Assessing an Index of Population Trends of the Ashy Storm-Petrel on Southeast Farallon Island, California, 1992-2010

Report to the U.S. Fish and Wildlife Service

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Introduction:

The Ashy Storm-Petrel (ASSP) (*Oceanodroma homochroa*) is a seabird species of major conservation concern. This small, colonially breeding species is endemic to waters of the California Current, along the coast of California and Mexico, concentrated between Bodega Bay and Point Piños (Spear & Ainley 2007), with breeding populations concentrated at the Farallon and Channel Islands. Sydeman et al. (1998) suggested a 44% decline, with a 95% confidence interval of 22-66% decline, in the population from 1972 to 1992 at Southeast Farallon Island (SEFI) – the largest colony with over 50% of the world population. Due to major population declines, threats from colony predation, at sea mortality (i.e., from oil spills etc.), and environmental variation, the species was listed as a California Species of Special Concern (Carter et al. 2008 [in: Shuford and Gardali 2008]) and was recently petitioned for listing under the Endangered Species Act. Despite the 2009 USFWS finding not to list the species, data gaps on current population trend and status were identified as critical information to assess the status of this species in the future. In this report we describe recent analyses of long term data from PRBO Conservation Science on SEFI to assess trends in an index of abundance from mist net data and predation from carcass surveys.

Methods:

Southeast Farallon Island is the largest of the 96 acre South Farallon Islands, located approximately 30 miles west of San Francisco, CA. Catch per Unit Effort Data (CPUE) used in this study was collected from mist netting efforts. Mist netting was conducted for 3 hours each session (from 22:20 – 01:30) as part of an on-going capture mark-recapture study. Two mist net sites were used and nets were only opened if there was less than 10 knots of wind and little or no moon visible. Net location and net type were kept constant at these two sites for the duration of the study. We used one 12m long, 4 shelf nylon mist nets (Avinet Inc.) with 30mm mesh and a height of 2.6m. We netted storm-petrels at two sites that differ in their characteristics (exposure, proximity to habitat, bird density etc.), one on Lighthouse Hill (LHH) and at the Carpentry or Carp Shop (CS) (Figure 1). LHH is south facing, approximately ½ way up Lighthouse Hill (~150ft elevation), and surrounding by a large amount of storm petrel breeding habitat and known high density of breeding sites (PRBO unpublished). CS is east facing, adjacent to the ocean (~20ft elevation), and in an area of less storm petrel breeding habitat and likely fewer breeding birds (PRBO unpublished). We restricted our analyses to the period between April 1st and August 15th, as this time range corresponded with relatively standardized effort across the time series, as well as with periods of regular ASSP colony attendance.

Social attraction (broadcast recordings of ASSP calls) was used during all net sessions to increase the chance of ASSP captures at the netting sites. A portable tape player was placed at the base of the middle of the mist net and broadcast at a volume of ~65db throughout the netting sessions. The main calls on the tape were “flight calls”, but there is a background of low frequency burrow “purring calls” and “rasping calls” (Ainley 1995). The flight call rate was approximately 0.44 calls per second or 26.5 calls per minute.

We used negative binomial regression methods to analyze our CPUE data. This method allows for non-linear relationships and residuals that are not normally distributed as in this study. These methods are suitable for count data, accounting for high and low values, and are more robust than Poisson regression as they account for overdispersion, when variance exceeds the mean (Carmen and Trivedi 1998).

We employed negative binomial regression methods (with program STATA 10.0) to model CPUE while controlling for variation in hours of netting effort, number of days spent netting at a site in a given year, Julian date, Julian date^2 for a quadratic seasonal effect, and site. Breeding propensity, defined here as occupancy rates of known breeding sites, was not used as a variable in these modeling efforts due to differences in methods and samples sizes across years. In the early 1990's very few natural sites were followed, with most breeding status and productivity data being gathered from a small sample of nest boxes ($n \le 10$). We used Akaike Information Criterion (AIC) to determine which model in our set best described annual variation in our negative binomial CPUE data. Models that were ranked included: 1) year-specific annual variation, 2) constant, 3) linear trend (Y), 4) quadratic curvilinear trend (Y^2), and 5) cubic curvilinear trend (Y^3). We also conducted exploratory analyses which added moon phase (data from United States Naval Office visible moon phase website) and oceanographic variables (Southern Oscillation Index, Northern Oscillation Index, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation Index) to the best fit model in order to identify possible causes for variation in capture rates. Monthly averaged values of oceanographic variables were used in analyses, depending on the date of the netting session.

Preliminary examination of the data suggested an overall change in capture frequency between the early part of the time series (1991-2001) and the later years (2002-2010). We explored this possibility by comparing capture index values averaged across the two decades in the time series and testing for significant differences between those values using a simple t-test with unequal variances. Modeled CPUE Index values presented are the output of the preferred negative binomial regression model after controlling for all other variables. Note that the index values are modeled and should only be interpreted relative to each other. They do not represent an absolute number of birds captured. Raw CPUE expressed as captures per hour of netting effort are presented in the summarized raw data (Figure 3).

In addition to modeling ASSP capture rates, we examined the effect of “top-down” control on trends in our netting data by incorporating predation data into our CPUE analysis. We determined annual storm-petrel depredation rates from 2003 to 2010, using data from standardized surveys and incidental collections, indexed by predator (Western Gull, Burrowing Owl, and unknown predation). Remains of depredated ASSP (wings and other body parts) were collected during standardized “wing walk” surveys, conducted from March to August every year, and also during regularly scheduled activities in the same areas during other months of the year. Predation data for 2010 only consist of wings found through October, but we considered this acceptable for our analyses since November and December data represent only 0.2% of wings found 2003-2009. Once the best trend model from CPUE was selected, the additional effect of predation was examined as 3 models of temporal variation, adding the effects of a single predation variable (WEGU predation, BUOW predation, and both sources of predation) in 3 scenarios.

Previous estimates of ASSP population trends made by Sydeman et al. (1998) used capture-recapture methods to estimate Farallon ASSP population size and changes between data from 1971/1972 and 1992. We did not repeat these methods because of their inability to produce reliable survival estimates. We address this issue in more detail in the Discussion.

Results:

We conducted a total of 143 netting sessions on SEFI from 1992-2010, during which 7,662 ASSP were captured. The number of mist net sessions conducted each year from 1993 to 2010 varied between 4 and 10 nights (Figure 2). Many more sessions were conducted in 1992, (n = 19), due to increased effort and favorable weather conditions (Sydeman et al. 1998). Annual CPUE results, both raw and modeled, showed relatively stable values between 1992 and 1997, followed by a sharp decline during the El Niño year of 1998(Figure 3, 4). After increasing in 1999, CPUE declined again until 2001 (Figure 3, 4). After 2001, a strong increase in CPUE was observed from 2002 to 2007, followed by a decrease over the last three years of the study (Figure 3,4). Model selection (controlling for date, effort, and site effects) identified the year specific model as the best fit for our CPUE data (Table 1, Figure 4). This means that the variation in the number of ASSP captured in SEFI mist netting was better explained by interannual variation than by any of the three time trend models tested.

Capture index data for early July, the period of typically highest capture rates, indicate that the mean ASSP capture index value obtained from 1992 to 2001 (133.62 +/- 10.10 SE) was less than ½ of the mean value obtained from 2002 to 2010 (281.75 +/- 25.64 SE), suggesting higher colony attendance in the second decade of the study. This is strongly significant result ($p=0.0001$). The variables date, $date^2$, hours netted, and site were all highly significant in the top model ($p < 0.001$), with positive coefficients for date and hours netted, and higher capture rates at the LHH site when compared to the CS site (1.32x) (Table 2, Figure 4). Number of days of netting was not a significant effect but was included to control for uneven effort among years and sites.

Exploratory analyses incorporating moon phase and oceanographic conditions into the preferred year effect model had resulting coefficients which were non-significant (Table 3, $p > 0.25$ except for PDO where $p=0.08$ with a positive coefficient.)

During the period from 2003 to 2010, 1,442 ASSP wings were recovered during predation surveys – 747 attributed to gulls, 579 attributed to Burrowing Owls, and 116 for which the cause could not be determined (Figure 5). Therefore, Burrowing Owls accounted for at least 40.15% of storm-petrel predation, compared to at least 51.80% for Western Gulls. As Western Gulls outnumber Burrowing Owls on SEFI by at least 1000 to 1 (PRBO, unpublished data), the relative individual predation impact to ASSP of an average Burrowing Owl compared to an average Western Gull is at least 775x. The year of highest detected gull predation was 2004 with 133 wings recovered. Burrowing Owl predation was greatest in 2010 with 148 wings recovered (Figure 5). The year of lowest detected gull predation was 2010 with 35 wings recovered, which may be related to Western Gull breeding failure early in the season. Burrowing Owl predation was lowest in 2003 with 30 wings recovered. The additional effect of predation (WEGU, BUOW, and total predation) on the year specific CPUE model, for years 2003-2010, showed that none of the predation variables had a significant effect on capture rates (all coefficients $p > 0.1$, negative coefficients for gull, and positive for owl and combined predation).

Discussion:

Despite its caveats, we believe that Catch per Unit Effort data from SEFI mist net studies currently provides the best available index of ASSP colony abundance, with the underlying assumption that more birds captured means a larger population. We believe that at present, population estimation using capture/recapture methodology is unadvised, due to issues with obtaining accurate adult survival data from ASSP with these methods. (Sydeman et. al 1998).

Seabirds typically have life-histories characterized by low productivity, delayed maturity, and relatively high adult survival probabilities, though there is a wide spectrum of strategies along the r- to k-selected gradient (Weimerskirch 2002). Of these components, adult survival typically has high elasticity values when computed from matrix population models, so variation in adult survival is expected to strongly influence population dynamics (Russell 1999, Crone 2001). The storm-petrels, and other members of the order Procellariformes, have the highest adult survival of all seabirds (Hamer et al. 2002 [in: Schreiber and Burger 2002]). Farallon mist net data shows ASSP longevity to be at least 35 years (Bradley and Warzybok 2003, PRBO unpublished data). So adult survival is likely the most important demographic parameter for ASSP, and measuring changes in adult survival would likely be the best way quantitative way to assess long term changes in this population. However, this is challenge for this species. Generating reliable absolute estimates of adult survival from mist net data have proved problematic (Sydeman et al. 1998, PRBO unpublished), due to low recapture rates that may be associated with trap avoidance. While we monitor known nests to obtain estimates of breeding success, the nature of ASSP breeding habitat - tiny rock crevices - precludes following known individual banded adults at the nest sites. While the was done in the 1970's and 1980's, when known nest sites were excavated and replaced with nest boxes to follow individual birds (Ainley and Boekleheide 1990), efforts to recruit ASSP to nest boxes in the 1990's and early 2000's were unsuccessful (PRBO unpublished). Therefore, our analyses here focus on the best available index of ASSP population size, catch per unit effort (CPUE) data from bi monthly mist netting sessions throughout the spring and summer.

CPUE gives us an index of storm petrel abundance from 1992-2010 – using consistent methods throughout the time series. We assume that CPUE is strongly positively correlated with the overall ASSP population on SEFI. While issues like trap avoidance and variable breeding status have the potential to influence the relationship between CPUE from mist nets and total ASSP, this is the best, and only, continuous dataset on ASSP abundance to assess their status on SEFI at this time. We could not compare CPUE results from netting efforts in the early 1970's, as those netting sessions were not standardized for effort (Sydeman et al. 1998).

Mean modeled capture index values from 1992-2001 are less than half of those from 2002-2010. This suggests that there were more storm-petrels present at the Farallones during the past decade than in previous years. However, while storm-petrel capture rates have increased overall, our model selection results suggest that variation in the number of ASSP captured in SEFI mist netting was better explained by interannual variation than by any overall time trend. Previous analyses of these data through 2006 had more support for a positive trend (PRBO unpublished data), but declining capture rates between 2008 and 2010 appear to have negated those results.

It should be noted that not all birds captured during our netting sessions were breeding birds. It is not possible to determine definitive breeding status from mist net data and many of those birds captured may be non-breeders or prospecting birds which are responding to social attraction. This idea is supported by the significant quadratic date (seasonal) effect with large increases in CPUE late in each season when more prospecting birds are likely attending the colony (Ainley and Boekelheide 1990). While preliminary examinations of data collected on ASSP brood patches show that lack of brood patches was most common before the breeding season in April, the presence of brood patches is not always a reliable indicator of breeding status in storm-petrels (Harris 1969, Boersma et al. 1980) and other seabirds like alcids (McFarlane Tranquilla et al. 2003). Trends described here may be confounded by changes in breeding propensity. Lower capture rates at the Carp Shop (CS) site likely reflect the reduced availability in breeding habitat near that site as compared to Lighthouse Hill (LHH). These results suggest that even for a wide ranging pelagic seabird, different colony areas only a few hundred meters apart can produce different netting densities, and site differences should be considered in netting efforts.

The lack of significant findings from assessing moon phase may seem surprising given that previous studies have shown that fewer storm-petrels visit nest sites on moonlit nights (Ainley and Boekelheide 1990). There are several reasons why moon phase may not influence our CPUE results. First, we only net on nights when there is little or no moon visible so the small differences in actual moon phase are likely insignificant. Moon phase would likely have a greater influence on capture rates if we attempted to net in all conditions. In addition, the moon phase data available from the USNO website may not reflect local conditions. Local moonlight data was not collected during netting sessions until the early 2000's. Future analyses might asses the impact of moon phase, other light sources and winds on capture rates in years when local data was collected during netting sessions.

The best fit model in our analysis clearly showed strong year effects in capture rates. We examined a series of oceanographic variables in order to explain this variation, but none of those tested had a significant relationship with modeled CPUE. This may reflect a lack of direct response in colony attendance with changing oceanographic productivity, or may be confounded by the variable breeding status of birds captured. There is some evidence to support a relationship between ocean productivity and ASSP CPUE. The strong El Niño event of 1998 coincided with a marked decrease in CPUE, while the increase in capture rates during the early 2000's was during a period of generally productive local ocean conditions from 1999-2004. However, periods of less favorable ocean conditions, from 2005-2007, corresponded with the highest recorded CPUE, and declines in capture rates in 2010 occurred during a year of very high local ocean productivity (Warzybok and Bradley 2010). Perhaps, outside of extreme events, some birds may attend the colony more frequently when foraging conditions are less favorable, and vice versa. The oceanographic models we examined may have been too coarse to reflect the signals that ASSP respond to. The wide foraging range of storm-petrels may allow them to buffer changes in prey availability more than other species. More specific models that correlate seasonal ocean climate to ASSP CPUE may be found in future modeling efforts.

Like this study, Ainley and Hyrenbach (2010) also documented strong year effects and a lack of a strong signal from oceanographic data in describing declines in ASSP detected at sea. However, these authors attribute proposed declines in ASSP numbers at sea to changes in breeding habitat on SEFI. While the changes have occurred, like the increase in the prevalence of introduced grasses, we have no evidence from our work on SEFI that these changes have directly impacted ASSP breeding efforts.

Predation surveys yielded an average of 206 wings per year. These results are the first quantitative estimates of predation for this population, but likely underestimate total predation impact. The areas that are surveyed, both during standardized “wing walks” and incidental collections, encompass a large proportion of the accessible ASSP breeding habitat. However, they do not include all areas of the island and some remains are surely missed in large areas that are inaccessible and not regularly surveyed. These inaccessible areas encompass at least 50% of the island’s landmass. Furthermore, even in areas that are regularly searched, some wings may not be found. If we assume that each wing represents 1.25 – 1.5 birds predated, based on preliminary assessments of numbers of left and right wings collected, then on average, 225 to 270 ASSP are being predated in our survey areas each year. We have shown that while Western Gulls typically take a greater number of ASSP, the impact of Burrowing Owl predation, at the level of an individual predator, is massively more significant – 775x more, due to the disparity in population size between Western Gulls and Burrowing Owl. This is nearly 3 orders of magnitude. However, the level of ASSP depredation, both overall and indexed by predator type, varied strongly between years in our data set and did not correlate with changes in CPUE. This could be because although overall predation is high, the differences observed between years may not be enough to detect in the capture data for the limited time series, 2003-2010, for which predation data is available.

In summary, our modeled CPUE data suggests that there were more storm-petrels captured in SEFI mist nets in the 2000's than during the 1990's. However, the trend models we tested to describe this dataset were outperformed by a year specific model of inter-annual variation. Therefore the effect of an individual year on ASSP capture rates describes the data better than any time trend. It is likely that the oceanographic variables we selected to account for further variation were too coarse to explain the variation in our capture data. Likewise, predation rates and moon phase may not have enough variation in themselves to explain changes in capture rates. The lack of a model in our set that outperforms the year-specific model suggests some currently unknown source of annual variation has significant influence on storm-petrel capture rate.

We have several recommendations for future study. More specific linkages between storm-petrel responses and oceanographic conditions are needed. More detailed examinations of local weather and oceanographic conditions should be conducted, as ASSP may be responding much more strongly to this scale than the large spatial scale of oceanographic indices. Future studies and analyses should focus on developing more accurate estimates of adult survival of breeders, perhaps using PIT tag studies or other technology with individually marked birds, in conjunction with more detailed population modeling to assess ongoing changes in the health of this population. We suggest that tracking adult survival of breeding birds, while methodologically difficult, would be extremely valuable in assessments of this population in the future. Breeding success patterns, using data following the same time series addressed here, exist from SEFI (Warzybok et al. 2010) and should be examined in conjunction to netting efforts. Our study has highlighted both advantages and caveats of assessing an index of population through CPUE. The need for consistent methods, and accounting for site specific differences should be considered in other storm-petrel netting studies. Finally, long term studies to asses breeding populations of all storm-petrel species are lacking throughout the California Current, and more baseline data is needed for multiple species to more quantitatively asses their status in the future.

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Table 1. Model selection results of negative binomial regression of ASSP captures, controlling for date, date^2, days of netting, net hours, and site in an additive model. Number of observations = 142.

Model	Log Likelihood	df	n	AIC	Delta AIC
Year	-611.652	23	142	1273.303	0
Y^3 (cubic trend)	-633.968	8	142	1287.936	14.633
Y^2 (quadratic trend)	-639.941	7	142	1297.882	24.579
Y (linear trend)	-645.04	6	142	1306.08	32.777
Constant	-665.189	5	142	1344.378	71.075

Table 2. Coefficient values, standard error (SE), p values, and 95% Confidence Interval of coefficients for all variables in top negative binomial regression model – year specific annual variation. Variables in this additive model include date, a quadratic effect of date, hours of netting effort per session, days netted at a given site in a given year, site, and year specific effects.

Variable	Coefficient	SE	p value	95% CI Low	95% CI High
date	0.021	0.004	<0.001	0.013	0.029
$date^2$	-0.0001	0.00003	<0.001	-0.0002	-0.0001
hours	0.734	0.158	<0.001	0.425	1.043
days	-0.005	0.057	0.937	-0.116	0.107
site = CS	-0.277	0.086	0.001	-0.446	-0.107
Y1993	0.014	0.414	0.974	-0.798	0.825
Y1994	0.265	0.384	0.491	-0.489	1.018
Y1995	0.182	0.415	0.661	-0.632	0.996
Y1996	0.042	0.384	0.913	-0.712	0.796
Y1997	0.118	0.312	0.706	-0.495	0.731
Y1998	-0.576	0.297	0.052	-1.158	0.006
Y1999	-0.113	0.387	0.771	-0.870	0.645
Y2000	-0.241	0.492	0.625	-1.204	0.723
Y2001	-0.361	0.386	0.349	-1.118	0.395
Y2002	0.404	0.359	0.261	-0.301	1.108
Y2003	0.113	0.385	0.770	-0.641	0.866
Y2004	0.594	0.405	0.142	-0.199	1.387
Y2005	0.918	0.346	0.008	0.239	1.596
Y2006	0.695	0.314	0.027	0.081	1.309
Y2007	1.048	0.467	0.025	0.134	1.963
Y2008	0.885	0.411	0.031	0.079	1.690
Y2009	0.864	0.382	0.024	0.115	1.612
Y2010	0.52	0.444	0.242	-0.350	1.390
constant	0.937	0.734	0.202	-0.501	2.376

Table 3. Coefficient values, standard error (SE) and p values for all variables added individually to the top model in exploratory analyses. Variables include visible moon phase (from USNO data) and oceanographic indices PDO (Pacific Decadal Oscillation), NOI (Northern Oscillation Index), SOI (Southern Oscillation Index), and NPGO (North Pacific Gyre Oscillation)

Variable	Coefficient	SE	p value
moon	-0.129	0.14	0.355
PDO	0.145	0.083	0.080
NOI	0.001	0.027	0.974
SOI	-0.005	0.005	0.276
NPGO	0.123	0.153	0.424

Figure 1: ASSP netting sites on Southeast Farallon Island, CA

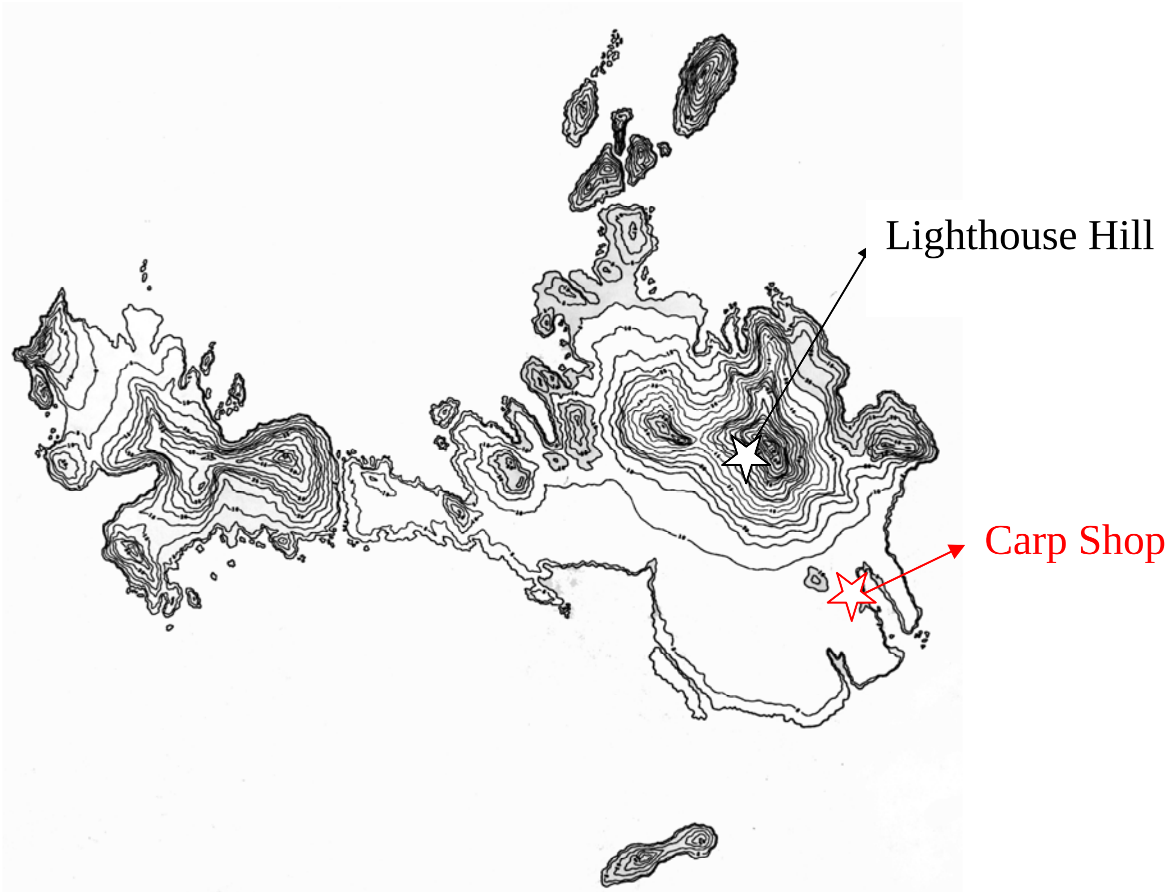

Figure 2. Number of ASSP mist net capture sessions per year, for both netting sites, 1992-2010

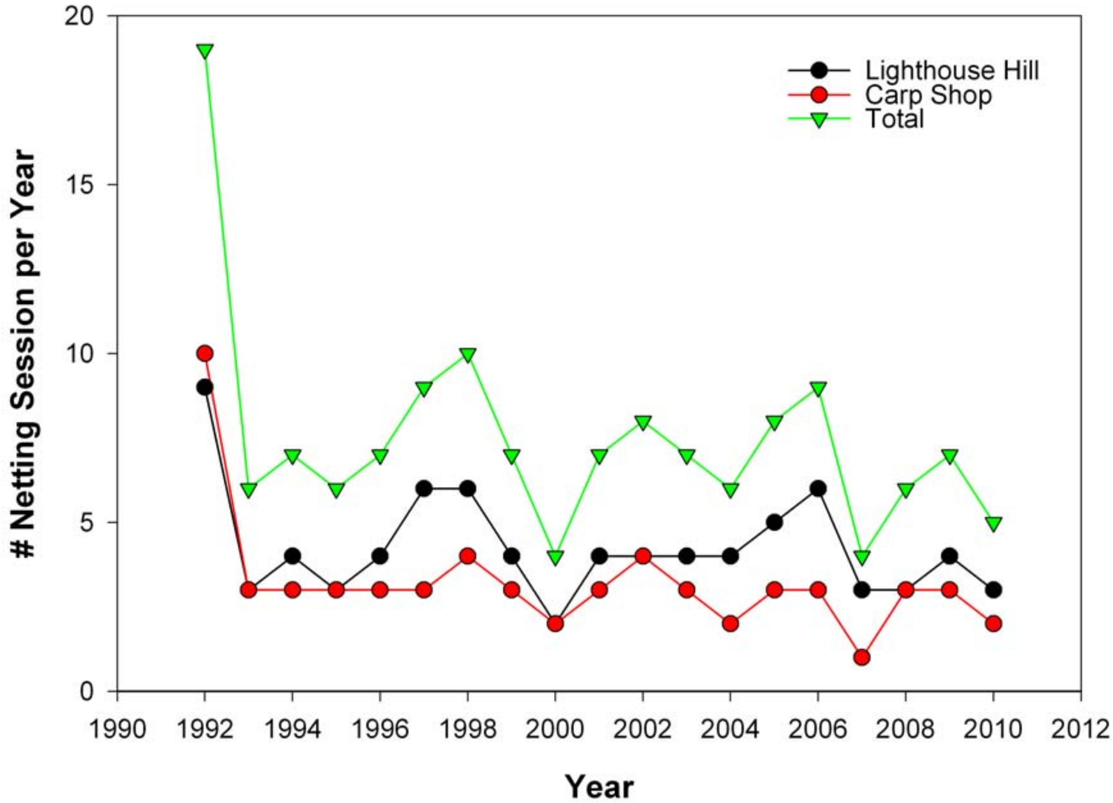

Figure 3. ASSP captures per hour, with standard error, by site, 1992-2010

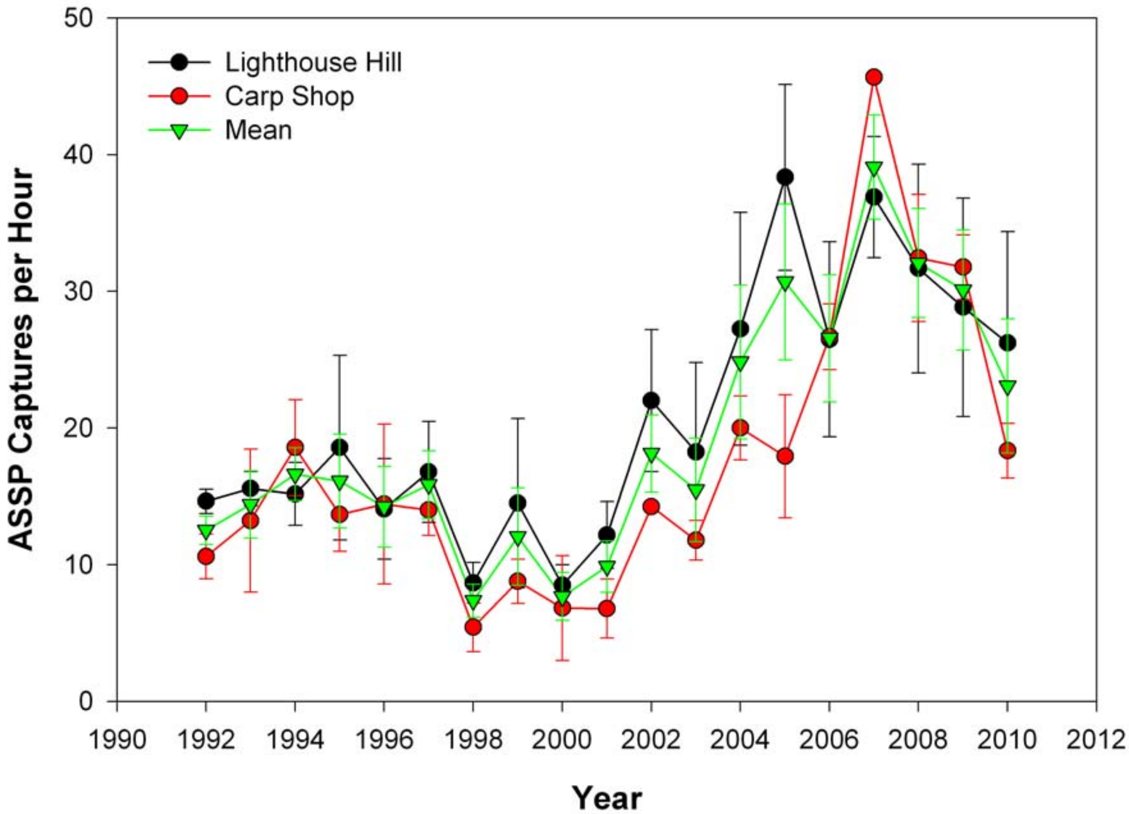

Figure 4. ASSP capture index, by site, from 1992 to 2010. Capture index was generated with the top negative binomial regression models of CPUE data – the year specific model. Capture index controls for date, date^2, hours of netting, number of netting days in a year by site, and site. Data in this figure is based on July 10th (Julian Day 100), with 3 hour netting sessions, and 4 sessions per site for a given year.

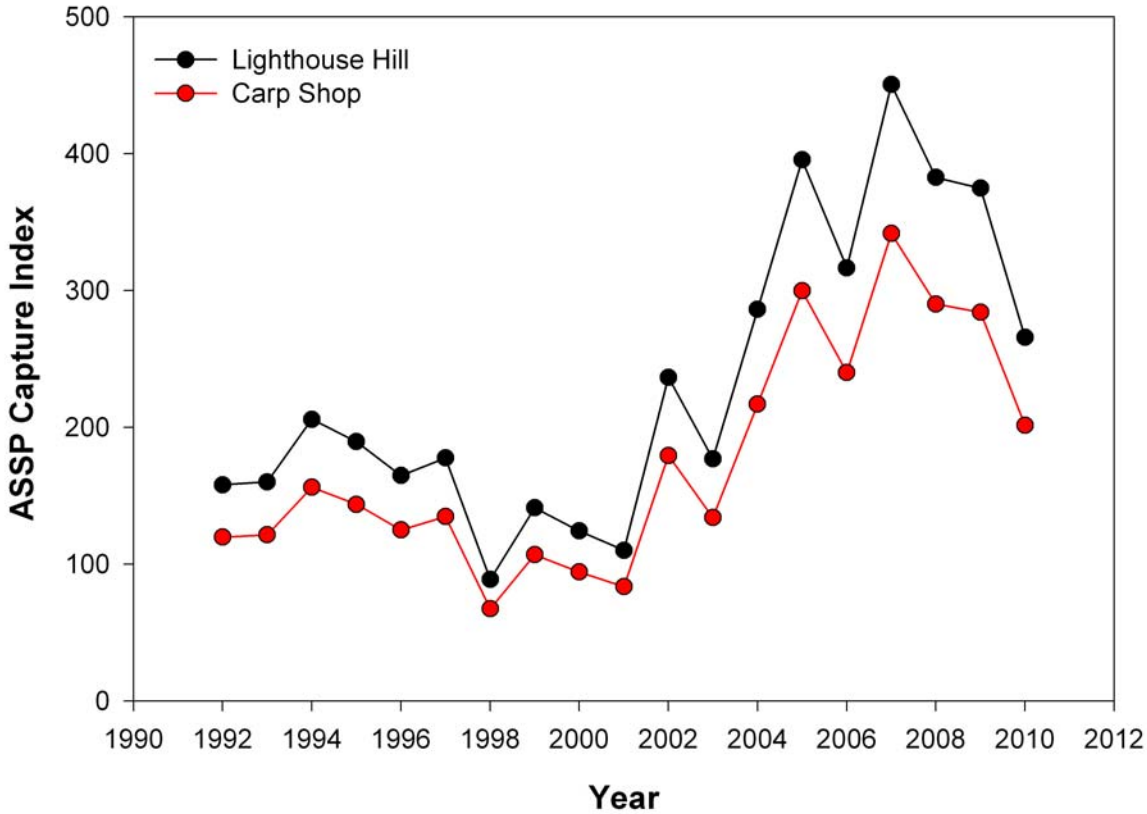

Figure 5. Number of ASSP wings found annually in predation surveys by predator type: Western Gull, Burrowing Owl, and unknown predation.