require sex and age-specific demographic rates, have been used to predict impacts of longline fisheries on populations of long-lived marine organisms, including the BFAL (Arata et al. 2008; Cousins 2001; Véran and Lebreton 2008). These models use three underlying assumptions in bycatch analyses: (1) males (♂) and females (♀) have equal bycatch mortality; (2) bycatch affects only after-hatch year birds (age >1 year) and is distributed among age classes proportionally to their relative abundance; and (3) yearly bycatch mortality has remained stable (in this case since 2005, when the last BFAL population assessment was completed (Bakker and Finkelstein, this report)).

In this paper, we analyzed the demographic composition of observed BFAL caught in Hawaii deep-set longline fishery to test population model assumptions concerning sex and age classes. Moreover, to investigate the potential drivers and population-level implications of the 2015–2016 increase in deep-set longline BFAL bycatch, we compared the bycatch composition and distribution by time period (pre-2015 vs. post-2015).

Methods

Data collection

Between 2010 and 2016, NMFS fishery observers recorded 358 incidentally killed BFALs, including ancillary information concerning the location and date of each fishery interaction, and retrieved 261 of these birds for necropsy. Oikonos personnel necropsied the specimens at the Marine Wildlife Veterinary and Research Center following standardized protocols to determine their sex and maturity status (Nevins et al. 2018). Briefly, the maturity status of the birds is based on the presence of the bursa of fabricius and morphometric measurements of the sex organs (oviduct, follicle, or gonad size) (Broughton 1994; van Franeker 2004), with immature birds considered ≤ 4 years of age and mature being > 4 years. Maturity categories were developed using known-age banded birds. We only used those specimens with complete demographic and fisheries data in the subsequent analyses; seven birds were removed from consideration. Thus, the sample size used for statistical analysis entails 254 birds collected by observers between January 2010 and December 2016 from the deep-set fishery.

Statistical approach

We performed all statistical analyses with R Studio (v.3.4.1) and used $\alpha = 0.05$ to determine statistical significance. Unless otherwise noted, we report the mean +/- one standard deviation (S.D.) of all parameter estimates. For binary categorical data (♀:♂, immature:mature), we calculated S.D.s assuming a binomial distribution.

First, we determined whether the subsample of necropsied birds was representative of the temporal distribution of the observed interactions. This was achieved by comparing the number of BFAL mortalities and necropsies by fishery quarter with a G-test of independence.

Temporal analyses

We used chi-squared tests to compare the overall sex ratio (♀:♂) and maturity status ratio (immature:mature) against the expected 50:50 sex ratio and the age composition from a stable age distribution (SAD) (Bakker and Finkelstein, this report). Because the bursa ageing approach classifies birds ≤ 4 years of age as immatures, we used the expected SAD proportions of 0.658 for mature birds (> 4 years) and 0.342 for immature birds (1–4 years), respectively.

We analyzed the demographic data on yearly, and quarterly time scales using chi-squared tests of independence to determine if there were significant differences in the demographic composition over time. Years are comprised of four quarters, based on the fishery reporting schedule and numbered sequentially according to the calendar months: Q1 (January 1–March 31), Q2 (April 1–June 30), Q3 (July 1–September 30), and Q4 (October 1–December 31). We first analyzed sex and maturity status separately, and then considered these two factors together, by comparing four sex-maturity groups: (mature ♀, mature ♂, immature ♀, immature ♂).

We compared overall (2010–2016) BFAL sex and maturity status ratios from (Nevins pers. comm.) with those before the increase (2010–2014), the years of the increase (2015–2016), and months of especially high bycatch (May–July 2015). We also compared BFAL and LAAL demographic data during the entire study period (2010–2016) (Nevins pers. comm.).

Spatial analyses

Because seabird mitigation measures are not required within the entire fishery grounds, we repeated the demographic analyses to determine if the results differed when considering only the mitigation area (north of 23ºN) or the entire fishery grounds. This subset of interactions north of 23ºN involved 216 (85.0%) of the 254 necropsied specimens considered in the overall analyses.

To further explore spatial trends in the demographic composition of the bycatch, we compared the latitude and the longitude between different demographic groups. Because the latitude and longitude coordinates did not follow normal distributions, we log transformed the data prior to these analyses (y' = log (y)). We performed three separate Analysis of Variance (ANOVA) tests on the log-transformed latitude and longitude locations to compare two sex groups (♀ vs. ♂), two maturity status groups (immature vs. mature), and four sex-maturity groups. We also tested for temporal trends within each group using year and quarter as factors. We used analysis of covariance (ANCOVA) tests, with year and quarter as continuous co-variates, to test for temporal trends in the distributions of the demographic groups (Appendix C). After significant ANOVA/ANCOVA results, we performed post-hoc Tukey tests to identify the pair-wise significant group comparisons. These results allowed us to identify those years and quarters when the location (latitude, longitude) of each demographic group varied significantly. Finally, we visualized these spatial distributions using ArcMap (v.10.5.1).

Conclusions

Overall, the temporal distribution of the necropsied specimens was representative of the observed interactions (X^2 =6.76 [27] p=0.999), suggesting that the necropsies proportionally sampled the bycatch across the study period (28 quarters between January 2010 and December 2016).

Demographic proportions

The overall maturity ratio of the BFAL bycatch was significantly different from the expected ratio from the SAD (χ^2=10.009 [1] p=0.001), with an excess of mature birds and a deficit of immature birds (Table 10). The overall sex ratio of BFAL was not significantly different from the expected 50:50 ratio (χ^2=2.859 [1] p=0.091) although there was a slight female-bias in the composition of the bycatch (Table 10). Because neither the yearly sex ratio nor the yearly maturity status ratio changed significantly, we calculated the overall proportions of these demographic groups for use in the population model (Table 11). When we analyzed the sex ratios of each maturity status group separately, they were not significantly different from the expected 50:50 ratio (mature 118♀:80 ♂, immature 28♀:28♂).

Nevertheless, both the sex ratio (χ^2=8.304 [3] p=0.04) and the maturity status ratio (χ^2 =9.702 [3] p=0.021) changed significantly over the four quarters: more males and more immature birds were caught during quarter 3.

Furthermore, the proportion of the combined demographic groups varied significantly over years (χ^2 =18.064 [18] p=0.006) and quarters (χ^2 =21,285 [9] p=0.011) (Figures 26 and 27). In 2010, there was a higher proportion of mature females. Overall, quarter 1 and quarter 3 had a higher proportion of mature females and mature males, respectively.

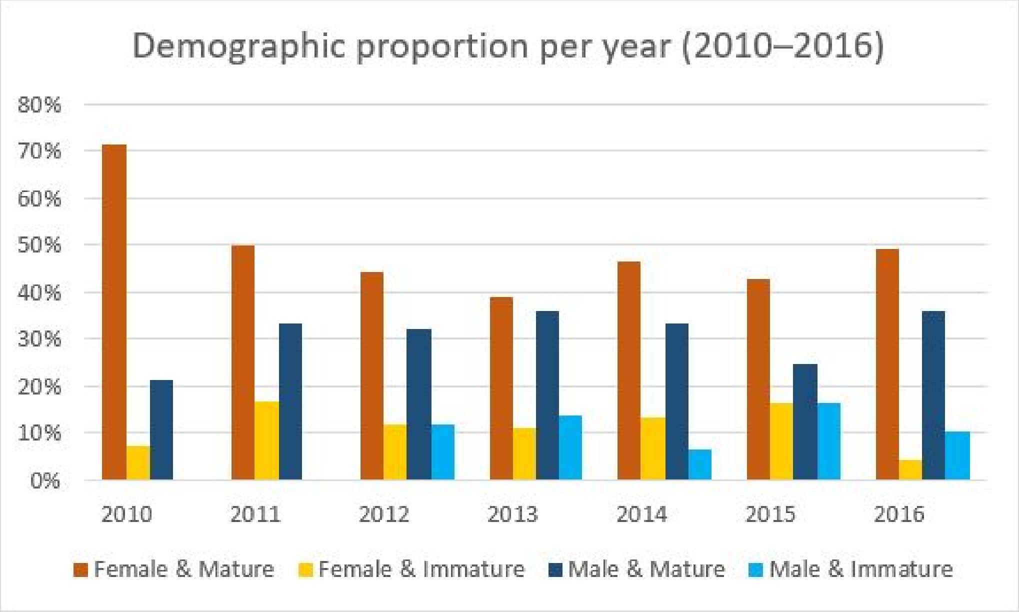

Figure 26. Proportion of BFAL demographic groups by year (all quarters combined).

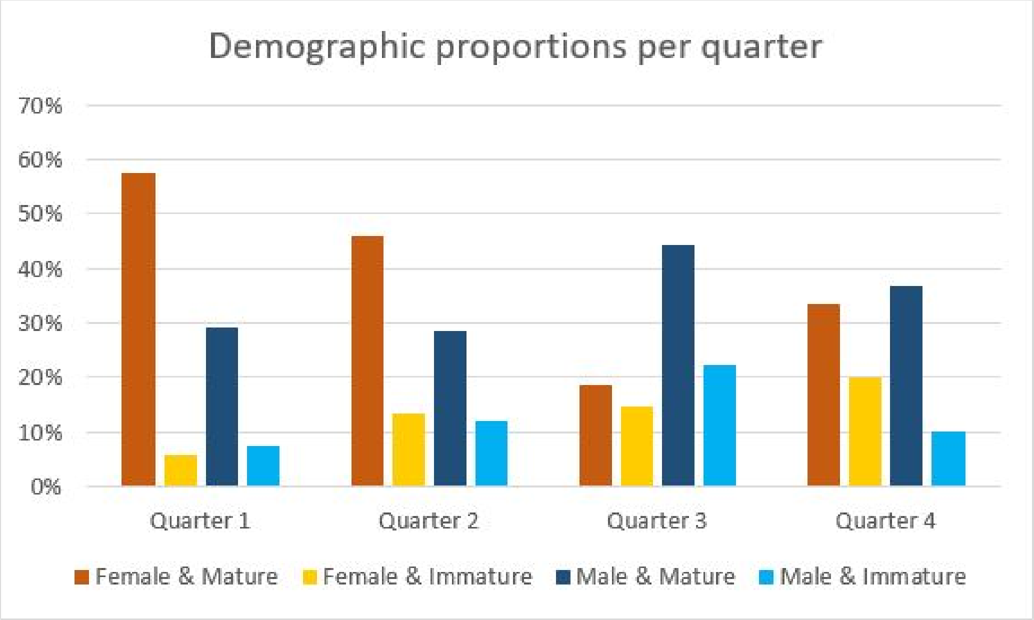

Figure 27. Proportion of BFAL demographic groups by quarter (2010–2016).

Demographic distribution

When we considered all the necropsied BFAL regardless of their latitude, we found several significant patterns (Table 12). Yet, when we limited the scope of the study to interactions north of 23ºN, we found little significant deviation from overall analyses and therefore included all birds (Tables 13, 14). Due to the limited sample size of birds caught below 23ºN, we were unable to test differences between the two areas. Below, we report the significant results from the analysis of the entire data set.

The distribution (latitude, longitude) of the bycaught BFAL did not differ between sexes. While the longitude of the mature and immature birds was significantly different, with immatures extending further east than mature birds (F=7.160 [df = 1, 252] p=0.008), the latitude of mature and immature birds was not significantly different (F=3.048 [df = 1, 252] p=0.080) (Tables 13, 14).

The latitude and longitude of female bycatch locations varied significantly by year and quarter. For mature females, the latitude and longitude varied significantly over years, but only the latitude varied by quarter. While the latitude and longitude did not vary from year to year for immature females, it did vary by quarter. Finally, the distributions of mature and immature males varied over quarters, but not over years.

Sex ratio

The overall sex ratio was not significantly different from the expected 50:50 ratio, although there was greater female bycatch in the deep-set longline fishery; this did not differ significantly from year to year. However, we documented seasonal variability of the demographic bycatch distribution, as evidenced by a significant difference in the sex ratio by quarter. There was a higher proportion of females in quarters 1 and 2.

Conversely, there was higher proportion of males caught in Q3, which balanced the overall sex ratio. Yet, the male proportion during Q3 (66.67 % ± 9.25 S.D.) was almost twice that during the other three quarters (39.65 % ± 3.25 S.D.). Together, these data suggest some level of spatial foraging segregation between sexes during different times of the year.

Moreover, the observed seasonal variability in sex ratios is relevant for assessing wider population-level effects. Considering that most of the fishery effort and albatross interactions take place during Q1 and Q2, the female-biased mortality during the vulnerable chick-rearing period may be disproportionally removing breeding-age females from the population. Additionally, since monogamous albatrosses are slow to re-pair with another mate, this mortality could further impact the population (Ryan and Boix-Hinzen 1999).

Maturity status ratio

The maturity status ratio was significantly different from the expected SAD proportions; a higher-than-expected proportion of mature birds were caught. This result can have important implications for population modeling efforts, as demonstrated by previous modeling during the 1998 BFAL workshop (Cousins 2001). Albatross are delayed breeders with low fecundity and high parental care and populations are highly sensitive to adult mortality, whereas some populations may be able to withstand levels of juvenile mortality (Tasker et al. 2000).

The analyses showed that while there is no significant variability in the maturity status ratio over the study years, the ratio does vary over quarters, with a higher proportion of immature birds caught during Q3 and Q4. This pattern may be a result of juveniles fledging from their breeding colonies in the Hawaiian Islands in June–July and their pelagic dispersal during Q3.

Demographic distribution

Because other species of seabirds exhibit at-sea segregation by sex and/or age, we hypothesized that the bycatch locations of different demographic groups would vary spatially (Prince et al. 1992; Weimerskirch et al. 2009). There were stronger changes in demographic distribution over quarters than over years, likely reflecting breeding seasons and seasonality of environmental factors, which affect the distributions of the fisheries and the birds. While we did not find a significant difference in bycatch locations between sexes, the pattern was significant for birds of different maturity statuses, with immatures extending further east than mature birds.

When we compared the year-to-year variability, the strongest differences in latitudinal distribution involved 2012 and 2015. The interactions were more widely distributed in 2012 and more concentrated during 2015. Over quarters, fall–winter (Q1 and Q4) and spring–summer (Q2 and Q3) had significantly different distributions, with the latter having higher latitude. There was also a significant shift in longitude during Q3, with interactions being further east than during the other quarters. These results match the understanding of the BFAL breeding seasons, with birds foraging closer to the colonies during the incubation and chick-rearing periods (December to June) and venturing further from the colonies during post-breeding period (July to November) (Žydelis et al. 2011).

Comparative Analyses

The demographic composition of the BFAL bycatch during 2010–2014 and 2015–2016 is comparable, with a slightly higher proportion of mature females during the former time period. During 2015, a cluster of three months (May–July) with a high number of BFAL caught was characterized by a significantly higher proportion of females and immature birds. Interestingly, the immature had an almost 1:1 sex ratio (Female 52.92 ± 1.16%), whereas the mature birds caught during this time had a higher female proportion (62.96 ± 1.12%).

Implication for population models

Our results support the assumption that the sex ratio of BFAL caught is 50:50, although we documented seasonal variability in the proportions of males and females. Because the higher number of mature birds caught by the fishery deviates from the SAD proportions, the assumption that bycatch is distributed proportionally across age classes is incorrect for these fisheries. Together, these results highlight the need to incorporate updated demographic information on fisheries bycatch composition into population models and underscore the valuable contribution of the NMFS Hawaii Observer Program and collaborative necropsy studies to inform the understanding of the demographic consequences of fisheries bycatch. These results contribute to improving population models for quantifying population-level fisheries impacts on albatross populations and enhance the understanding of albatross distributions and life-history.

Acknowledgements

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Black-Footed Albatross Reproductive Dynamics: Breeding Population Size and Reproductive Success

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Introduction

Seabird populations respond to oceanographic variability at a variety of temporal scales, ranging from days to decades and longer-term changes in ocean climate (Ainley and Hyrenbach 2010; Thorne et al. 2015). In particular, the number of birds attempting to breed and their reproductive success, defined as the number of fledged chicks divided by the number of eggs laid, vary from year to year in response to changes in ocean productivity before (winter) and during the breeding season (Schroeder et al. 2009). In turn, because breeding seabirds are central-place foragers obliged to return to their colony to feed their chicks, fluctuations in the number of breeding individuals can influence their at-sea distribution. Namely, in years of low colony attendance or early breeding failures, mature birds can disperse widely.

These changes in the spatial distribution and degree of aggregation of foraging adults can also influence their susceptibility to fisheries interactions by altering their degree of overlap and their reliance on predictable food resources in the vicinity of breeding colonies. Additionally, in years of high productivity, large numbers of fledging chicks would be expected to disperse from the colony and to first encounter fisheries at the end of the breeding season (July).

Based on the combined analysis of standardized nest counts (1998–2007) at the three largest colonies (Midway Island, French Frigate Shoals, Laysan Island), the Black-footed Albatross' (*Phoebastria nigripes,* BFAL) global population has increased in size by an average of 1.1% per year (95% CI, = 0.99 - 1.22 %) (ACAP 2009). Yet, colony-based monitoring has revealed substantial changes in the size of breeding populations (number of breeding pairs) and reproductive success (number of chicks fledged/number of eggs laid) (Keller et al. 2009).

These fluctuations are influenced by large-scale oceanographic patterns (North Pacific Gyre Oscillation, ENSO), regional changes in water-mass distributions and productivity (location of the Transition Zone Chlorophyll Front, TZCF), and episodic local weather events (e.g., winter storms, tsunami inundation) (Reynolds et al. 2015; Thorne et al. 2015).

This chapter explores the oceanographic drivers of the breeding population size (based on total colony counts of breeding birds at the beginning of the breeding season) and the productivity (reproductive success at the end of the reproductive season) of BFAL breeding on the Northwestern Hawaiian Islands. The goal of this analysis is to inform trends in albatross fishery interactions over time.

Methods

Study sites and data collection

The current long-term USFWS monitoring program initiated in 1980 provides information on the size of BFAL breeding populations and their reproductive success at three sites: French Frigate Shoals (FFS), Midway Island, and Laysan Island (Keller et al. 2009). For these analyses, we used annual count data (1992–2017) and annual productivity data (1980–2017). While colony counts and reproductive success data are available at the three sites, the time series vary in length and in the number of missing years. Moreover, geographical comparisons are inhibited by the different methods used across these locations (Keller et al. 2009).

Nest counts

USFWS field personnel counted the island-wide numbers of breeding BFAL pairs annually using standardized methods (Flint et al., Extended Abstract). Based on the BFAL population sizes (1992–2017), the abundances varied as follows: Midway (mean = 22,436.8 ± 3,246.1 S.D., median = 21,829, range = 28,610–17,617, n = 25) and FFS (mean = 4,375.5 ± 730.6 S.D., median = 4,284, range = 5,725–3,328, n = 8).

Reproductive success data

USFWS field personnel quantified yearly BFAL reproductive success, defined as the number of chicks produced divided by the number of eggs laid (Keller et al. 2009). Because albatrosses produce only one egg per breeding attempt, this ratio represents the proportion of active pairs, defined as having laid an egg, which successfully fledged a chick at the end of the season. Thus, this metric integrates the BFAL breeding season, from incubation (November) to chick-fledging (July) (Awkerman et al. 2008).

On average, BFAL reproductive success was 0.68 ± 0.11 S.D. (median = 0.71) in FFS, with values ranging from 0.38 to 0.86 (n = 32). At Midway, BFAL productivity was 0.59 ± 0.14 S.D. (median = 0.62), with values ranging from 0.29 to 0.76 (n = 14). Two anomalous years with values > 2 S.D. below the mean, were 1999 (FFS) and 2017 (Midway).

Environmental data We correlated albatross reproductive success (Figure 28) to three metrics of ocean conditions (Figure 29): the Pacific Decadal Oscillation (PDO), the Multivariate El Niño Index (MEI), and a regional index of sea-surface temperature (SST) from the area fished by the Hawaii deep-set fishery during winter and spring, spanning 25°–30 ° N latitude and 150 °–160 ° W (Polovina and Abecassis, this report).

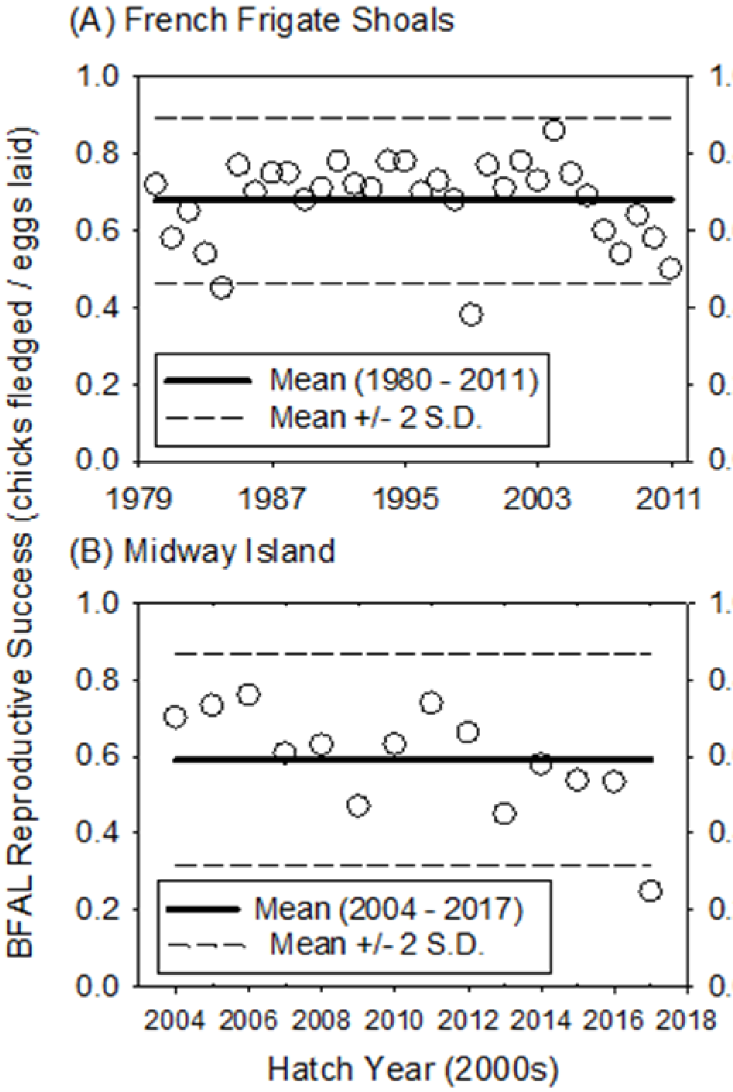

Figure 28. Time series of BFAL reproductive success at two study sites. To highlight interannual variability, yearly values are compared to the mean + 2 standard deviations.

The PDO Index, defined as the leading principal component (PC) of monthly North Pacific SST poleward of 20 ° N, indicates large-scale atmospheric and water mass distributions in the North Pacific. In particular, positive and negative PDO values correspond to anomalously warm- and cold-water conditions in the North Pacific, respectively (Mantua et al. 1997). The MEI is based on the first PC of oceanic and atmospheric conditions in the tropical Pacific Ocean (30 ° S–30 ° N), seasonally-adjusted with respect to the 1950–1993 reference period. Negative values of the MEI represent La Niña (cold conditions), while positive values represent El Niño (warm conditions) (Wolter and Timlin 1998).

In addition to the large-scale PDO and the MEI values, we included a regional index of SST conditions, derived from the monthly data from the National Centers of Environmental Prediction (NCEP) Reanalysis Dataset (Kalnay et al. 1996).

We averaged these monthly data into the same 3-month periods (quarters) used to quantify fishery interactions which correspond to the following stages of the BFAL breeding season: Q1 (hatching, brooding, and early chick rearing), Q2 (late chick rearing), Q3 (chick fledging and post-breeding), and Q4 (return to breeding colonies and incubation) (Awkerman et al. 2008).

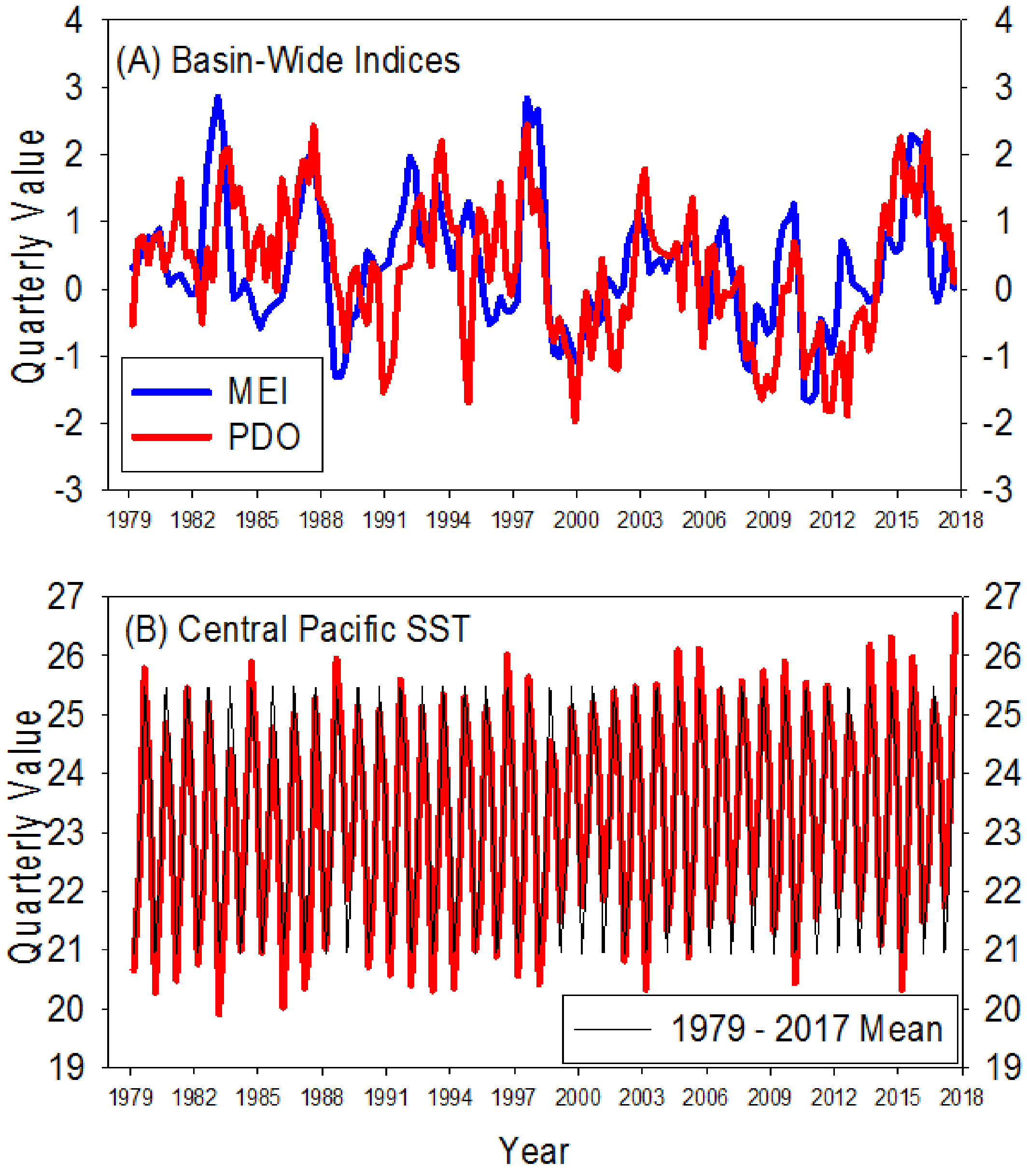

Figure 29. Time series of environmental variables used to characterize oceanographic conditions. Sea surface temperature (SST) data from the longline fishing grounds (25º–30ºN, 150º–160ºW) show quarterly values and long-term (1979–2017) mean.

Finally, to account for time lags between oceanographic conditions and shifts in albatross productivity, we matched the reproductive success of a given hatch year (y) with environmental conditions during four quarters: two (Q3 and Q4) preceding the hatch year (y–1), and two (Q1 and Q2) during the hatch year (y) (Ainley and Hyrenbach 2010). Thus, the environmental data set involved 12 time series of 38 quarterly values, spanning from Q3 of 1979 to Q2 of 2017.

Statistical analysis

Environmental conditions (1979–2017)

To account for the co-variation of these oceanographic variables, we combined them into multi-variate environmental factors using PCA, employing PC-Ord 6.1 software (MjM Software 2006). Before performing the PCA, we standardized the data giving the 12 environmental data sets the same weight in the analysis, with a mean of 0 and an S.D. of 1 (McCune et al. 2002).

BFAL time series

We analyzed the yearly population counts and the arc-sine transformed ($y' = asin(y)$) reproductive success using a generalized linear model (GLM) with four explanatory variables: the three PC axis scores to test for environmental drivers, and the hatch year to test for trends over time. We performed three analyses: a 32-year time series at FFS (1980–2011) provided a long-term perspective of BFAL productivity patterns; and a 14-year time series at Midway (2004–2017) provided a short-term perspective of BFAL abundance and reproductive success, including the recent period of anomalous oceanographic conditions (2015–2016). Over the 8 years with data from both sites (2004–2011), reproductive success was not significantly correlated ($r = 0.225$, $n = 8$, $p < 0.10$).

Conclusions

Despite the fragmentary data sets of BFAL breeding population numbers and reproductive success, these analyses revealed two significant temporal trends: declining nest counts and increasing productivity at Midway Island. Additionally, we documented a significant negative relationship between reproductive success at FFS and the environmental conditions captured by PC2. Because this axis was correlated with negative SST conditions during Q3 and Q4, this result underscores the importance of summer/fall environmental conditions pre-conditioning BFAL reproductive success the following year. This result suggests that higher BFAL productivity lags behind warm water anomalies in the central Pacific.

Environmental conditions (1979–2017)

The PCA revealed three dominant principal components (PCs) with eigenvalues >1 (Ainley and Hyrenbach 2010), which together explained 77.6 % of the observed variance. We interpreted these three PC axes using the significant correlations with the individual environmental data sets. We used the axes correlations with the variable "year" to assess temporal trends (Table 15).

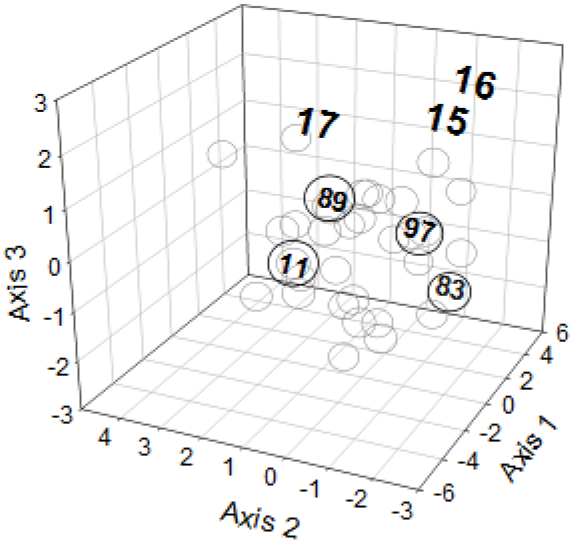

Figure 30. PCA results, showing the yearly coordinates (1980–2017), highlighting the three last years (2015–2017). To facilitate comparisons with previous El Niño (1983, 1997) and La Niña (1989, 2011), these years are also highlighted.

Axis 1, which accounted for 52.35 % of the observed variability, was highly correlated ($p < 0.001$) with 11 of the 12 environmental variables: positive MEI values (all four quarters), positive PDO values (all four quarters), and negative SST anomalies (Q1, Q2 and Q3). This axis captured concurrent changes in the MEI and PDO and local SST in the study area (25°–30 ° N, 150 °–160 ° W), with colder water anomalies during periods of positive PDO and MEI indices.

Axis 2, which accounted for 13.45 % of the observed variability, was highly correlated ($p < 0.001$) with 2 of the 12 environmental variables: negative SST anomalies (Q3 and Q4). This axis was also correlated with one MEI (Q2), one PDO (Q3), and one SST index (Q2). This axis, which captured cold-water anomalies in the study area during summer and fall when albatross fledge, was negatively correlated with BFAL reproductive success at French Frigate Shoals (1980–2011).

Axis 3, which accounted for 11.80 % of the observed variability, was not highly correlated ($p < 0.001$) with any of the environmental variables but was significantly correlated ($0.05 < p < 0.001$) with positive PDO indices (Q1, Q2) and with positive SST anomalies (all quarters). Altogether, the PCA ordination highlighted the unusual conditions during the two focal years (2015–2016) of high BFAL-fishery interactions (Figure 30).

BFAL productivity–French Frigate Shoals (1980–2011)

BFAL productivity was negatively related to PC2 (coefficient = -0.047 +/- 0.022 S.E.). This relationship explained 18.1% of the variance (multiple R^2) (Table 16A), and the GLM residuals were normally distributed (n = 32, SW statistic = 0.987, p value = 0.965). This analysis suggests that BFAL reproductive success was influenced by changing environmental conditions during the

32-year period (1980–2011). This result reinforces previous analyses of BFAL responses to latitudinal variability in the location of the Transition Zone Chlorophyll Front (TZCF) and MEI (Thorne et al. 2015).

BFAL nest counts and productivity–Midway Island (2004–2017)

BFAL reproductive success declined significantly over time (coefficient = -0.029 ± 0.008 S.E.) which explains 63.4% of the observed variance (multiple R^2) (Table 16B). The GLM residuals were normally distributed (n = 14, SW statistic = 0.950, p value = 0.568). The declining trend in BFAL reproductive success was significant, even after removing the final year of the time series (2017), when unusual flooding early during the egg laying season led to anomalously low reproductive success (coefficient = -0.016 +/- 0.006 S.E., n = 13, p = 0.037).

While this analysis suggests that BFAL productivity at Midway Island has declined during the last 14-year period (2004–2017), the number of BFAL breeding pairs increased significantly over the same time period (coefficient = +390.923 ± 140.377 S.E.). This relationship explained 50.3 % of the observed variance (multiple R^2) (Table 16C), and the GLM residuals were normally distributed (n = 14, SW statistic = 0.976, p value = 0.947).

Overall, these exploratory analyses suggest that the increasing number of breeding BFAL and the declining reproductive success may contribute to higher fishery interactions early in the breeding season (Q1), when larger number of breeding birds forage closer to their colonies, and later in the breeding season (Q2) when failed breeders disperse from breeding colonies. Yet, we would expect these interactions to take place closer to colonies during Q1 and farther from colonies during Q2, assuming that failed breeders disperse widely across the North Pacific, as post-breeding birds do during the non-breeding period (July–October).

Acknowledgements

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Examination of Factors Affecting Seabird Bycatch Occurrence Rates in Japanese Longline Fisheries

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Seabird bycatch in the southern hemisphere

In preliminary analyses using Japanese seabird bycatch data at high latitudes in the southern hemisphere, we found that this rate could be affected by seabird distribution, oceanic conditions, seabird bycatch species composition, and bycatch mitigation measures. The goal of this study was to identify the factors affecting longline bycatch of seabirds in the southern hemisphere using a modelling approach. To determine the most important factors, we divided bycaught seabird species into two groups (albatross and giant petrels, petrels, and shearwaters) because different mechanisms affect their bycatch occurrence. Briefly, we investigated the factors affecting bycatch occurrence rate including species group, season, year, environmental factors, distance from the colonies, lunar phase, and fish catch.

Seabird abundance on fishing grounds as well as other factors may be related to seabird bycatch occurrence. A random forest algorithm was used to analyze the factors affecting seabird bycatch occurrence. Random forest (RF) is an ensemble of decision trees, and it considers uncertainty in parameters and input data by resampling them. One of the advantages of an RF model is it can analyze the effects of interaction terms among explanatory variables in a data set with low coverage, which cannot be done with a generalized linear model (GLM) due to the missing data. RF can analyze interaction terms using resampling.

We used operational data obtained by scientific observers from 1997 through 2015 from longline sets carried out south of 20°S to build four different RF models. The number of bycaught seabirds of different species groups during longline operations covered by observers was the response variable. Two models used albatross and giant petrels as the response variable, and two models used shearwaters and petrels as the response variable. For spatial and temporal explanatory variables, we used latitude, longitude, year, and elapsed days from the first of the year (hereafter, the day of the year). For fishing effort or vessel explanatory variables, we used number of observed hooks, cruise ID, observer ID, and fishing master ID. Information such as gear configuration and bait type were unavailable; thus, we used catch composition data as proxy explanatory variables for fishermen's intents. Other included explanatory variables were sea surface temperature at noon, wind speed, distance from colony, the night-setting rate (proportion of setting during the night/day), and lunar phase. Since shearwaters and diving petrels may induce albatross and giant petrels to go after bait, we used bycatch numbers of white-chinned petrels, grey petrels, flesh-footed shearwaters, and other petrels as explanatory variables in the two albatross/giant petrel models. One of the albatross/giant petrel models and one of the shearwater/petrel models also included the use of mitigation measures. These mitigation measures are weighted branch line; number of tori lines; use of blue-dyed bait; use of underwater setting;

use of combination of side setting, bird curtain, and weighted branch line; and use of bait caster (Table 9).

Table 9. Summary of data used in each of the four random forest models.

Data	Model			
	Albatross	**Albatross mitigation**	**Petrels**	**Petrel mitigation**
Temporal scope	1997–2015	2011–2015	1997–2015	2011–2015
Seabird species group	Albatross and giant petrels		Shearwaters and petrels	
Explanatory variables (All models)	Cruise ID, observer ID, fishing master ID, longitude, latitude, year, day of the year, seabird species group, fish catch by species, number of observed hooks, environmental variables, night-time setting rate			
Explanatory variables (Model-specific)	Bycatch number of petrels	Bycatch number of petrels, use of mitigation measures	N/A	Use of mitigation measures

The results of the analysis indicated that latitude, longitude, day of the year, observed number of hooks, species group, and sea surface temperature significantly affected seabird bycatch occurrence rate in all four models. Variables that were significant for two or three of the four models were year, cruise ID, observer ID, and lunar phase. Other significant variables were fish master ID, wind speed, catch numbers of albacore, southern bluefin tuna and blue shark, and use of weighted branch lines.

Longitude affected bycatch occurrence rates and were higher off Cape Howe and in the Tasman Sea. In the southern hemisphere, the bycatch occurrence rate also increased with increasing latitude which is likely related to the distribution of fishing effort and the at-sea distribution patterns of albatross and petrels. Bycatch occurrence rate increased in 2014 and 2015 as compared to prior years. Bycatch occurrence rate also increased from January to March in all models. This is the part of the breeding season with the highest number of bycaught albatross (ACAP 2012a, 2012b, 2012c, 2012d, 2012e, 2012f, 2012g). Increase in energetic demands during the breeding season might increase bycatch occurrence. Bycatch occurrence rate increased when the sea surface temperature was either 9–11 ºC or 8–13 ºC, which is the temperature range of albatross and petrel foraging areas, respectively (Xavier et al. 2003; Nel et al. 2001; Catard et al. 2000). These results suggest that seabird bycatch in the Japanese longline fishery occurs at the northern edge of albatross foraging grounds.

Our analysis identified a number of factors that affect seabird bycatch occurrence rates. Nevertheless, these results should be considered carefully because observer coverage is low at high latitudes of the southern hemisphere, and many more variables should be considered in the light of complicated mechanisms of bycatch occurrence.

Seabird bycatch in the North Pacific

In addition to the RF analyses of seabird bycatch in the south Pacific, we also performed a preliminary analysis of the effects of oceanographic features on the bycatch rates of Black-footed and Laysan Albatross in the North Pacific. Many Japanese tuna longline fisheries operate in temperate, sub-tropical, and tropical regions of the North Pacific, and incidental seabird (mainly Laysan and Black-footed Albatross) mortality occurs as a result. Levels of bycatch for both species are known to seasonally fluctuate so it is possible that seasonal changes in spatial oceanography in the western North Pacific drive those fluctuations. For the projection of bycatch rates related to oceanography, statistical extrapolation is done using spatio-temporal oceanographic data because observed bycatch data are sparse (Figure 31) in space and time. We investigated factors affecting occurrence of seabird bycatch in the North Pacific using observer data and predicted spatio-temporal distribution of bycatch of both species.

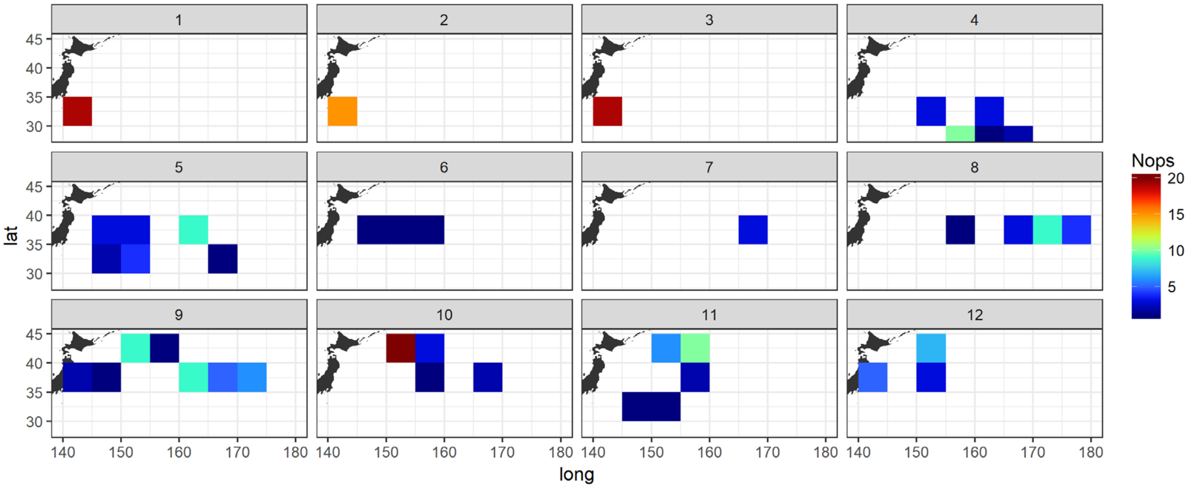

Figure 31. Monthly spatial distribution from January (1) to December (12) of observer effort in the Japanese offshore fleet during 2014–2016. The number of observed fishing operations (sets) are color coded.

This analysis used bycatch data collected by the Japanese scientific observer program from offshore longline vessels during 2014–2016. Japanese offshore vessels are medium-sized (50–200 GRT), usually operate in the western North Pacific, and mainly target swordfish, bigeye tuna, and sharks. Total observed longline operations during that period involved 211 sets. Two generalized additive models (GAM) were developed, one for Black-footed Albatross (BFAL) and one Laysan Albatross (LAAL), using the mgcv R package.

The response variables were the observed bycatch numbers of the two albatross species, and the spline considered three explanatory variables: (i) sea surface temperature (SST), (ii) primary productivity (log-transformed), and (iii) location (based on a 1° × 1° grid); with the observed number of hooks as an offset term. A zero-inflated Poisson distribution was adopted as the error distribution, and parameters were estimated. For this study, no model selection was performed. The estimated GAM equations and monthly oceanographic data were then used to predict monthly spatio-temporal bycatch rates for both seabird species.

For Black-footed Albatross, bycatch number increased with higher SST and primary productivity (Figure 32). Predicted bycatch rates of Black-footed Albatross were highest in the southern part of the Kuroshio Extension (Figure 33). During winter and spring, bycatch rate is lower north of 35°N.

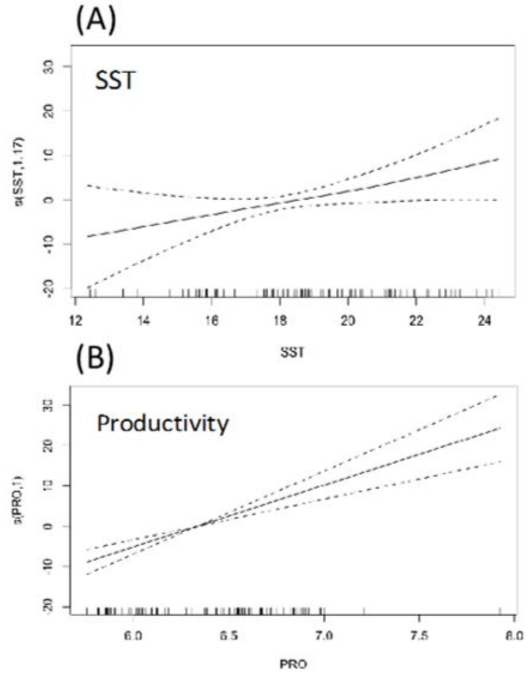

Figure 32. Spline curves relating the number of bycaught BFAL to (A) SST and (B) primary productivity.

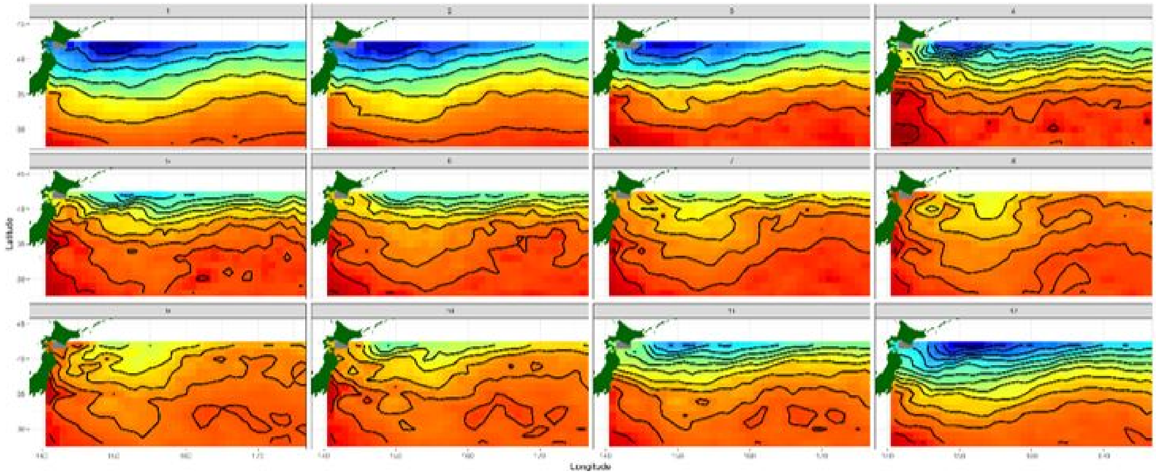

Figure 33. Monthly BFAL bycatch rates predicted from estimated GAM parameters and monthly oceanographic data (SST and primary productivity).

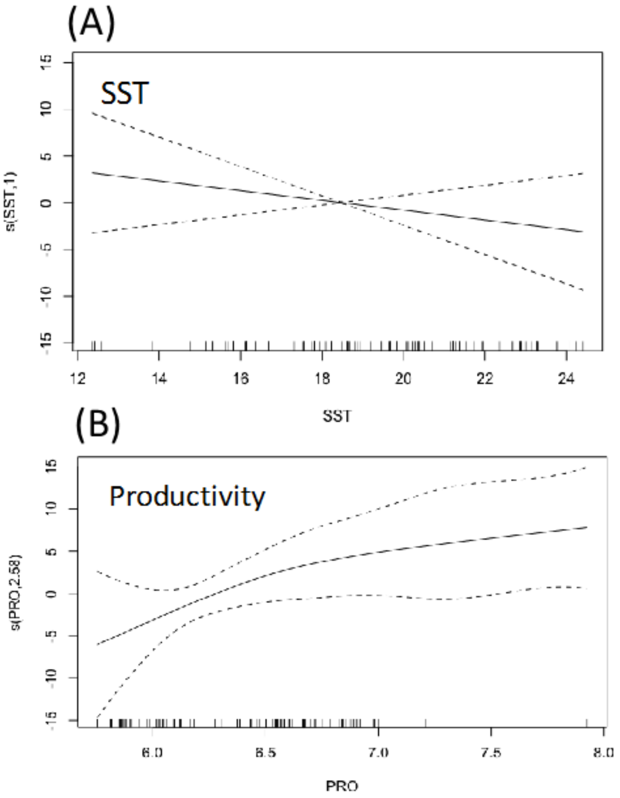

Figure 34. Spline curves relating the number of bycaught Laysan Albatross to (A) SST and (B) primary productivity.

For Laysan Albatross, bycatch numbers increased with lower SST and higher primary productivity (Figure 34). The predicted spatiotemporal distribution of Laysan Albatross bycatch rate was more complex than that of Black-footed Albatross. Laysan Albatross are more likely to be bycaught in the sub-tropical area of the central Pacific during winter and spring and in the northern part of the Kuroshio Extension during summer and autumn (Figure 35).

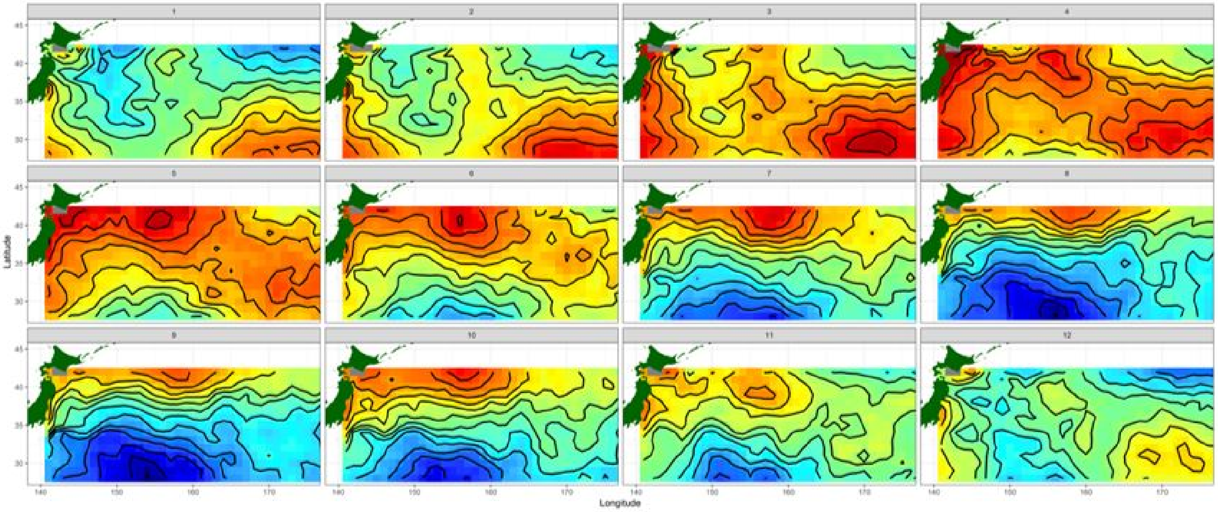

Figure 35. Monthly bycatch rate of Laysan Albatross predicted from estimated GAM parameters and monthly oceanographic data (SST and primary productivity) during 2014–2016.

This study showed that occurrence of bycatch varies with oceanographic features and that the spatial distribution of bycatch rates differed between Black-footed and Laysan Albatross. The observer program for Japanese longline vessels in the North Pacific was recently started, based on a conservation management measure from the Western and Central Pacific Fisheries Commission (CMM2012-07). When more observer data are available, better models for the prediction of albatross bycatch rates can be developed.

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Survival and Breeding Probability of Black-Footed and Laysan Albatrosses at Midway Atoll and Laysan Island, 2006–2015

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Introduction

Banding of Black-footed and Laysan Albatrosses has been conducted in the Northwestern Hawaiian Islands dating back to at least the 1950s. This has occurred somewhat sporadically, by various investigators at different islands. At Tern Island, beginning in 1979, chicks were banded before fledging, systematically and annually. Beginning in 1991, adults on the nest within several study plots were captured and rebanded. Capture effort was applied throughout the island to resight those banded birds, starting in 1998. Systematic sampling of nesting birds was implemented under a specified protocol (described below) to provide robust estimates of survival and breeding probabilities. The protocol was implemented for nesting birds on Midway Atoll and Tern Island beginning in 2005/2006, and on Laysan Island beginning in 2006/2007. This effort continues annually at Midway. At Tern Island and Laysan Island, this effort was suspended after the 2012/13 and 2011/12 seasons, respectively.

Sampling Protocols

Protocols were designed to address two challenges: adults that skip breeding in any given year do not reliably return to the colony in a sabbatical year; sampling at Midway and Laysan must be conducted via plots, rather than the whole colony, due to colony size.

Unobservable skipped breeders

Marked individuals in an unobservable state (capture probability of 0) cause bias in estimates of survival and breeding probability from mark-recapture analyses. This bias is largely mitigated by employing a robust design, where each breeding season consists of multiple sampling periods (Kendall et al. 1997). Because of this, each season consisted of three capture/recapture ‘sweeps’ of the colony or study plots, each time randomly choosing nests and recording band numbers or applying bands. Because in a given sweep only one of the mated pair could be captured, sweeps one and two were spaced two weeks apart to allow for trading off incubation/attendance duties, and the data from these two sweeps were pooled as one capture period. The third sweep was conducted 2–3 weeks later, assuming by that time that each individual has some probability of being captured (probability of being present × probability of capture).

Plots on Midway and Laysan

We established 30 m × 30 m plots for each species on Midway (Sand and Eastern Islands) and Laysan. On the assumption that individuals might nest as far as 10 m from their last nest, we also established a search buffer 10 m outside the plots. No birds in that buffer were to be banded, but the buffer was searched for previously banded birds to mitigate the problem of a bird nesting outside the plot being unobservable and therefore mistaken for a skipped breeder or a mortality.

Analysis

Data for 10 years of sampling (2005/06 to 2014/15) at Midway, and 6 years of sampling (2006/07 to 2011/12) at Laysan, under the above protocols, were vetted for errors by personnel in Hawaii and Midway, and the USGS Bird Banding Laboratory (BBL), and stored at the BBL. After removing records with errors, capture histories were developed for two albatross species (Black-footeds (BFAL) and Laysans (LAAL)) on two islands: 4,478 BFAL and 7,438 LAAL on Midway; 2,536 BFAL and 3,484 LAA on Laysan Island.

For each location, data were analyzed using a multistate model (based on a Markov chain), allowing for two sampling periods per year. We used a two-state model, nester (N) and skipped nester (S), where capture probability was assumed 0 for skipped nesters. Parameters included species-, state- and time-specific survival and transition probabilities, and species- and time-specific capture probabilities for nesters. Because of the unobservable skipped nesting state, two constraints were required (Kendall et al. 1997): (1) we assumed survival probability was the same for nesters and skipped nesters; (2) for models with fully time-varying parameters, the last transition probabilities (nester to skipped and skipped to nester) are not estimable; therefore, we needed to constrain them to equal the same parameter for a previous time interval. For the purposes of this workshop, we analyzed each species separately (no parameters in common).

Results

We considered a larger number of different models in our analysis, evaluating whether there was evidence of substantial variation in capture, survival, and breeding probabilities across time and species. The data supported annual variability in all parameters and differences between species.

At Midway, the probability of capturing an individual nester at least once in the three sweeps of each plot was high for each species throughout the time series, although there was some decrease in effort over time (Figure 36). Survival was generally higher for LAAL (Figure 37). The last two survival estimates for each species are not reliable, due to an artifact of the constraint on the last breeding probabilities needed because of the unobservable state (Kendall et al. 1997; Langtimm 2009). Survival varied little for either species, except for the interval from 2010/11 to 2011/12. This period coincides with the Japanese tsunami, which may have resulted in decreased survival. The impact may have caused some birds to abandon their plot. The pattern of breeding decisions appears to differ for the two species. BFAL skip breeding at a fairly low rate but for those that do skip, their rate of return in subsequent years is moderate to low (Figure 38). For LAAL, the probability of skipping is higher, with some variability, but there is high probability that those that do skip return the following year (Figure 39).

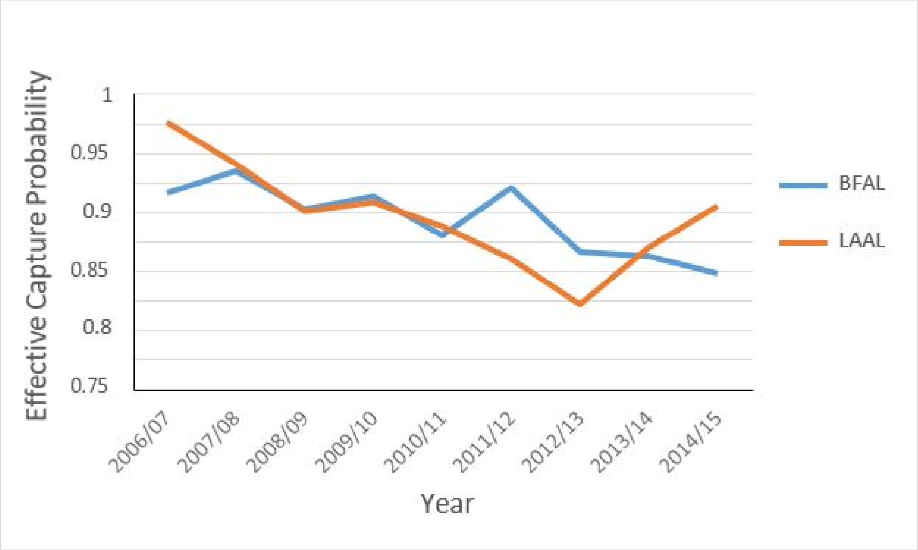

Figure 36. Midway Island effective capture probability for Black-footed and Laysan Albatross from 2006 to 2015.

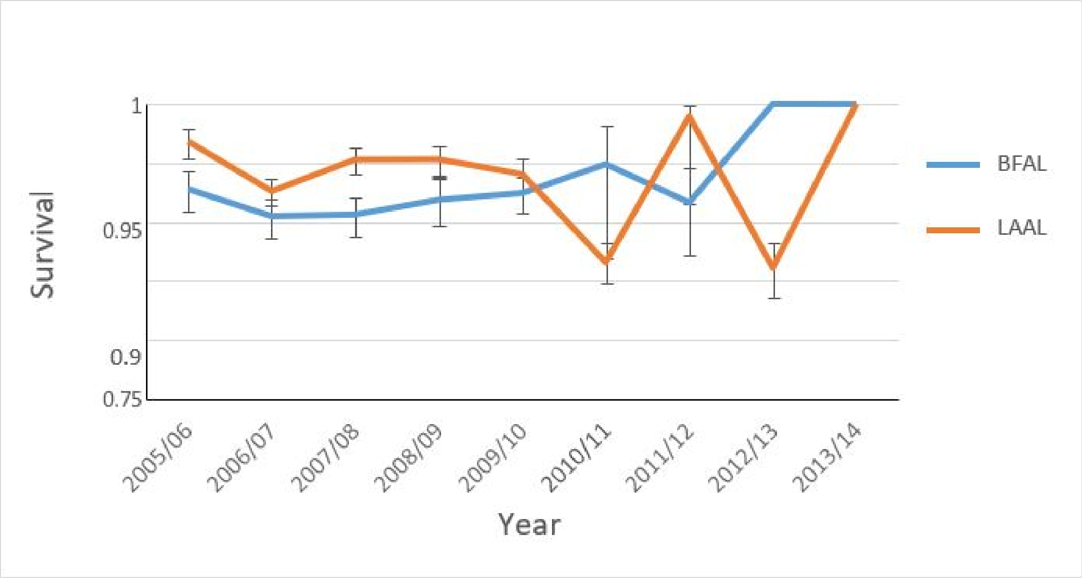

Figure 37. Midway Island Black-footed and Laysan Albatross survival from 2005 to 2014.

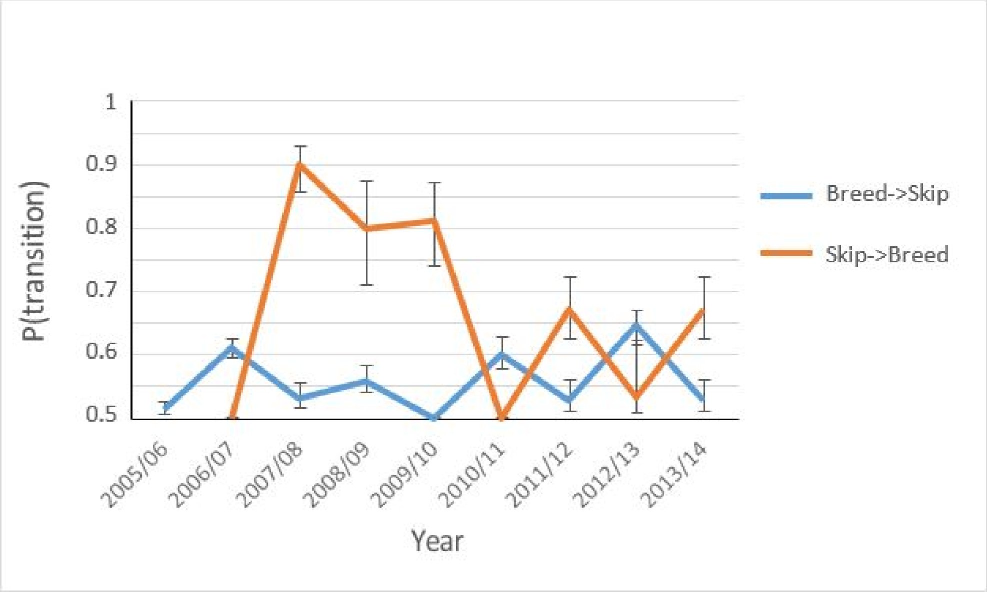

Figure 38. Midway Island Black-footed Albatross breeding probabilities from 2005 to 2014.

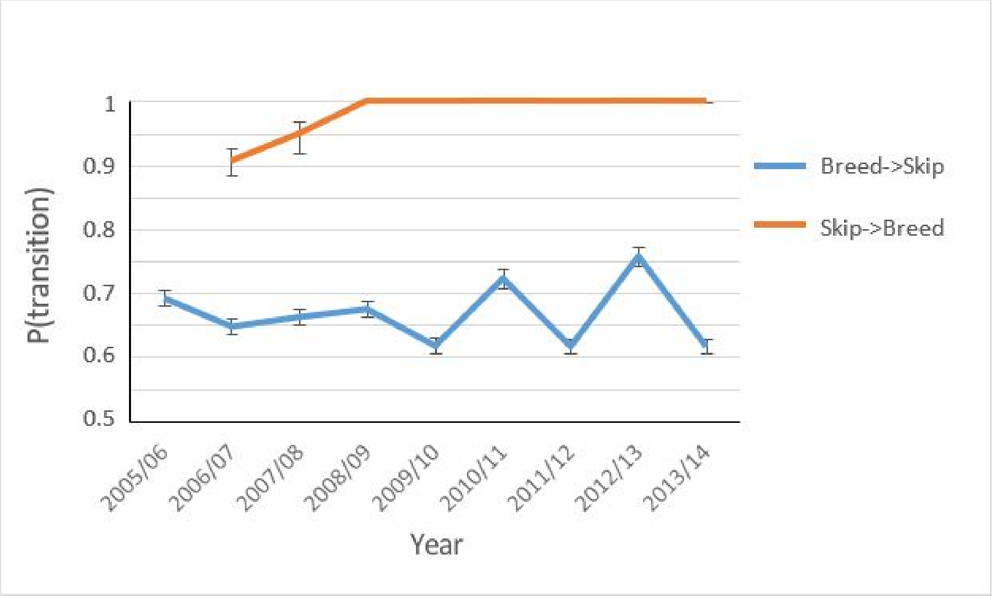

Figure 39. Midway Island Laysan Albatross breeding probabilities from 2005 to 2014.

The time series for Laysan Island was only six years. Capture effort was also high at this location, resulting in good to excellent capture probabilities, although lower for LAAL than BFAL (Figure 40).

The last two estimates for each species' survival should be considered unreliable as the circumstances are similar to those at Midway (although the 2009/10 estimate is consistent with its predecessors for BFAL). Again, survival for LAAL tends to be higher than for BFAL (Figure 41).

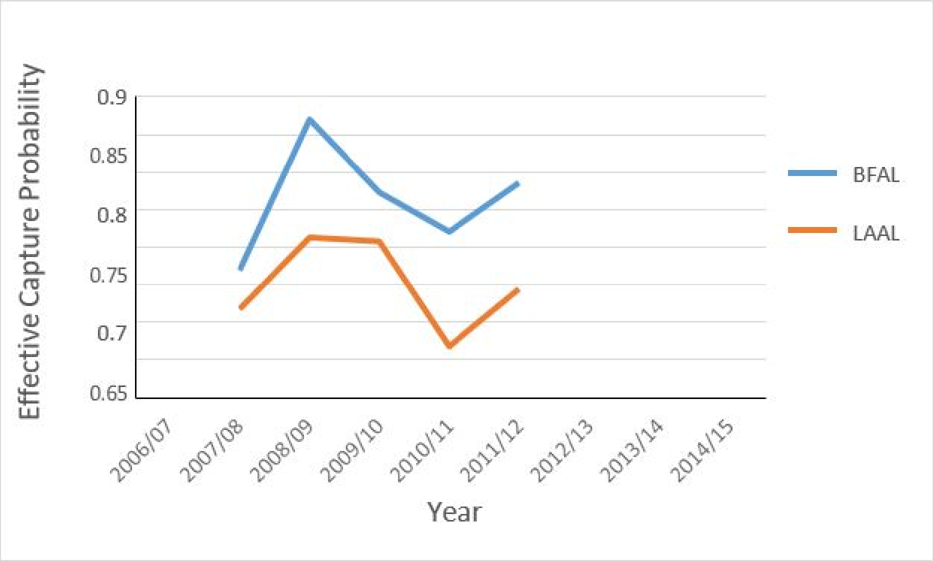

Figure 40. Laysan Island effective capture probability for Black-footed and Laysan Albatross from 2007 to 2012.

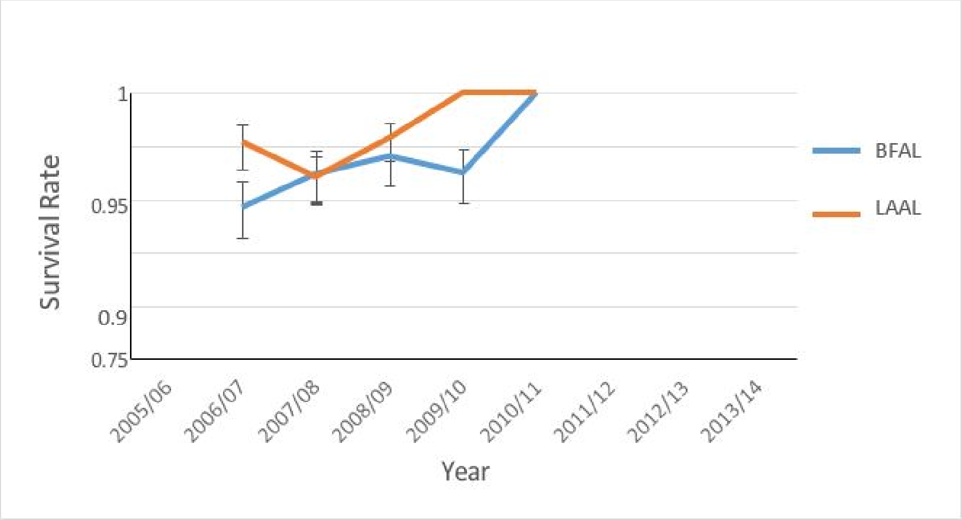

Figure 41. Laysan Island albatross survival rate from 2007 to 2012.

The probability of BFAL skipping was higher at Laysan than at Midway in the beginning of the time series, with the probability of return moderate to high (Figure 42). The pattern for LAAL at Laysan is similar to the pattern at Midway during the beginning of the time series, with a high rate of return (Figure 43).

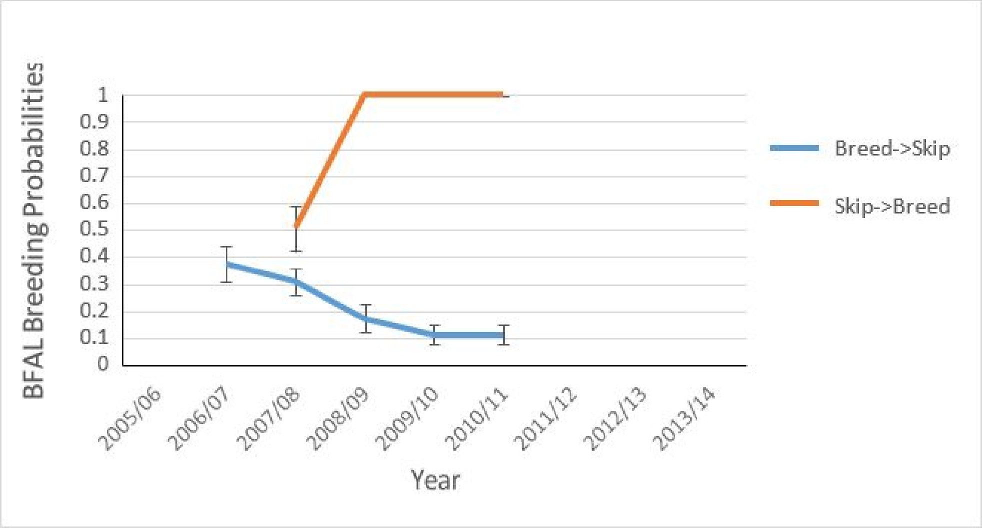

Figure 42. Laysan Island Black-footed Albatross breeding probabilities from 2006 to 2011.

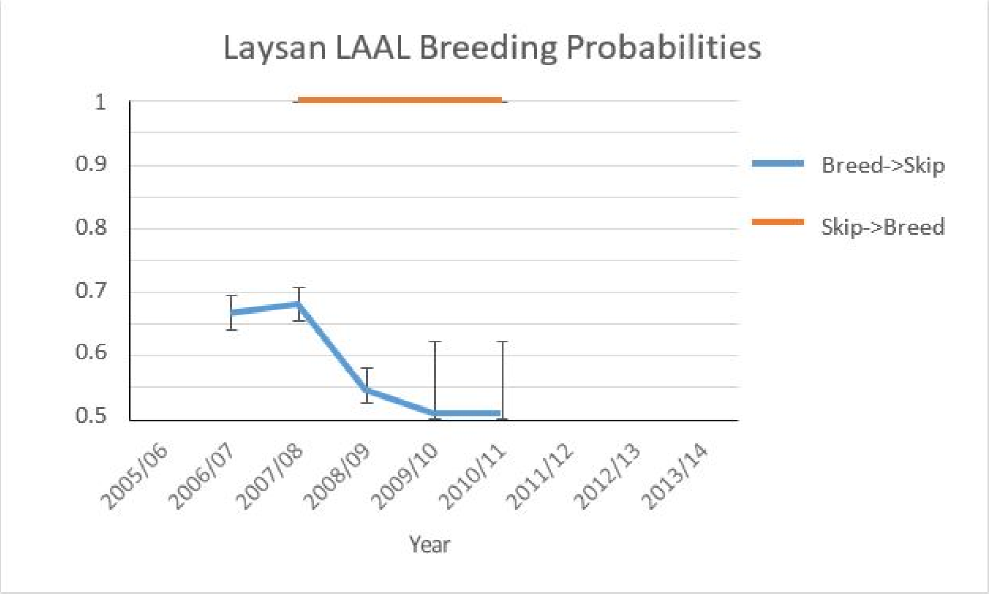

Figure 43. Laysan Island Laysan Albatross breeding probabilities from 2006 to 2011.

Discussion

Inference based on 10 years of data is tenuous for such a long-lived bird, and more so when based on only six years. Survival tends to be high for both species, but slightly higher for LAAL. LAAL tend to skip breeding more often than BFAL but come back more quickly. Survival rates are similar between Midway and Laysan. Breeding patterns are also similar, although the probability of BFAL skipping might be a bit higher.

In addition to the short time series, interpretation of results needs to be done with caution due to the limitations of monitoring plots rather than the whole colony. Despite the establishment of buffer search areas around each plot, the fate of a marked bird that nests outside the search area the following year could be confused with the fate of a bird taking a sabbatical year (if it is a temporary movement) or with a mortality event (if they remain permanently unobservable). The probability of a marked bird nesting outside the search areas likely varies spatially (across demographic plots and breeding islands) and temporally (from year-to-year).

Literature Cited

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Potential Impacts of Recent Increases in Hawaiian Longline Bycatch on the Population Dynamics of Black-Footed Albatross *Phoebastria Nigripes*

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Introduction

The status of Black-footed albatross (*Phoebastria nigripes*, BFAL) has been of recent concern due to mortality from fisheries bycatch (Lewison and Crowder 2003; Véran et al. 2007). One of three species of North Pacific albatross, BFAL breed mainly on the Northwestern Hawaiian Islands and forage throughout the North Pacific (Awkerman et al. 2009) where they are at risk from interactions with both U.S.-based and international fishing operations (Arata et al. 2009). Although accurate estimates of fisheries bycatch are inherently challenging to obtain (Brothers et al. 2010; Lewison and Crowder 2003), recent evidence suggests that BFAL bycatch rates from Hawaiian longline fisheries have significantly increased over the past decade (WPRFMC 2017). A comprehensive understanding of the causes of these increases is currently lacking, although two studies have identified ocean productivity as a key driver of BFAL fisheries interactions and bycatch rates (Gilman et al. 2016). Here we use our published population model (Bakker et al. 2018) along with updated estimates of survivorship and skipping and return probabilities for breeders (B. Kendall, unpublished) to assess the potential impacts on BFAL population dynamics from observed increases in BFAL bycatch within the Hawaiian deep-set and shallow-set longline fisheries.

Methods

Demographic rates and model structure

We built a stochastic demographic female-only matrix population model with best available estimates for BFAL demographic rates, incorporating parameter uncertainty in key rates (Bakker et al. 2009), using Matlab (R2016b. Natick, MA: The MathWorks Inc., 2016). The model tracks population dynamics using stage + age-based projection matrices with a pre-breeding census, seven pre-breeder age classes, and two breeder stages (breeder and widow; Bakker et al. 2018). We incorporated variance in observed breeders by applying an annual stochastic breeding probability to fecundity estimates. We assumed no density-dependent effects on demographic rates.

To avoid double-counting of mortality due to fisheries bycatch, we discounted the effects of estimated bycatch mortality on demographic rates and used these "natural" rates as a baseline for exploring scenarios in which bycatch increases. For survival, we used estimates based on mark-recapture studies of 13,854 chicks banded on Tern Island from 1980 to 2004, corrected for bycatch mortality (Lebreton and Véran 2013), considering this the "natural" survival in the absence of bycatch.

We also considered BFAL population dynamics using newly updated estimates of the mean and process variance of annual survival (2006–2012) and probability of transitioning from breeder to unobserved and from unobserved to breeder states (2006–2013) from Midway Island (B. Kendall, unpublished). These more recent estimates are derived from data collected using standardized procedures, and thus may provide a more accurate assessment of population status over the past decade than our use of earlier "natural" rates combined with estimates of current bycatch. However, the recent survival estimates rely on a relatively short time series, especially for a long-lived species such as BFAL, which may limit their representativeness. Because we lacked year-specific estimates of bycatch mortality after 2005, we were unable to discount bycatch mortality to estimate natural survival from these recent survival estimates. Instead, we assumed the recent survival estimates reflected the product of natural and bycatch survival, and we ran simulations using these probabilities without adding additional mortality from bycatch.

To incorporate estimates of skipping and return probabilities, we revised our published BFAL matrix model, which included only widow and breeder classes, and added a skipper class (Figures 47, 48), similar to our matrix for Laysan Albatross (Bakker et al. 2018). Because unobserved breeders may be either widows or skippers, use of estimated transition probabilities to and from the unobserved breeder state ($\boldsymbol{T_{Breed\_Unobserved}}$ = 0.1217, $\boldsymbol{T_{Unobserved\_Breed}}$ = 0.3994, Kendall, unpublished data) required separating the probabilities of breeders transitioning to and from widow and skipper classes to obtain skip ($\boldsymbol{T_{Breed\_Skipper}}$) and return ($\boldsymbol{T_{Skipper\_Return}}$) probabilities. Adjusting $\boldsymbol{T_{Breed\_Unobserved}}$ to yield the skip probability is straightforward when survival, S, is 0.9121 (Kendall, unpublished data), and probability of immediate widow repair (i.e., before the next breeding season), a, is 0.3410 (Véran 2006).

$$\boldsymbol{T_{Breed\_Unobserved} = T_{Breed\_Widow} + T_{Breed\_Skipper}}$$

The first transition is the probability of a female surviving while her mate does not survive and she does not immediately repair, and thus transitions to the widow class. The second transition is a female and her mate survive but they skip breeding, and thus transition to the skipper class:

$$\boldsymbol{T_{Breed\_Unobserved} = S(1-S)(1-a) + S^2 Skip}$$

Because the transition $\boldsymbol{T_{Breed\_Unobserved}}$ is estimated conditional on the individual surviving, survival of the female is set to one, and only the survival of her mate is retained:

$$\boldsymbol{T_{Breed\_Unobserved} = (1-S)(1-a) + S(Skip)}$$

Thus, it follows that:

$$\boldsymbol{Skip = S^{-1}\left[T_{Breed\_Unobserved} - (Sa - a - S + 1)\right]}$$

and the estimated $\boldsymbol{T_{Breed\_Unobserved}}$ of 0.1217 adjusts to a skip probability of 0.0755.

Estimating the probability of return for a skipper from the transition $\boldsymbol{T}_{Unobserved\_Breed}$ is somewhat more complex as $\boldsymbol{T}_{Unobserved\_Breed}$ represents a weighted average of widows repairing and skippers returning, and thus requires knowledge of the proportions of each in the population. These proportions are dependent on the return probability:

$$\boldsymbol{T}_{\boldsymbol{Unobserved}_{\boldsymbol{Breed}}} = \frac{\boldsymbol{N}_{\boldsymbol{widow}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{Sb} + \frac{\boldsymbol{N}_{\boldsymbol{skipper}}}{\boldsymbol{N}_{\boldsymbol{total}}}[\boldsymbol{S}(\boldsymbol{1}-\boldsymbol{S})\boldsymbol{a} + \boldsymbol{S}^{\boldsymbol{2}}\boldsymbol{Return}]$$

where N_{total}, $N_{skipper}$, and N_{widow} are the total number and the numbers of skippers and widows, respectively, and $\boldsymbol{b}$ is a widow's probability of repairing after entering the widow class. Female survival is again set to 1:

$$\boldsymbol{T}_{\boldsymbol{Unobserved\_Breed}} = \frac{\boldsymbol{N}_{\boldsymbol{widow}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{b} + \frac{\boldsymbol{N}_{\boldsymbol{skipper}}}{\boldsymbol{N}_{\boldsymbol{total}}}[(\boldsymbol{1}-\boldsymbol{S})\boldsymbol{a} + \boldsymbol{SReturn}]$$

We used an iterative approach, assigning a starting number of widows, breeders, and skippers, estimating return probability as follows:

$$\boldsymbol{Return} = \frac{\boldsymbol{T}_{\boldsymbol{Unobserved\_Breed}} - \frac{\boldsymbol{N}_{\boldsymbol{skipper}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{a} + \frac{\boldsymbol{N}_{\boldsymbol{skipper}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{Sa} - \frac{\boldsymbol{N}_{\boldsymbol{widow}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{b}}{\frac{\boldsymbol{N}_{\boldsymbol{skipper}}}{\boldsymbol{N}_{\boldsymbol{total}}}\boldsymbol{S}}$$

We then calculated the proportions in each class after two years and re-estimated return until estimates stabilized. Using this approach, when $\boldsymbol{b}$ is 0.6230 (Véran, 2006), $\boldsymbol{T}_{Unobserved\_Breed}$ of 0.3994 adjusts to a return probability for skippers of 0.2712.

Predicting effects from an increase in bycatch

Bycatch estimates

Accurate and comprehensive estimates of annual levels of BFAL bycatch are not available, and our projections use estimates that rely on numerous simplifying assumptions. We used the 'high' scenario for total BFAL bycatch reported in Arata et al. (2009) in our models as we found that model projections using this bycatch level provided a better fit to observed BFAL count data (Bakker et al. 2018). Arata et al. (2009) provide estimates of BFAL bycatch from all fisheries through 2005, and of BFAL bycatch from pelagic longline fisheries through 2002. Estimated bycatch from pelagic longline fisheries has comprised the vast majority (≥ 88% since 1994) of estimated total BFAL bycatch. We obtained estimates of BFAL bycatch by Hawaiian longline fisheries from NMFS (2005) for 1994–2003 and from the SAFE report (WPRFMC 2017) for 2002–2016 (Table 17). Based on these sources, bycatch of BFAL by Hawaiian longline fisheries dropped substantially after seabird mitigation measures were implemented in 2001, and increased starting in 2012, reaching ~six times 2002–2011 levels in 2015 and 2016.

Importantly, there are discrepancies between data on longline effort north of 20ºN from ~1975–2002 reported in Arata et al. (2009) and updated data for the same time period recently provided by the Oceanic Fisheries Programme (OFP). The Arata et al. (2009) longline effort data are substantially lower than the more recent OFP data, suggesting they may have been incomplete. At the same time, estimates of BFAL bycatch per unit effort used by Arata et al. (2009) were derived from the Hawaii longline fishery observer data prior to the implementation of seabird mitigation measures, which may not be representative of bycatch per effort rates throughout the North Pacific over time. Available data on seabird bycatch per effort for non-U.S. longline fisheries operating in the North Pacific (Huang et al. 2011; Huang 2014), although limited, suggest that the North Pacific-wide Black-footed Albatross bycatch per effort rates since 2002 may be lower than those used in Arata et al. (2009). In the absence of more recently published estimates of BFAL bycatch across North Pacific longline fisheries, we rely on estimates from Arata et al. (2009) for our baseline bycatch assumption (as described above), although we acknowledge added uncertainty in these estimates. These data discrepancies highlight the need to compile more accurate and comprehensive information on longline effort and albatross interaction rates in longline fisheries throughout the North Pacific to support future assessments of the effects of bycatch on BFAL population dynamics.

Modeling potential effects from increases in bycatch

Hawaiian longline fisheries experienced several years of elevated BFAL bycatch recently, but we do not know the causes of these increases or their likely duration, nor if total BFAL bycatch has increased proportionally. Thus, to assess potential effects of Hawaiian bycatch increases on albatross population dynamics, we simulated eight scenarios:

> **Scenario 1, Bycatch constant:** assumed future total bycatch continues at the 2005 bycatch mortality rate (Bakker et al. 2018). This scenario implicitly assumes increases in bycatch in the Hawaiian longline fisheries are offset by reductions in bycatch in other fisheries, which might occur if Hawaiian increases were driven by shifts in BFAL distributions.
>
> **Scenario 2.1, Minimum increase, temporary:** assumed the observed increases occurred only in the Hawaiian longline fishery while all other bycatch remained constant at the 2005 bycatch mortality rate. For this scenario, we simulated that bycatch from Hawaiian longline fisheries increased at the observed rates starting in 2012 and ending 2016. To do this, we estimated the expected Hawaiian bycatch based on a bycatch mortality rate of 0.000357 (mean 2002–2011), and then added the excess Hawaiian longline bycatch from 2012–2016 to the total estimated from Arata et al. (2009). From 2017 onward, bycatch returns to the 2005 bycatch mortality rate.
>
> **Scenario 2.2, Minimum increase, permanent**: assumed the observed increases occurred only in the Hawaiian longline fishery while all other bycatch remained constant at 2005 bycatch mortality rates. For this scenario, we simulated that bycatch from Hawaiian longline fisheries increased at the observed rates starting in 2012, then stabilized and remained constant at the 2015 and 2016 bycatch mortality rates (either the 2015 or 2016 rate was selected randomly for each year), using the methods described for scenario 2.1.
>
> **Scenario 2.3, Minimum increase, episodic:** assumed only Hawaiian fisheries have experienced increased BFAL bycatch, similar to scenarios 2.1 and 2.2, but years of high bycatch occur episodically, as determined by ocean conditions. Based on Gilman

et al. (2016), we performed a simple comparison of BFAL bycatch from the Hawaiian longline fisheries and annual mean multivariate ENSO index (MEI) (http://www.esrl.noaa.gov/psd/enso/mei/table.html, Figure 44). Because bycatch of BFAL appears elevated when mean annual MEI is high, we used this relationship to simulate variation in bycatch levels driven by ocean conditions. As with scenarios 2.1 and 2.2, we simulated observed increases through 2016. After 2016, we simulated future MEI by randomly sampling from MEI values from 1980–2016 and assumed elevated Hawaiian bycatch (again at the 2015 and 2016 rates, selected randomly, as in scenario 2.2) occurred only when the annual MEI was high (> 0.79, Figure 44).

Scenario 3.1, Maximum increase, temporary: assumed all fisheries have experienced increased BFAL bycatch, proportional to the increases in Hawaiian longline fisheries. For this scenario, we simulated total bycatch increased proportional to the Hawaiian rate starting in 2012 and ending in 2016. Specifically, we assumed that from 2012–2016, Hawaiian bycatch continued to represent the same fraction of total bycatch as it had historically (mean fraction from 2002–2011 was 0.0104).

Scenario 3.2, Maximum increase, permanent: assumed all fisheries have experienced increased BFAL bycatch, proportional to the increases in Hawaiian longline fisheries. For this scenario, we simulated total bycatch increased proportional to the Hawaiian rate starting in 2012, using the same methods described in scenario 3.1, then stabilized and remained constant at the proportionally elevated 2015 and 2016 bycatch mortality rates (either the 2015 or 2016 rate was selected randomly for each year).

Scenario 3.3, Maximum increase, episodic: assumed all fisheries have experienced increased BFAL bycatch, similar to scenario 3.1, but that after 2016, years of high bycatch occur episodically, as determined by ocean conditions, similar to scenario 2.3. After 2016, we simulated future MEI by randomly sampling from MEI values from 1980–2016 and assumed elevated total bycatch (again at the proportionally elevated 2015 and 2016 rates, selected randomly, as in scenario 2) occurred only when the annual MEI was high (> 0.79, Figure 44).

Scenario 4, Updated demographic rates: assumed BFAL dynamics are best characterized using estimates of recent survival, skipping, and return probabilities (B. Kendall unpublished). Rather than using a baseline “natural” survival and adding estimated bycatch, this approach assumes newly estimated survival incorporates both natural and bycatch-associated mortality. For this scenario, we assumed updated demographic rates characterized BFAL population dynamics from 2006 onward.

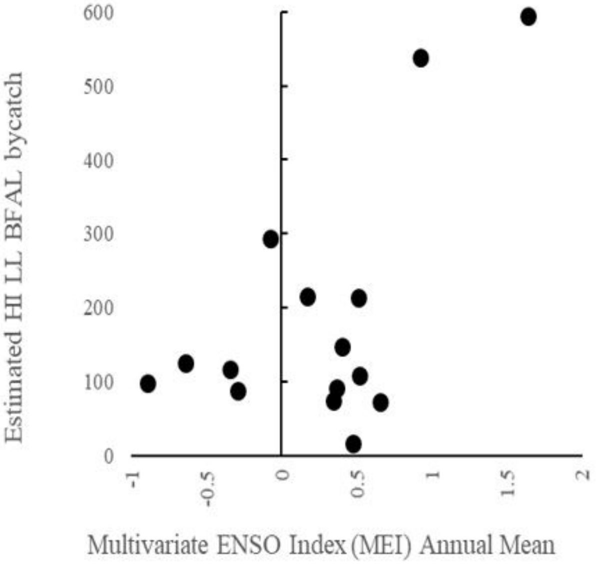

Figure 44. Estimated bycatch of Black-footed Albatross (BFAL) in the Hawaiian longline fishery (2002–2016) in relation to the annual mean Multivariate ENSO Index (MEI).

For each scenario, we initiated populations at the observed breeding pair estimate and assumed a stable stage distribution. For scenarios 1–3, we simulated stochastic population trajectories from 2001 to 2040, with each of 10,000 replicate runs incorporating parameter uncertainty in the mean and variance of key demographic rates, but not in bycatch rates. For scenario 4, we simulated populations from 2006, the first year of demographic rates estimates from B. Kendall, to 2040, and did not include uncertainty. For all scenarios, we assumed bycatch affected only post-hatch-year birds and that bycatch mortality was proportional to abundance. However, as bycatch from Hawaiian longline fisheries appears to disproportionately affect mature individuals (Russell et al., this workshop), we also explored the effects of this bias in the age distribution of bycaught individuals on predicted population dynamics. The mean probability that bycaught individuals were mature (> 4 years old) was 0.784, which is somewhat higher than number of mature individuals expected in the population at the stable age distribution of 0.678. We simulated this age skew in the Hawaiian fishery only and in all fisheries, using scenario 2.2, Minimum increase, permanent.

Relationship between changes in adult survival and changes in population growth rate

To gain a broader understanding of the implications of changes in bycatch which directly affect survival of after-hatch-year birds, we simulated population trajectories to 2040 using a range of survival rates. We used the updated estimates for skip and return and the model structure described for scenario 4 and simulated 100 replicate runs for a range of survival rates ranging from 0.88 to 0.98 and recorded stochastic population growth rate, λ, from 2017 to 2040.

Results

Modeling potential effects from increases in bycatch

Scenario 1.0, Bycatch constant: If bycatch increases in the Hawaiian longline fishery are offset by reductions in bycatch elsewhere, and bycatch remains constant at the 2005 rate, the BFAL population is expected to increase at an annual rate of about 3% from 2017 to 2040 (realized stochastic λ, λ_{23} = 1.030, Bakker et al. 2018, Figure 45). At this rate, the predicted median number of breeding pairs by 2040 is about 185,000, globally.

Scenario 2.1, Minimum increase, temporary: If increased bycatch occurs only in the Hawaiian longline fisheries and returns to 2005 levels after 2016, the overall population level effect is minimal (Figure 45), with the predicted population growth rate essentially the same as that predicted by the constant bycatch scenario (scenario 1).

Scenario 2.2, Minimum increase, permanent. If increased bycatch occurs only in the Hawaiian longline fisheries and stabilizes at the bycatch mortality rates observed in 2015 and 2016, the overall population level effect is relatively small (Figure 45). Realized stochastic λ from 2017 to 2040 (λ_{23}) drops 0.5% relative to the constant bycatch scenario, from1.030 to 1.025.

Scenario 2.3, Minimum increase, episodic. If increased bycatch occurs only in the Hawaiian longline fisheries and the high bycatch mortality rates observed in 2015 and 2016 occur episodically when simulated MEI is high, stochastic λ from 2017 to 2040 (λ_{23}) drops 0.1% relative to the constant bycatch scenario, from 1.030 to 1.029.

Scenario 3.1, Maximum increase, temporary: If bycatch affects all fisheries proportional to the Hawaiian fisheries but returns to 2005 levels after 2016, the median number of breeding pairs is predicted to decline sharply until 2017 (Figure 45). The predicted median number of breeding pairs by 2040 is 117,000, nearly 70,000 fewer than expected under the constant bycatch scenario (scenario 1). However, because the bycatch mortality rate returns to the 2005 level in 2017 in this scenario, stochastic λ from 2017 to 2040 (λ_{23}) is close to that predicted by the constant bycatch scenario (1.029 vs. 1.030).

Scenario 3.2, Maximum increase, permanent: If bycatch affects all fisheries proportional to the Hawaiian fisheries and stabilizes at the bycatch mortality rates observed in 2015 and 2016, the overall population level effect is dramatic. In this scenario, increased bycatch results in a stochastic λ of 0.877 and a sharp and unsustainable decline in median numbers of BFAL to only ~2,500 breeding pairs by 2040 (Figure 45).

Scenario 3.3, Maximum increase, episodic: If elevated bycatch affects all fisheries but the high bycatch rates of 2015 and 2016 only occur episodically when MEI is high, the resulting population is predicted to decline sharply until 2017, and then to decline at a rate of 1.4% annually from 2017 to 2040 (λ_{23} = 0.986, Figure 45).

Scenario 4, Updated demographic rates: Using updated estimates of survival, skipping, and return, the BFAL population is predicted to be approximately stable (λ_{23} = 1.009, Figure 45) ~2% lower than the λ_{23} of the constant bycatch scenario (scenario 1).

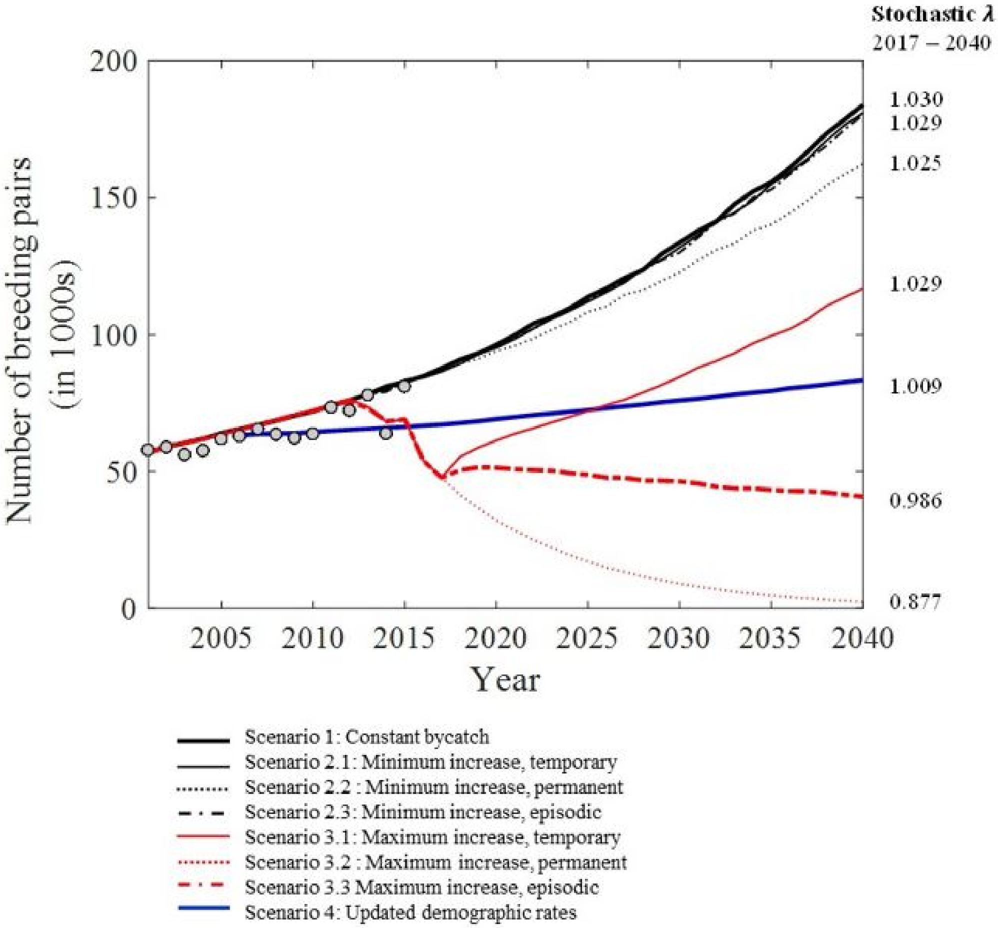

Figure 45. Median numbers of breeding pairs of Black-footed Albatross under eight bycatch scenarios (see methods). Numbers to the right of each trajectory represent mean stochastic λ from 2017 to 2040.

The observed modest skew towards mature individuals in bycaught BFAL (Russell et al., unpublished data) is predicted to have a negligible effect on population growth rates if it occurs only in the Hawaiian fishery (scenario 2.2, Minimum increase permanent, with and without out age skew in Hawaiian fishery, λ_{23} = 1.025). However, if a similar skew affects all fisheries, the population growth rate is modestly reduced (scenario 2.2, Minimum increase permanent, without age skew, λ_{23} = 1.025, and with age skew in all fisheries, λ_{23} = 1.022).

Relationship between changes in adult survival and population growth rate

Our analysis of the trade-offs between survival of after-hatch-year individuals and stochastic lambda highlights the pivotal role at-sea mortality plays in driving population dynamics. Similar to Cousins and Cooper (2000), we found that for each one percent decline in survival of after-hatch-year birds, population growth rate declined by about one percent (Figure 46).

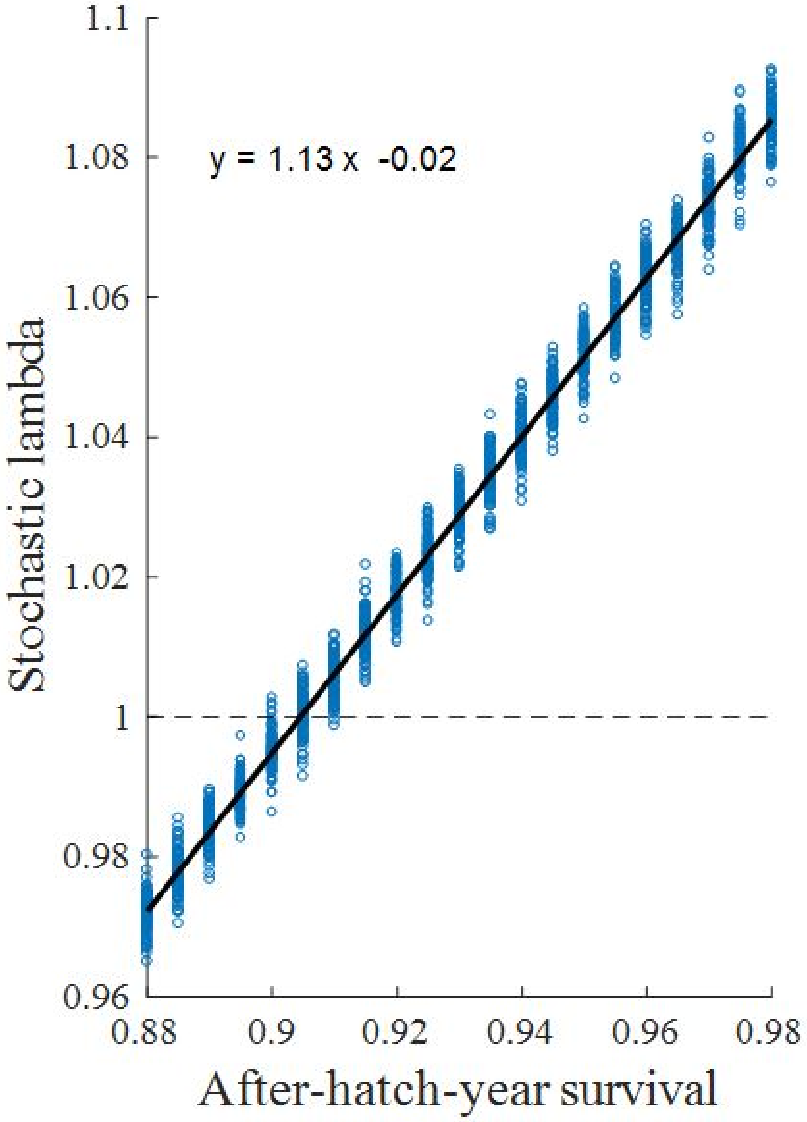

Figure 46. Relationship between after-hatch-year survival of Black-footed Albatross and stochastic λ from 2017 to 2040, based on 100 simulated trajectories for a range of survival rates and using the demographic rates and matrix described for scenario 4 (Appendix, Figure A1–2).

Conclusions

The potential effects of the observed increases of bycatch in the Hawaiian longline fisheries on BFAL depend strongly on the geographic extent and temporal duration of these increases. Increases in BFAL bycatch are predicted to have minimal population level effects if they occur only in Hawaiian fisheries and are temporary or episodic. Likewise, effects are predicted to be relatively small if bycatch increases occur only in Hawaiian fisheries and stabilize at 2015 and 2016 levels. However, in scenarios in which bycatch increases occur in all fisheries, either permanently or episodically, BFAL population growth is substantially affected, with predicted future trajectories at best stable or at worst declining dramatically (Figure 45). Indeed, BFAL populations are predicted to decline as much as 95% by 2040 if total BFAL bycatch has increased proportional to Hawaiian bycatch. While it is unlikely that all fisheries have exhibited identical increases in BFAL bycatch, assessing the extent to which observed increases in the Hawaiian longline fishery are indicative of increases in other fisheries is critical.

Model projections using updated survivorship and skipping and return estimates from the past decade had a reasonable fit to observed count data (i.e., within the 75% confidence intervals, not shown) but suggest a future population growth rate that is essentially stable. Of concern, these updated demographic rate estimates end in 2012, prior to the bycatch increases of 2015 and 2016. Extending analyses of mark-recapture data would shed light on the extent to which observed and unobserved increases in bycatch are impacting BFAL populations. Further, model simulations using updated survivorship and skipping data indicate that BFAL population growth is lower than previously predicted (Bakker et al. 2018; Arata et al. 2009), adding to uncertainty about BFAL population health.

In summary, our simulations highlight the need to i) continue to monitor BFAL populations and demographic rates and ii) work to obtain estimates of total BFAL bycatch to better predict the effects of bycatch on BFAL population dynamics. Our findings also underscore the importance of continued efforts to reduce BFAL bycatch mortality in the Hawaiian as well as other longline fishing fleets.

Acknowledgements

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Integrated Modelling of Seabird Populations

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Introduction

Seabirds are more threatened than other comparable groups of birds and their conservation status has deteriorated faster over recent decades (Croxall et al. 2012; Spatz et al. 2014). Currently, 31% of the world’s seabird species are listed as threatened on the International Union for the Conservation of Nature’s Red List (IUCN 2017). Among the principal current threats are alien invasive predators, commercial fisheries through competition for the same food resources and through accidental mortality on fishing gear, climate change, and pollution. Particularly threatened groups of seabirds are penguins (56% of the species threatened) and Procellariiformes including albatrosses, petrels, and shearwaters (45% of the species threatened). However, assessing seabird population status and trends, and proposing management actions require an understanding of these threats and a quantification of their impact on seabird demographics and population dynamics (Soulé 1987; Croxall et al. 2012; Lewison et al. 2014).

Several statistical methods exist to describe and explain demographic processes in populations (the demographic paradigm) and to quantify the impact of environmental factors on demographics (the ecological paradigm). Until recently, two main approaches were used (Véran and Lebreton 2008). Analyzing time series of successive surveys of population abundance calculates the rate of change and variability of population size and the effects of covariates (Royama 1992; Turchin 2003). This approach requires accurate and precise repeated surveys but can be sensitive to observation errors (Dennis et al. 2006) and provides few insights into the demographic and ecological processes involved. The other more process-oriented approach is based on estimation and analysis of demographic parameters, such as survival probabilities or breeding probabilities, assessment of the effect of environmental covariates on these parameters, and joint modelling of these parameters using matrix population models (Caswell 2001; Williams et al. 2002). This demographic approach can also be affected by uncertainties in vital rates estimations and in many cases not all demographic parameters can be estimated due to a lack of data.

Integrated population modelling, defined as the joint analysis of population size data and demographic data (Schaub and Abadi 2011), is a powerful and promising new approach to combine individual demographic information and information brought by population surveys (Besbeas et al. 2002; Brooks et al. 2004; Schaub and Abadi 2011). Although integrated population models (IPM) have long been used in fisheries stock assessments (Fournier and Archibald 1982; Tuck and Possingham 1994; Maunder 2004; Maunder and Punt 2013), this approach is increasingly being used in ecology and conservation biology, especially when dealing with incomplete data sets (Besbeas et al. 2002). Here, I provide a short review of published IPM applied to seabirds. I discuss the current state of the research and attempt to demonstrate the potential benefits of using these models for seabird ecology and conservation in the future.

A brief overview of integrated population models

IPMs combine several sources of data, involving different population parameters (e.g., counts of different age classes, bycatch counts, demographic rates), into a single analysis. The inference is based on the joint likelihood of the observed data, obtained by the multiplication of the likelihoods from the single data sets. To allow joint estimation, at least one parameter in common is needed across multiple components of the likelihood. Examples of IPM applications entail the joint analyses of mark-recovery and count data (Brooks et al. 2004; Baillie et al. 2009) or fecundity, capture-mark-recapture, and count data (Gauthier et al. 2007; Tavecchia et al. 2009; Abadi et al. 2010). IPMs can also blend more heterogeneous types of information such as count, fecundity, and telemetry data in a spatialized framework (Tuck et al. 2001).

IPM are receiving increasing attention since this modelling approach has several advantages (Besbeas et al. 2002; Taveccchia et al. 2009; Abadi et al. 2010; Maunder and Punt 2013). First, all uncertainty originating from the fact that the data come from a random sample of animals are explicitly accounted for since IPM use all the available data in a single framework. As a consequence, predictions of future population sizes can include the full propagation of parameter uncertainty (Fonnesbeck and Conroy 2004; Gauthier et al. 2007; Tavecchia et al. 2009). Second, demographic parameters for which no explicit data are available, such as immigration or juvenile survival, can be estimated in some cases (Abadi et al. 2010; Schaub and Fletcher 2015; Abadi et al. 2016). Nevertheless, the precision of such parameters is generally low (Abadi et al. 2010) and may be biased when time-dependent models are applied (Tavecchia et al. 2009). Third, demographic parameter estimates are more precise and more accurate compared to estimates obtained using separate analyses, particularly with small sample sizes. Fourth, integrating all the available data into one analysis makes it easier to investigate the sensitivity of the results to the underlying model assumptions and to each data set, by including or omitting specific components or by weighing the data sets differently (Maunder and Punt 2013).

Despite these advantages, IPM make several assumptions sometimes leading to problems, which are the subject of an active field of research (Schaub and Abadi 2011; Maunder and Punt 2013; Schaub and Fletcher 2015). First, a newly developed goodness-of-fit method assesses the fit of IPM, but it remains relatively complex, computer intensive, and may not perform well in all cases (Besbeas and Morgan 2014). Second, model selection remains an open research topic when using IPM, particularly in a Bayesian framework which is the most frequently used due to its flexibility (King et al. 2008; Baillie et al. 2009). Third, parameter confounding is a potential problem given the complexity of IPM. Parameter redundancy can lead to unrealistic parameter estimates. Fourth, IPM rely on the critical assumption that the different data sets that are jointly analyzed are independent from each other. Recent methodological studies seem to indicate that violation of this assumption has a minimal impact on the parameter estimates (Besbeas et al. 2009; Abadi et al. 2010; Schaub and Fletcher 2015). Fifth, model misspecification may lead to inconsistent parameter estimates. Model misspecification occurs when an influential process is omitted or incorrectly specified in the model or incorrect values for fixed parameters are used. Due to the joint likelihood formulation of the model, bias in demographic parameters or inadequate modelling of processes, such as the observation process, may result in biased estimates of other parameters (Schaub et al. 2015). Finally, fitting IPM is generally more computationally intensive than traditional methods because there are usually more data and more parameters.

Review of existing integrated population models in seabirds

Integrated population models have been used in studies on birds, mammals, and fishes; here I review publications that used an IPM on seabirds. From each considered study, I extracted the following information: 1) the species of interest, 2) the types of data that were modelled jointly, 3) the covariates that were tested, 4) the focus of the study, 5) whether the IPM was spatialized, and 6) the benefit brought by the IPM. I searched Web of Science (date of accession, October 2017) and found a total of 17 published studies (Table 18).

Tuck et al. (2001) was the first publication that discussed an IPM that was applied to a seabird. The IPM, adapted from an integrated stock assessment model used in fisheries, and examined the effect of bycatch on wandering albatross demographics and population dynamics. Since this first application, the number of publications increased, and my review of the literature identified studies on 15 different species. The main focus was understanding the ecological and demographic processes involved in the dynamics of the populations as well as the statistical development of methods. Eight of the studies used IPM for conservation purposes, and all 17 focused on albatross species. All papers used counts and different types of capture-mark-recapture data; some incorporated other types of data sets such as telemetry and fishing effort. A recent improvement to IPM is the integration of multi-state capture-mark-recapture with census data (Borysiewicz et al. 2009; Péron et al. 2010; McCrea et al. 2010; Tuck et al. 2015; Thomson et al. 2015; Michael et al. 2017), which allows the estimation of large sets of demographic parameters and the integration of multi-species data sets (Lahoz-Monfort et al. 2017), which allows the estimation of synchrony in the fluctuations of demographic parameters of seabird communities. A particularly interesting development for conservation biology is the integration of spatial data sets in IPM. Integrated population models developed on several albatross species (Tuck et al. 2001, 2011, 2015; Thomson et al. 2015; Michael et al. 2017) included spatialized telemetry data and spatialized fishing effort and bycatch data which allowed identifying oceanic areas of major mortality due to bycatch and the most impactful fisheries.

One benefit of IPM over conventional analyses is that they provide estimates of demographic parameters for which little or no information exists. For seabirds, this applies particularly to survival of juvenile and immature individuals who remain at sea permanently after fledging (where they remain unobservable) and return to colonies (where they can be observed) several years after fledging. Emigration is also difficult to estimate for seabird populations, as often only a single site is monitored. A further benefit of IPM for modelling seabird population dynamics is the ability to assess the impact of fisheries bycatch. Providing adequate data on the spatial distribution of different age-classes and fishing effort by fleet, Tuck et al. (2015) were able to highlight areas, times, and fleets prone to increased bycatch. They also developed a model in which some birds were assumed to be more susceptible to fisheries bycatch which successfully replicated the observed trend in breeding pairs.

Only one study estimated immigration in a seabird population using an IPM, although some more recent studies estimated this parameter for other bird species using IPM (Abadi et al. 2010; Schaub et al. 2010; Tenan et al. 2017). Simulation studies suggest that the choice of parametrization of IPM is important when estimating immigration (Schaub and Fletcher 2015). Immigration is an important demographic process that has long been neglected in population modelling, despite its potential to have a critical impact on population dynamics in seabirds (Oro and Ruxton 2001; Jenouvrier et al. 2003).

Many seabirds have complex life histories and are long-lived which makes them highly susceptible to additional incidental mortality from fishing vessels or other threats and complicates the estimation of key demographic parameters such as juvenile survival, emigration, or immigration. Integrated modelling is a powerful tool to help understand the demography of seabirds and the effects of environmental drivers on their population dynamics. Spatialized IPM is an effective method for identifying key areas and fleets where mitigation is required to minimize the impact of fisheries on populations. This should inform conservation managers' actions to reduce seabird bycatch through spatial management and fleet-specific mitigation efforts.

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Appendix A: Workshop Participants

List of the twenty-two participants who attended the workshop:

Name	Affiliation
Asuka Ishizaki	WPRFMC
Beth Flint	U.S. Fish and Wildlife Service
Bill Kendall	Colorado State University
Chris Boggs	Pacific Islands Fisheries Science Center, NOAA
Christophe Barbraud	Centre National de la Recherche Scientifique–Chizé, France
Daisuke Ochi	National Research Institute Far Seas Fisheries, Japan
David Hyrenbach	Hawaii Pacific University/Oikonos
Eric Gilman	The Nature Conservancy
Jeff Polovina	Pacific Islands Fisheries Science Center, NOAA
Johanna Wren	Pacific Islands Fisheries Science Center-JIMAR, NOAA
John Peschon	PIRO Observer Program, NOAA
Karen Baird	BirdLife International, New Zealand
Melanie Abecassis	Pacific Islands Fisheries Science Center, NOAA
Milani Chaloupka	Ecological Modelling Services Pty., Australia
Myra Finkelstein	University of California, Santa Cruz
Paul Dalzell	WPRFMC
Sarah Ellgen	PIRO Sustainable Fisheries Division, NOAA
Scott Shaffer	San Jose State University
Sean Martin	Hawaii Longline Association
Tamara Russell	NOAA Hollings Scholar
Vickie Bakker	Montana State University
Yukiko Inoue	National Research Institute of Far Seas Fisheries, Japan

List of the six observers who attended the workshop:

Name	Affiliation
Jessie Beck	Marine Wildlife Veterinary Care and Research Center, Santa Cruz
Melanie Brown	Sustainable Fisheries Division, PIRO
MiAe Kim	Office of International Affairs, NOAA
Rachael Orben	Oregon State University
Neville Smith	Ocean Fisheries Programme, Pacific Community, New Caledonia
Roberta Swift	U.S. Fish and Wildlife Service

Appendix B: Workshop Agenda

Workshop on the Factors Influencing Albatross Interactions in the Hawaii Longline Fishery: Towards Identifying Drivers and Quantifying Impacts

WESTERN
PACIFIC
REGIONAL
FISHERY
MANAGEMENT
COUNCIL

November 7–9, 2017
Council Office
Honolulu, Hawaii

9 a.m.–5 p.m., Tuesday, November 7, 2017

1.	Welcome and Introductions	Polovina, Chair
2.	Objectives and Activities of the Workshop	Steering Committee
3.	Overview of Albatross Interactions in the Hawaii Longline Fishery	
A.	Overview of the Hawaii Longline Fishery	Dalzell
B.	Time Series of Albatross Interactions in the Hawaii Longline Fishery	Ishizaki
C.	Status and Trends of NWHI Albatross Populations	Flint
D.	Albatross Distributions and Habitats	Shaffer
E.	Risk Factors of Albatross Interactions	Gilman
	Lunch Break 12:00 p.m.–1:00 p.m.	
4.	Explore Possible Factors for Influencing Albatross Interactions	
A.	Oceanographic Setting	Polovina
B.	Seabird Interactions-Oceanography and fleet dynamics	Wren
C.	Seabird Interactions-Demographics (Age / Sex)	Russell
D.	Seabird Reproductive Dynamics-Nest Counts and Productivity	Hyrenbach
5.	Discussion: Were 2015 and 2016 Unusual? How and Why?	Hyrenbach
6.	Discussion: Factors Influencing Albatross-Fishery Interactions	Hyrenbach
7.	Working Group Assignments and Plan for Day Two	Polovina

9 a.m.–5 p.m., Wednesday, November 8, 2017

8. Recap of Day 1 and Continue Discussion from Day 1	Steering Committee
9. Case Studies from Other Areas: Factors influencing seabird bycatch in southern and northern hemispheres in the Japanese longline fishery	Inoue/Ochi
10. Evaluating Albatross Population Impacts	
A. Albatross demography-survivorship and skipping	Kendall
B. Overview of demographic model and results-BFAL status	Finkelstein
C. Updated demographic model with new data	Bakker

Lunch Break 12:00 p.m.–1:30 p.m.

11. Keynote: Integrated Demographic Modelling	Barbraud
12. Discussion: Albatross Population Impacts in 2015–16	Hyrenbach
13. Discussion: Long-term Albatross Population Impacts	Hyrenbach
14. Discussion: Future Data Needs and Analyses	Polovina
15. Working Group Assignments and Plan for Day Three	Polovina

9 a.m.–5 p.m., Thursday, November 9, 2017

16. Working Group Work Session	To be assigned

Lunch Break 12:00 p.m.–1:00 p.m.

17. Working Group Reports	Working Groups
18. Results & Hypotheses: Factors Responsible for Increased Interactions	Hyrenbach
A. Discussion	
B. Future Data Needs and Analyses	
19. Results and Hypotheses: Population-Level Impacts	Hyrenbach
A. Discussion	
B. Future Data Needs and Analyses	
20. Wrap-up and Next Steps	Polovina

Appendix C: Demographics of Black-footed Albatross caught in the Hawaii deep-set longline (DSLL) fishery

Table 10. Overall proportion (%) of Black-footed Albatross by sex and maturity status (2010–2016) compared to the expected proportions assuming an equal sex ration and a stable population age structure.

Overall Proportions (2010–2016)				
	Female	Male	Mature	Immature
Observed	57.48	42.52	78.35	21.65
Expected	50.00	50.00	65.80	34.20

Table 11. Yearly demographic composition of Black-footed Albatross bycatch from 2010 to 2016 by sex and age class, showing the mean and S.D. (%) of each demographic group. N refers to the number of bycaught albatross examined by necropsy.

		Female		Male		Mature		Immature	
Year	N	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
2010	14	78.57	2.22	21.43	2.22	92.86	3.16	7.14	1.98
2011	12	66.67	12.08	33.33	12.08	83.33	4.29	16.67	3.39
2012	34	55.88	10.80	44.12	10.80	76.47	1.50	23.53	1.29
2013	36	50.00	13.21	50.00	13.21	75.00	1.43	25.00	1.24
2014	30	60.00	8.06	40.00	8.06	80.00	1.69	20.00	1.38
2015	61	59.02	3.81	40.98	3.81	67.21	0.82	32.79	0.78
2016	67	53.73	8.08	46.27	8.08	86.57	0.76	2.88	0.52

Table 12. Composition of Black-footed Albatross bycatch by sex and age class, showing the mean (%) of each demographic group. N refers to the number of bycaught albatross examined by necropsy.

	N	Female	Male	Mature	Immature
Deep-set (2010-2016)	254	57.48	42.52	78.35	21.65
Shallow-set (2010-2016)	48	52.08	47.92	95.83	4.17
Pre-2015	126	58.73	41.27	79.37	20.63
2015-2016	128	56.25	43.75	77.34	22.66
May-July 2015	44	59.09	40.91	61.36	38.64
Laysan (2010-2016)	154	50.98%	49.02%	88.96%	11.04%

Table 13. ANOVA and ANCOVA analyses of annual locations (log latitude, log longitude) of Black-footed Albatross caught in the Hawaii deep-set fishery from 2010 to 2016. Tests compare all birds (overall) and groups defined by sex (male, female) and age class (mature, immature). The tests consider two geographic areas: all interactions are the subset of interactions in the core fishing grounds (north of 23° N). Significant results are highlighted with bold font.

		All Interactions			North of 23°N		
	Variable	F	df	p	F	df	p
Overall	**Latitude**	**4.59**	**11,444**	**<0.001**	**3.90**	**6,209**	**0.001**
	Longitude	**7.246**	**11,444**	**<0.001**	**5.45**	**6,209**	**<0.001**
Between Sexes	Latitude	0.24	1,250	0.622	2.10	1,212	0.149
	Longitude	0.81	1,250	0.370	0.48	1,212	0.488
Between Age Class	Latitude	0.08	1,250	0.778	0.11	1,212	0.740
	Longitude	1.04	1,250	0.309	1.04	1,212	0.308
Females	**Latitude**	**2.64**	**6,136**	**0.019**	**2.72**	**6,117**	**0.017**
	Longitude	**3.91**	**6,136**	**0.001**	**5.07**	**6,117**	**<0.001**
Males	Latitude	1.06	6,101	0.395	1.72	6,85	0.125
	Longitude	**2.45**	**6,101**	**0.030**	**2.93**	**6,85**	**0.012**
Mature	**Latitude**	**2.30**	**6,192**	**0.037**	**2.88**	**6,161**	**0.011**
	Longitude	**2.88**	**6,192**	**0.010**	**3.62**	**6,161**	**0.002**
Immature	Latitude	1.08	6,48	0.390	1.49	6,41	0.207
	Longitude	1.34	6,48	0.257	1.66	6,41	0.156
Female & Mature	**Latitude**	**2.77**	**6,112**	**0.015**	**2.56**	**6,95**	**0.024**
	Longitude	**2.79**	**6,112**	**0.015**	**3.90**	**6,95**	**0.002**
Female & Immature	Latitude	1.54	6,20	0.216	0.55	6,16	0.765
	Longitude	1.11	6,20	0.392	0.96	6,16	0.483
Male & Mature	Latitude	0.80	6,73	0.571	1.05	6,60	0.401
	Longitude	1.51	6,73	0.189	1.66	6,60	0.146
Male & Immature	Latitude	0.92	4,23	0.467	1.38	4,20	0.277
	Longitude	0.93	4,23	0.464	1.59	4,20	0.216

Table 14. ANOVA and ANCOVA analysis of quarterly locations (log latitude, log longitude) of Black-footed Albatross caught in the Hawaii deep-set fishery from 2010 to 2016. Tests compare all birds (overall) and groups defined by sex (male, female) and age class (mature, immature). The tests consider two geographic areas: all interactions and the subset of interactions in the core fishing grounds (north of 23° N). Significant results are highlighted with bold font.

		All Interactions			North of 23°N		
	Variable	F	df	p	F	df	p
Overall	**Latitude**	**4.59**	**11,444**	**<0.001**	**3.90**	**6,209**	**0.001**
	Longitude	**7.246**	**11,444**	**<0.001**	**5.45**	**6,209**	**<0.001**
Between Sexes	Latitude	0.24	1,250	0.622	2.10	1,212	0.149
	Longitude	0.81	1,250	0.370	0.48	1,212	0.488
Between Age Class	Latitude	0.08	1,250	0.778	0.11	1,212	0.740
	Longitude	1.04	1,250	0.309	1.04	1,212	0.308
Females	**Latitude**	**2.64**	**6,136**	**0.019**	**2.72**	**6,117**	**0.017**
	Longitude	**3.91**	**6,136**	**0.001**	**5.07**	**6,117**	**<0.001**
Males	Latitude	1.06	6,101	0.395	1.72	6,85	0.125
	Longitude	**2.45**	**6,101**	**0.030**	**2.93**	**6,85**	**0.012**
Mature	**Latitude**	**2.30**	**6,192**	**0.037**	**2.88**	**6,161**	**0.011**
	Longitude	**2.88**	**6,192**	**0.010**	**3.62**	**6,161**	**0.002**
Immature	Latitude	1.08	6,48	0.390	1.49	6,41	0.207
	Longitude	1.34	6,48	0.257	1.66	6,41	0.156
Female & Mature	**Latitude**	**2.77**	**6,112**	**0.015**	**2.56**	**6,95**	**0.024**
	Longitude	**2.79**	**6,112**	**0.015**	**3.90**	**6,95**	**0.002**
Female & Immature	Latitude	1.54	6,20	0.216	0.55	6,16	0.765
	Longitude	1.11	6,20	0.392	0.96	6,16	0.483
Male & Mature	Latitude	0.80	6,73	0.571	1.05	6,60	0.401
	Longitude	1.51	6,73	0.189	1.66	6,60	0.146
Male & Immature	Latitude	0.92	4,23	0.467	1.38	4,20	0.277
	Longitude	0.93	4,23	0.464	1.59	4,20	0.216

Appendix D: Black-footed Albatross Reproductive Dynamics: Breeding Population Size and Reproductive Success

Table 15. Summary of PCA results, showing the following information for the three dominant axes: eigenvalues, % of variance explained, and correlations (n = 38) with environmental variables and "year." Significant (0.05 < p < 0.001) and highly significant (p < 0.001) Pearson correlations are shown in italics and bold font, respectively.

	Axis1	Axis2	Axis3
Eigenvalues	6.075	1.677	1.369
% Variance	52.35	13.45	11.80
Correlations	r	r	r
MEI Q1	**+0.871**	-0.297	-0.138
MEI Q2	**+0.662**	*-0.438*	-0.186
MEI Q3	**+0.852**	-0.086	+0.048
MEI Q4	**+0.878**	-0.235	-0.068
PDO Q1	**+0.819**	+0.108	*+0.339*
PDO Q2	**+0.772**	-0.059	+0.224
PDO Q3	**+0.758**	*+0.390*	+0.299
PDO Q4	**+0.758**	+0.281	*+0.423*
SST Q1	**-0.769**	-0.016	*+0.412*
SST Q2	**-0.531**	*+0.472*	*+0.512*
SST Q3	+0.031	**-0.729**	*+0.470*
SST Q4	**-0.532**	**-0.613**	*+0.465*
Year	*-0.352*	*-0.442*	*+0.449*

Table 16. Results of general linear model (GLM) analyses of BFAL productivity and number of breeding pairs over long and short time scales. Significant results are highlighted with bold font.

number of breeding pairs over long and short time scales. Significant results are highlighted with bold font.

A) French Frigate Shoals (1980–2011)–Reproductive Success

Effect	Std. Coef.	t	p value
CONSTANT	0.000	0.947	0.352
YEAR	-0.195	-0.839	0.409
PC1	0.133	0.654	0.519
PC2	**-0.430**	**-2.159**	**0.040**
PC3	0.111	0.583	0.565

B) Midway Island (2004–2017)–Reproductive Success

Effect	Std. Coef.	t	p value
CONSTANT	**0.000**	**3.418**	**0.008**
YEAR	**-0.713**	**-3.387**	**0.008**
PC1	-0.462	-1.338	0.214
PC2	-0.452	-1.766	0.111
PC3	0.417	1.311	0.222

C) Midway Island (2004–2017)–Breeding Pairs

Effect	Std. Coef.	t	p value
CONSTANT	**0.000**	**-2.700**	**0.024**
YEAR	**0.683**	**2.785**	**0.021**
PC1	-0.409	-1.017	0.336
PC2	-0.010	-0.033	0.974
PC3	0.157	0.424	0.682

Appendix E: Potential impacts of recent increases in Hawaiian longline bycatch on the population dynamics of the Black-footed Albatross *Phoebastria nigripes*

Table 17. Annual levels of bycatch and related data for black-footed albatross.

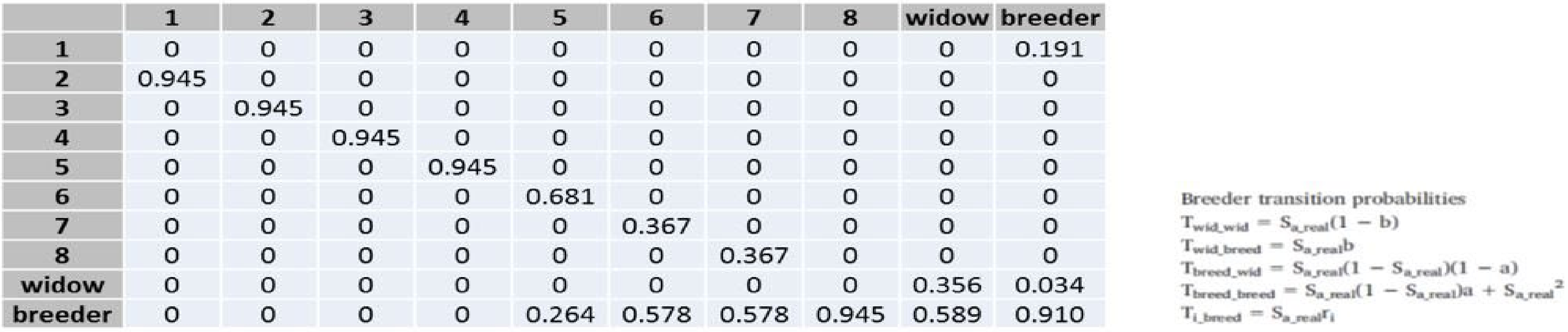
		BFAL Bycatch													
Year	Est. non HY population size	Total, high scenario	Total, mod scenario	Pelagic LL, high scenario	Pelagic LL, mod scenario	HI LL	HI Shallow-set LL[1]	HI Deep-set LL	Total HI LL	Annual Mean Enso Index (MEI)	Mortality Rate from HI LL Bycatch, Non HY birds	HI LL Bycatch/ Total Bycatch	Excess HI Bycatch over mean 2002–2011 rate	Total Bycatch, Minimum Increase Assumption (Total + Excess)	Total Bycatch, Maximum Increase Assumption (HImean =HI LL/Total) (from 2002–2011)
Source		Bakker et al. 2018, Arata et al. 2009				NMFS 2005	WPRFMC 2017			www.esrl.noaa.gov/psd/enso/mei/table.html	calculated				
1994	345762	12530	7929	12046	7674	1830	--	--	1830	0.7611	0.0053	0.1460	--	--	--
1995	280451	11057	6906	9907	6115	1134	--	--	1134	0.2311	0.0040	0.1026	--	--	--
1996	265354	10234	6462	8975	5597	1472	--	--	1472	-0.2948	0.0055	0.1438	--	--	--
1997	294366	8698	5399	8097	5075	1305	--	--	1305	1.5672	0.0044	0.1500	--	--	--
1998	260503	8871	5480	7793	4941	1283	--	--	1283	0.9086	0.0049	0.1446	--	--	--
1999	266608	9781	5999	8971	5545	1301	--	--	1301	-0.8584	0.0049	0.1330	--	--	--
2000	228327	9468	6026	8610	5488	1339	--	--	1339	-0.4798	0.0059	0.1414	--	--	--
2001	242720	7356	4549	6717	4215	258	--	--	258	-0.1108	0.0011	0.0351	--	--	--
2002	247152	8246	5215	7603	4835	65	0	73	73	0.6553	0.0003	0.0089	--	--	--
2003	235640	8712	5388	7939	5005	111	0	108	108	0.5157	0.0005	0.0124	--	--	--
2004	241791	8718	5447	7939	5005	--	0	16	16	0.4747	0.0001	0.0018	--	--	--
2005	259804	8743	5227	7939	5005	--	10	82	92	0.3683	0.0004	0.0105	--	--	--
2006	264086	9047	5409	--	--	--	4	70	74	0.3454	0.0003	0.0082	--	--	--
2007	275016	9421	5633	--	--	--	11	77	88	-0.2961	0.0003	0.0093	--	--	--
2008	266822	9141	5465	--	--	--	8	118	126	-0.6426	0.0005	0.0138	--	--	--
2009	261114	8945	5348	--	--	--	38	110	148	0.3999	0.0006	0.0165	--	--	--
2010	267422	9161	5477	--	--	--	52	65	117	-0.3403	0.0004	0.0128	--	--	--
2011	308435	10566	6317	--	--	--	25	73	98	-0.8954	0.0003	0.0093	--	--	--
2012	303717	10404	6221	--	--	--	49	167	216	0.1723	0.0007	0.0208	108	10512	20869
2013	327276	11212	6703	--	--	--	37	257	294	-0.0728	0.0009	0.0262	177	11389	28405

		BFAL Bycatch													
Year	Est. non HY population size	Total, high scenario	Total, mod scenario	Pelagic LL, high scenario	Pelagic LL, mod scenario	HI LL	HI Shallow-set LL[1]	HI Deep-set LL	Total HI LL	Annual Mean Enso Index (MEI)	Mortality Rate from HI LL Bycatch, Non HY birds	HI LL Bycatch/ Total Bycatch	Excess HI Bycatch over mean 2002–2011 rate	Total Bycatch, Minimum Increase Assumption (Total + Excess)	Total Bycatch, Maximum Increase Assumption (HImean =HI LL/Total) (from 2002–2011)
2014	268088	9184	5491	--	--	--	38	175	213	0.5083	0.0008	0.0232	117	9301	20579
2015	340510	11665	6974	--	--	--	54	541	595	1.6400	0.0017	0.0510	473	12138	57486
2016		--	--	--	--	--	53	485	538	0.9233	0.0016[2]	--	416[2]	12081[2]	51979
										Mean 2002–2011	0.000357	0.010350			

---

[1] Assumes a dropoff rate of 0.31 (NMFS 2011).

[2] HI LL Mortality rate and Excess HI bycatch assume 2016 BFAL population size equals that of previous year. Total bycatch, Minimum Increase Assumption assumes 2016 total bycatch equals that of previous year.



	1	2	3	4	5	6	7	8	widow	breeder
1	0	0	0	0	0	0	0	0	0	0.191
2	0.945	0	0	0	0	0	0	0	0	0
3	0	0.945	0	0	0	0	0	0	0	0
4	0	0	0.945	0	0	0	0	0	0	0
5	0	0	0	0.945	0	0	0	0	0	0
6	0	0	0	0	0.681	0	0	0	0	0
7	0	0	0	0	0	0.367	0	0	0	0
8	0	0	0	0	0	0	0.367	0	0	0
widow	0	0	0	0	0	0	0	0	0.356	0.034
breeder	0	0	0	0	0.264	0.578	0.578	0.945	0.589	0.910

Breeder transition probabilities

$T_{wid\_wid} = S_{a\_real}(1 - b)$

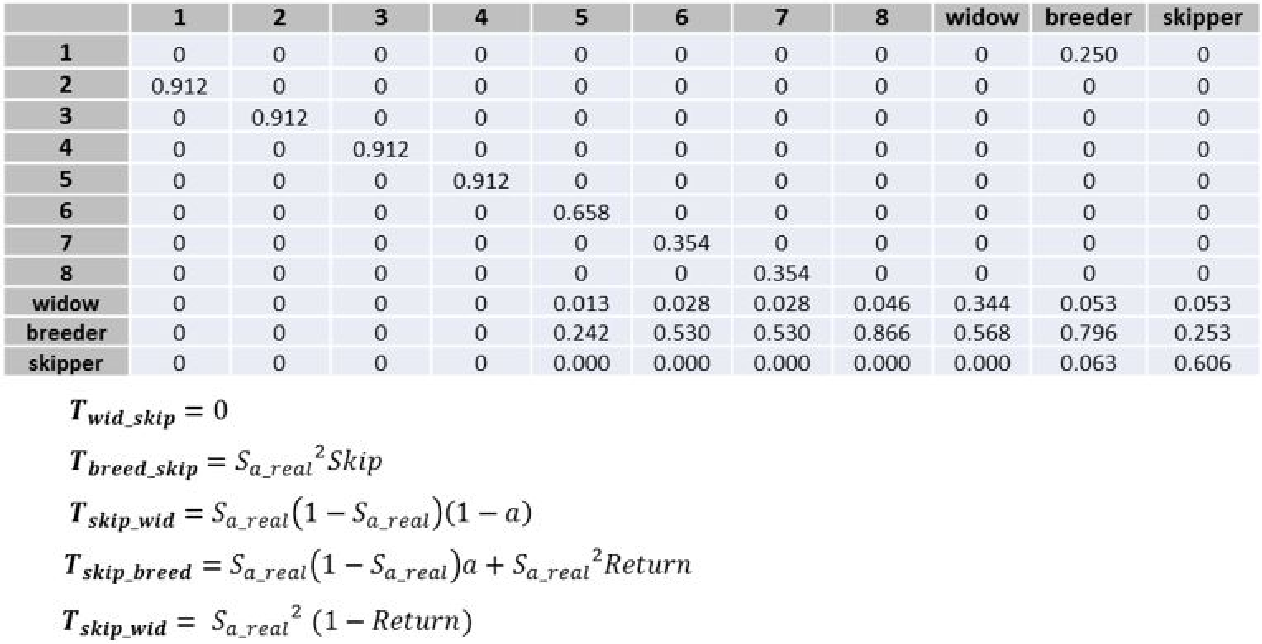
$T_{wid\_breed} = S_{a\_real}b$

$T_{breed\_wid} = S_{a\_real}(1 - S_{a\_real})(1 - a)$

$T_{breed\_breed} = S_{a\_real}(1 - S_{a\_real})a + S_{a\_real}^2$

$T_{i\_breed} = S_{a\_real}r_i$

Figure 47. BFAL matrix used in published model (Bakker et al. 2018), used in Scenarios 1–3.



	1	2	3	4	5	6	7	8	widow	breeder	skipper
1	0	0	0	0	0	0	0	0	0	0.250	0
2	0.912	0	0	0	0	0	0	0	0	0	0
3	0	0.912	0	0	0	0	0	0	0	0	0
4	0	0	0.912	0	0	0	0	0	0	0	0
5	0	0	0	0.912	0	0	0	0	0	0	0
6	0	0	0	0	0.658	0	0	0	0	0	0
7	0	0	0	0	0	0.354	0	0	0	0	0
8	0	0	0	0	0	0	0.354	0	0	0	0
widow	0	0	0	0	0.013	0.028	0.028	0.046	0.344	0.053	0.053
breeder	0	0	0	0	0.242	0.530	0.530	0.866	0.568	0.796	0.253
skipper	0	0	0	0	0.000	0.000	0.000	0.000	0.000	0.063	0.606

$$\boldsymbol{T}_{\boldsymbol{wid\_skip}} = 0$$

$$\boldsymbol{T}_{\boldsymbol{breed\_skip}} = S_{a\_real}{}^{2} Skip$$

$$\boldsymbol{T}_{\boldsymbol{skip\_wid}} = S_{a\_real}(1 - S_{a\_real})(1 - a)$$

$$\boldsymbol{T}_{\boldsymbol{skip\_breed}} = S_{a\_real}(1 - S_{a\_real})a + S_{a\_real}{}^{2} Return$$

$$\boldsymbol{T}_{\boldsymbol{skip\_wid}} = S_{a\_real}{}^{2}\,(1 - Return)$$

Figure 48. BFAL matrix incorporating skipper class, used in Scenario 4.

Appendix F: Integrated Modelling of Seabird Populations

Table 18. Summary of 17 reviewed studies applying integrated population models to seabirds.

Species	Data types^a	Included covariates	Focus^b	Spatialised	Benefit of IPM	Reference
Emperor penguin *Aptenodytes forsteri*	C, CMR, P	Sea ice cover, SAM	Ecology, statistics	No	Juvenile survival	Abadi et al. (2016)
Macaroni penguin *Eudyptes chrysolophus*	C, CMR, P	SST, ENSO, SAM, predation	Ecology, statistics	No	Relative impact of top-down and bottom–up factors	Horswill et al. (2016)
Wandering albatross *Diomedea exulans*	C, CMR, P, T, B, E	-	Conservation, statistics	Yes	Density-dependence, spatialized mortality, fleet impacts	Tuck et al. (2001), (2011), Thomson et al. (2008)
Wandering albatross *Diomedea exulans*	C, MS, P, T, B, E	-	Ecology, conservation	Yes	Density-dependence, spatialized mortality, fleet impacts, individual heterogeneity	Tuck et al. (2015)
Short-tailed albatross *Phoebastria albatrus*	C, P, E	-	Conservation	No	Population growth rate, decision analysis	Zador et al. (2008)
Black-footed albatross *Phoebastria nigripes*	C, CMR, P	Fishing effort	Ecology, conservation, statistics	No	Immature survival, impact of fisheries	Véran and Lebreton (2008)

Species	Data types[a]	Included covariates	Focus[b]	Spatialised	Benefit of IPM	Reference
Black-browed albatross *Thalassarche melanophris*	C, CMR, P, T, B, E	-	Conservation	Yes	Density-dependence, spatialized mortality, fleet impacts	Thomson et al. (2008) Tuck et al. (2011)
Black-browed albatross *Thalassarche melanophris*	C, MS, P, T, B, E	SST	Conservation	Yes	Density-dependence, spatialized mortality, fleet and climate impacts	Michael et al. (2017)
Shy albatross *Thalassarche cauta*	C, MS, P, T, B, E	Rainfall, temperature, sea surface height	Ecology, conservation	Yes	Density-dependence, spatialized mortality, fleet and climate impacts	Thomson et al. (2015)
Yellow-nosed albatross *Thalassarche chlororhynchos*	C, CMR, P, T, B, E	-	Conservation	Yes	Density-dependence, spatialized mortality, fleet impacts	Tuck et al. (2011)
Buller's albatross *Thalassarche bulleri*	C, CMR, B, E	-	Conservation, statistics	No	Population trend, bycatch impact	Francis and Sagar (2011)
Great cormorant *Phalacrocorax carbo*	C, MR, CMR	-	Statistics, evaluation	No	Productivity	Borysiewicz et al. (2009)
Great cormorant *Phalacrocorax carbo*	C, MS	-	Statistics, ecology	No	Productivity	McCrea et al. (2010)
Black-headed gull *Larus ridibundus*	C, MS	-	Statistics, ecology	No	Productivity, dispersal	Péron et al. (2010)

Species	Data types[a]	Included covariates	Focus[b]	Spatialised	Benefit of IPM	Reference
Common tern *Sterna hirundo*	C, MS, P	-	Ecology	No	Immigration	Szostek et al. (2014)
Common guillemot *Uria aalge*	C, CMR, MR, P	-	Statistics, ecology	No	Emigration, band loss	Reynolds et al. (2009)
Atlantic puffin *Fratercula arctica*, common guillemot *Uria aalge*, razorbill *Alca torda*	C, MR, CMR, P	-	Statistics, ecology	No	Multi-species synchrony	Lahoz-Monfort et al. (2017)

The studies are ordered taxonomically. [a]Data types: *C* population counts, *CMR* capture-mark-recapture data, *MR* mark-recovery data, *MS* multi-state capture-mark-recapture data, *P* productivity data, *T* telemetry data, *B* bycatch data, *E* fishing effort data. [b]Focus: *Statistics* development of new models; *Evaluation* model evaluation; *Ecology* understanding population dynamics; *Conservation* identifying causes of decline.