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 α = 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.

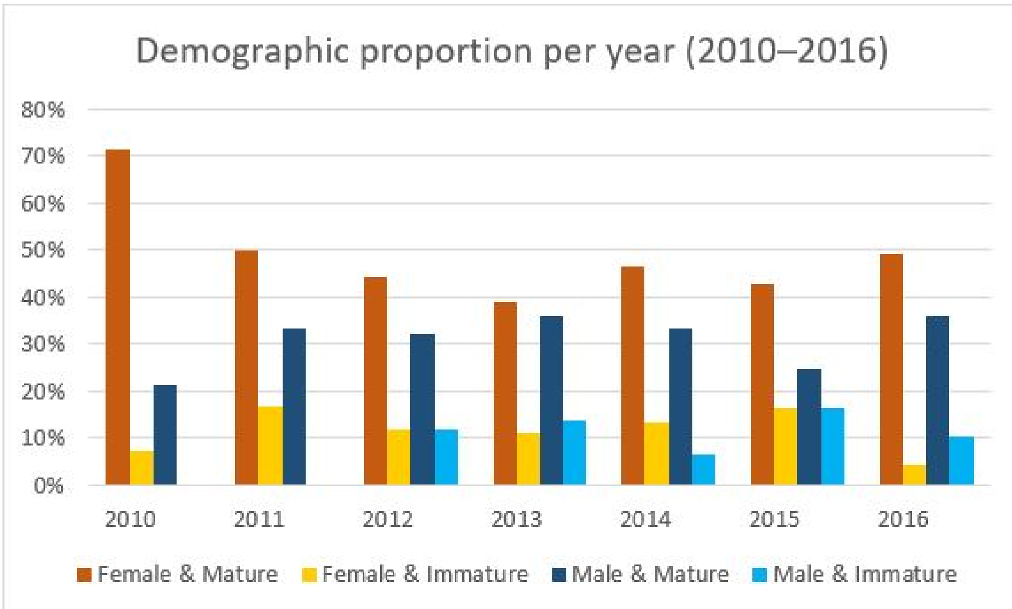

Figure 26. Proportion of BFAL demographic groups by year (all quarters combined).

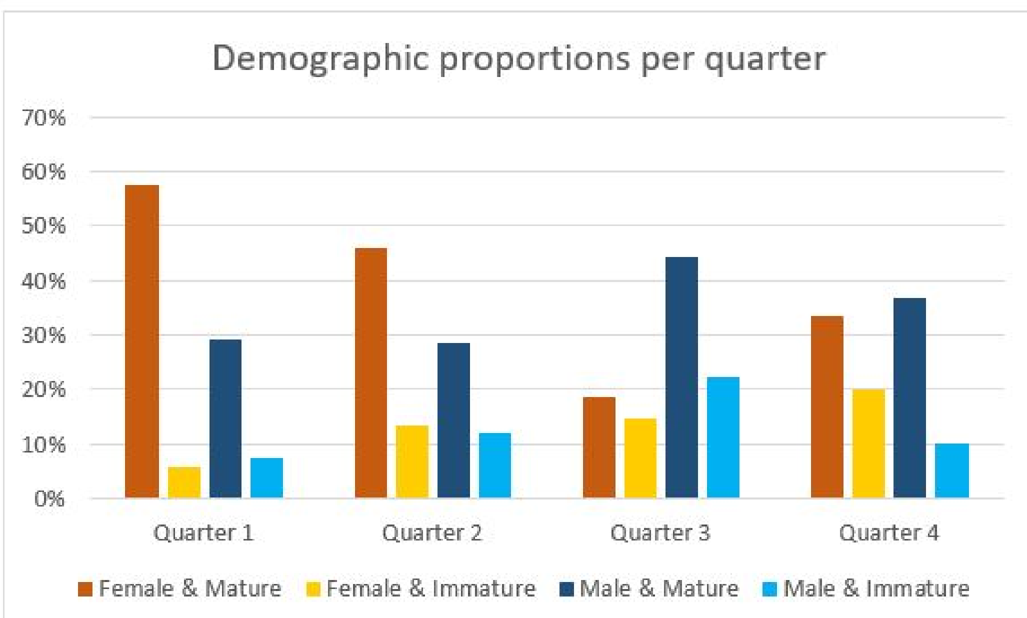

Figure 27. Proportion of BFAL demographic groups by quarter (2010–2016).

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 $\pm$ 1.16%), whereas the mature birds caught during this time had a higher female proportion (62.96 $\pm$ 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.

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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.

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	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

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