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 25º–30º N latitude and 150º–160º W (Polovina and Abecassis, this report).

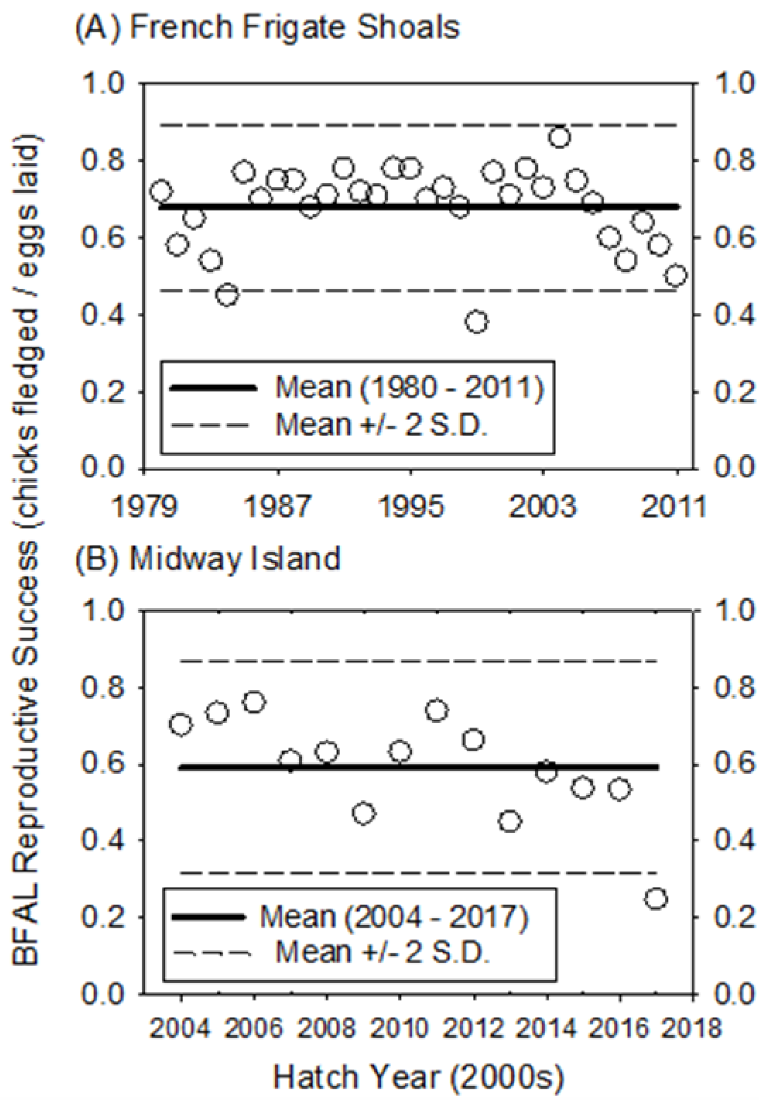

Figure 28. Time series of BFAL reproductive success at two study sites. To highlight interannual variability, yearly values are compared to the mean + 2 standard deviations.

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).

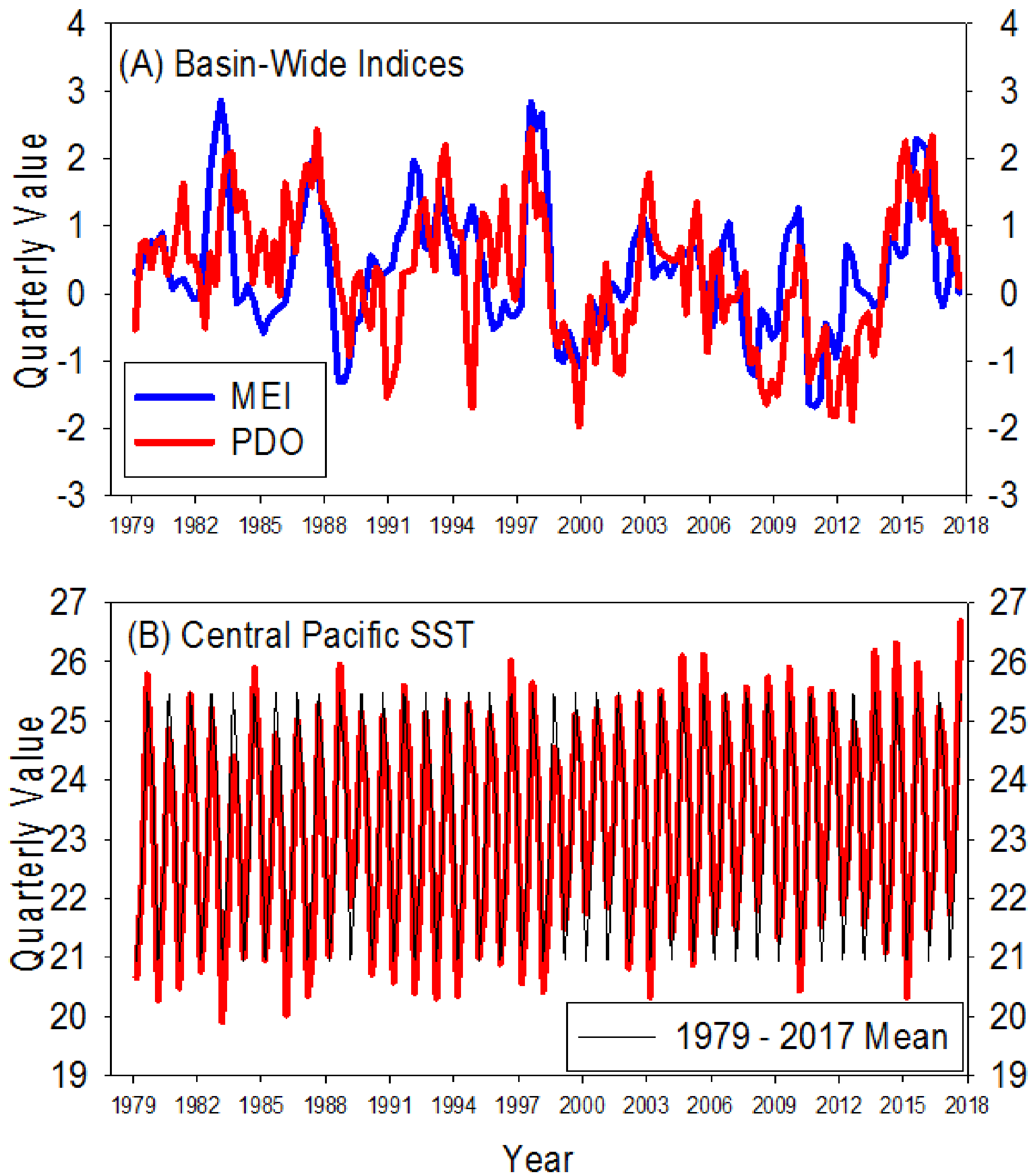

Figure 29. Time series of environmental variables used to characterize oceanographic conditions. Sea surface temperature (SST) data from the longline fishing grounds (25º–30ºN, 150º–160ºW) show quarterly values and long-term (1979–2017) mean.

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 ($y' = \text{asin}(y)$) 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).

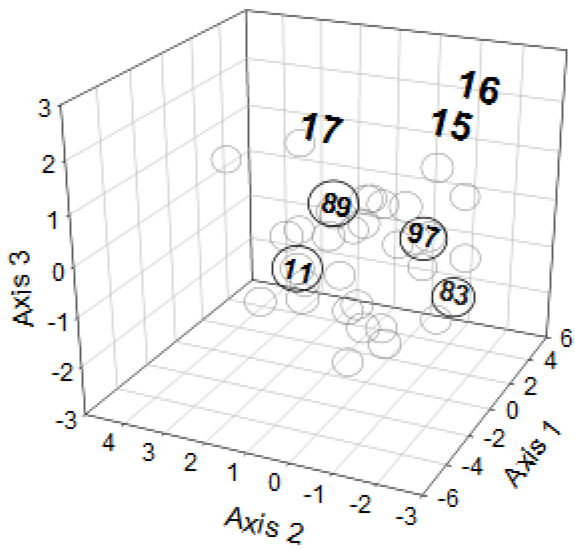

Figure 30. PCA results, showing the yearly coordinates (1980–2017), highlighting the three last years (2015–2017). To facilitate comparisons with previous El Niño (1983, 1997) and La Niña (1989, 2011), these years are also highlighted.

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 (25º–30 º N, 150 º–160 º 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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Literature Cited

ACAP. 2009. Species Information – Black-footed Albatross (Phoebastria nigripes). Hobart (Australia): ACAP. https://acap.aq/en/acap-species/239-black-footed-albatross/file.

Ainley DG, Hyrenbach KD. 2010. Top-Down and Bottom-Up Factors Affecting Seabird Population Trends in the California Current System (1985-2006). Prog Oceanogr. 84(3-4):242–254.

Awkerman JA, Anderson DJ, Whittow GC. 2008. Black-footed Albatross (Phoebastria nigripes). In: Rodewald PG, ed. The Birds of North America. Ithaca (NY): Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/bkfalb. doi:10.2173/bna.65.

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Leetmaa A, Reynolds R, Chelliah M, Ebisuzaki W, Higgins W, Janowiak

J, Mo KC, Ropelewski C, Wang J, Jenne R, Joseph D. 1996. The NCEP/NCAR Reanalysis 40-year Project. Bull Am Meteorol Soc. 77:437–471.

Keller KW, Anders AD, Shaffer SA, Kappes MA, Flint E, Friedlander A. 2009. Seabirds. pp. 235-274. In: Friedlander A, Keller K, Wedding L, Clarke A, Monaco M, editors. 2009. A Marine Biogeographic Assessment of the Northwestern Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 84. Prepared by NCCOS's Biogeography Branch in cooperation with the Office of National Marine Sanctuaries Papahānaumokuākea Marine National Monument. Silver Spring (MD). 363 pp.

Mantua NJ, Hare SR, Zhang Y, Wallace JM, Francis RC. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull Am Metereol Soc. 78:1069–1079.

McCune B, Grace JB, Urban DL. 2002. Analysis of Ecological Communities. Gleneden Beach (OR): MjM Software Design.

Polovina J, Abecassis M. In Review. Oceanographic variation during winter and spring in the Hawaii-based deep-set longline fishing grounds north of 25o N latitude. In: Hyrenbach KD, Ishizaki A, Polovina J, Ellgen S, editors. The Factors Influencing Albatross Interactions in the Hawaii Longline Fishery: Towards Identifying Drivers and Quantifying Impacts.

Reynolds MH, Courtot KN, Berkowitz P, Storlazzi CD, Moore J, Flint E. 2015. Will the Effects of Sea-Level Rise Create Ecological Traps for Pacific Island Seabirds? PLoS One. 10(9):e0136773. doi:10.1371/journal.pone.0136773.

Schroeder ID, Sydeman WJ, Sarkar N, Thompson SA, Bograd SJ, Schwing FB. 2009. Winter pre-conditioning of seabird phenology in the California Current. Mar Ecol Prog Ser. 393:211–223. doi:10.3354/meps08103.

Thorne LH, Hazen EL, Bograd SJ, Foley DG, Conners MG, Kappes MA, Kim HM, Costa DP, Tremblay Y, Shaffer SA. 2015. Foraging behavior links climate variability and reproduction in North Pacific albatrosses. Mov Ecol. 3(27):1–15. doi: 10.1186/s40462-015-0050-9.

Wolter K, Timlin MS. 1998. Measuring the strength of ENSO—how does 1997/98 rank? Weather 53:315–324.

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

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

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