



Technical Report HCSU-060

## FARALLON DE MEDINILLA SEABIRD AND TINIAN MOORHEN ANALYSES

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January 2015



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This product was prepared under Cooperative Agreement G09AC00042 for the Pacific Island Ecosystems Research Center of the U.S. Geological Survey.

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## ABSTRACT

This report assesses the trends in brown booby (*Sula leucogaster*), masked booby (*S. dactylatra*), and red-footed booby (*S. sula*) counts collected on Farallon de Medinilla and Mariana common moorhen (*Gallinula chloropus guami*) counts on Tinian, Commonwealth of the Northern Mariana Islands to help elucidate patterns in bird numbers. During either monthly or quarterly surveys between 1997 and 2014 counts of all four bird species were recorded, generating a relatively noisy time series revealing inter-annual variation in index counts by as much as 1,000%. For the purposes of assessing long-term population trends across years we chose a single, species-specific month to assess trends. Doing so reduces the effect of intra-annual variation allowing the analysis to focus on inter-annual variation important to long-term trends assessment. There are clear fluctuations in the counts of all four species. Although the trends were non-significant, there is some evidence that masked and red-footed booby species have declined while brown booby and moorhen have increased.

## INTRODUCTION

Island birds, especially in the Pacific, are amongst the world's most endangered species (King 1985). Between 13–14% of the world's avian species are considered threatened, with approximately 30% of these occurring in Oceania, where 34% of the world's extinct avian species once existed (International Union for the Conservation of Nature [IUCN] 2013). Accurate and timely population estimates and trend assessment are essential to the conservation and management of the remaining species. The Mariana Archipelago in the western Pacific is designated as an Endemic Bird Area by BirdLife International (Stattersfield *et al.* 1998). Farallon de Medinilla (FDM) and Tinian are two of the 14 islands in the Mariana Archipelago that support important populations of seabirds and waterbirds, respectively, and are important for U.S. Department of Defense training.

The U.S. Navy presence on the uninhabited, tropical island of FDM is due to its strategic location within the Pacific Ocean and the ability to periodically perform training exercises. During the most recent ground-survey, November 1996, seventeen species of seabird, migratory shorebird, and resident landbirds were recorded (Lusk *et al.* 2000). The Navy conducts seabird surveys on FDM in order to provide an index of the population and record population trends of three nesting seabird species: brown booby (*Sula leucogaster*), masked booby (*S. dactylatra*), and red-footed booby (*S. sula*). Although all three species are found throughout the Pacific Basin, FDM boasts a large breeding population of brown boobies, the largest masked booby breeding population within the Mariana Archipelago, possibly all of Micronesia, and a breeding population of red-footed boobies (Vogt and Williams 2004). For the purposes of this report, "population" refers to the birds sampled in that specific location, not the statutory definition under federal law.

Brown, masked and red-footed boobies of the Pacific have high inter-annual variability in the timing of nest initiation, although nesting is fairly synchronous. Brown boobies nest on the ground and masked boobies create nest scrapes on ground. Red-footed boobies typically build stick nests on shrubs and trees, although they may utilize ground surfaces and low-lying vegetation (USFWS 2005). Lusk *et al.* (2000) reported masked booby nests on hardpan soil and red-footed booby nests in the small pockets of shrubby vegetation primarily comprised of the native *Pisonia grandis*. Brown boobies were not observed nesting, although unfledged juveniles

were observed, indicating a breeding population. Boobies were observed across the island except in the central portion; all vegetation on FDM was  $\leq 2$  meters in height.

The U.S. Navy presence on Tinian is also due to its strategic location within the Pacific Ocean and the ability to periodically perform training exercises. The sub-species of the common moorhen (*Gallinula chloropus guami*) endemic to the Mariana Islands are currently found only on Guam, Rota, Saipan and Tinian. The sub-species is listed as endangered (USFWS 1984). The common moorhen on Tinian likely breeds year-round in suitable wetlands usually on floating rafts (USFWS 1991). Moorhens are capable of flying among wetlands on Tinian and between Saipan and Tinian. Moorhen counts increased at Hagoi Wetland during the wet season suggesting an inter-island seasonal migration of birds between wet and dry seasons (Takano and Haig 2004). The U.S. Navy surveys moorhens at Hagoi Wetland on Tinian with the objectives of producing an index of the population and tracking the long-term population trend.

In this report we assess the trends in counts of the three seabird species on FDM and moorhen at Hagoi Wetland on Tinian. We assessed change in population counts using a log-linear state-space model following methods described in Kéry and Schaub (2012). We interpreted the posterior distribution of the slopes using equivalency testing methods to differentiate between inconclusive and biologically meaningful trends (Camp *et al.* 2008). Results of these analyses will help elucidate population patterns.

## METHODS

### Study Areas

Farallon de Medinilla (FDM) is an uninhabited island in the Commonwealth of the Northern Mariana Islands (CNMI). It is the smallest of 14 islands within the CNMI archipelago. FDM is located 80 kilometers (45 nautical miles) NNE of Saipan at 16.0172° N, 146.0586° E. The island is an uplifted limestone ridge, wedged-shaped, and approximately 2,800 meters long. The island is broken into distinct northern and southern sections. The northern section is approximately 520 meters wide narrowing to 20 meters at the isthmus with the southern section. The southern section is approximately 150 meters wide (Vogt 2009). The island has severely inclined coastal cliffs and an uneven, contoured plateau. The total area is approximately 74 ha (0.736 square kilometers) and the highest elevation is 81 meters (U.S. Department of Navy 2013a) (Figure 1).

FDM is leased by the U.S. military from CNMI and is used for live and inert bombing via surface-to-ground and air-to-ground training via strike, amphibious, and special warfare. Three impact areas are targeted: inert ordnance is used in Area 1 and inert and live ordnance is used in Areas 2 and 3. These impact areas total approximately 13.8 hectares, which accounts for approximately 20% of the island's area (USFWS 2010). The northern portion of the island as well as the narrow isthmus separating impact areas 2 and 3 are not targeted and are referred to as Special Use Areas (Figure 2).



Figure 1. Farallon de Medinilla (FDM) on which aerial seabird surveys were conducted between 1997-2014. The wider, northern end of the island is shown in the foreground, and the isthmus and narrower southern tip in the distance. Photo courtesy of Department of Navy.

Tinian is the second largest island in the CNMI at 10,101 hectares and is inhabited. Tinian is located 4.9 kilometers (2.6 nautical miles) SSW of Saipan at 15.0000° N, 145.7042° E. The island consists of low-lying plateaus and a gentle limestone ridge dominated by Puntan Carolinas (elevation 196 meters). The vegetation of Tinian currently consists of mixed second growth forests, grassy savannas, and introduced forests, most of which are tangantangan thickets (*Leucaena leucocephala*; Engbring *et al.* 1986). The small amount of native vegetation that remains on Tinian (5%) (Engbring *et al.* 1986, Liu and Fischer 2006) has been greatly altered by centuries of human use and nonnative species and is basically confined to a few cliffs and adjacent steep limestone slopes. The Department of Defense (DoD) leases 6,211 hectares

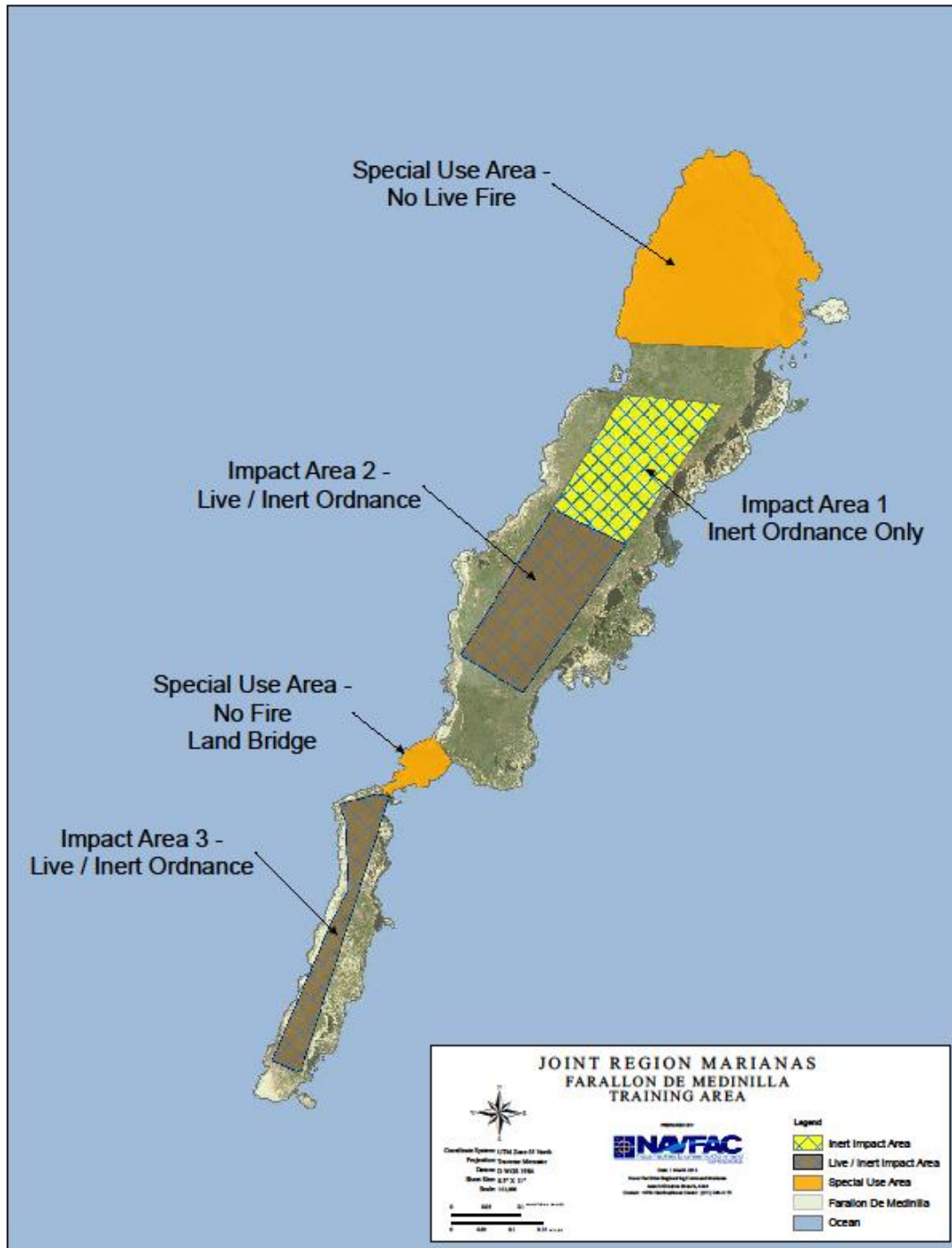


Figure 2. Impact areas and Special Use areas of Farallon de Medinilla (FDM). Graphic courtesy of Department of Navy.

on the northern part of the island for field training, which includes the semi-permanent Hagoi Wetland. Hagoi Wetland, also referred to as Hagoi Lake, is approximately 15.5 hectares of impounded rainwater and is dependent upon rainwater to refresh and maintain water levels.



Thus, water levels fluctuate with the wet and dry seasons, and during periods of drought, open water areas decrease and may completely dry (Figure 3). The wetland is fringed by forest and marsh vegetation (U.S. Department of Navy 2013b).

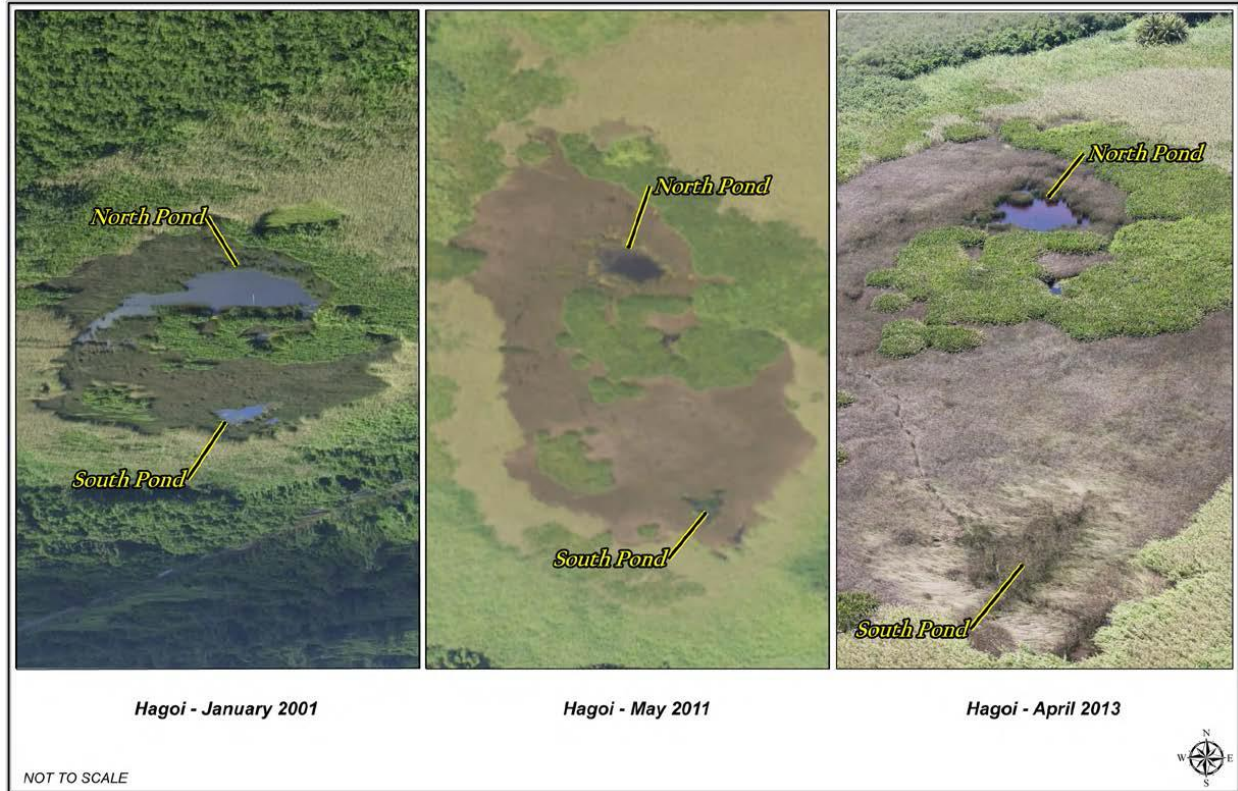


Figure 3. Hagoi Wetland on Tinian showing water impoundment area (North and South Ponds), seasonal water levels and surrounding vegetation. Graphic courtesy of Department of Navy.

### **Aerial Surveys FDM**

From 1997 through 2014, seabird surveys of FDM were conducted via helicopter. The surveys were conducted monthly (most months) from 1997–2008. From 2009 through 2014, the surveys were conducted on a quarterly basis (Appendix I; Naval Base Guam 2013, 2014). The surveys were all conducted with one observer riding in the back seat of the helicopter and one assistant riding in the front seat next to the pilot. On each survey, the helicopter made one pass by the east side of the island and one pass by the west side of the island. During each pass, the observer scanned the island using 10x42 image stabilizing binoculars. The observer called out the presence of boobies by species while the assistant recorded the data (Figure 4). Surveys were conducted during daylight hours and usually between mid-morning and early afternoon, however, survey time was not always recorded. No delineation of bird age, juvenile or adult, was recorded. Breeding and nest count surveys, typical count methods used for estimating seabird population size, were not feasible due to the presence of ordnance across the island.

To improve survey consistency the island was divided into 43 survey blocks (Naval Base Guam 2013, 2014). These blocks were used only as markers to insure observer accuracy and avoid

double counting of birds as the helicopter passed by, and do not hold any biological or statistical significance. Birds in flight were not counted. Lusk *et al.* (2000) noted that some birds flushed in response to the helicopter. Direct observations indicate that only a small portion of birds (< 10%) respond to the helicopter (FJ, personal observation). This flushing behavior could induce a bias in the counts (i.e., under counting the numbers of birds); however, we assume that this bias is consistent among surveys and therefore does not adversely affect trend assessment. After one pass from each side of the island, the survey was concluded. Counts from each survey block were tallied to produce a species-specific population index for each survey (134 monthly and 19 quarterly surveys) in an 18-year time series.

Upon completion of the survey the helicopter then flew once completely around the island for the purpose of taking photographs and observations of any additional species of interest such as great frigatebirds (*Fregata minor*), sea turtles, or marine mammals. Data on these other species were not used in this report.



Figure 4. Red-footed boobies perched on shrubs on Farallon de Medinilla (FDM). Photo courtesy of Department of Navy, February 2013.

### **Hagoi Lake Surveys, Tinian**

The U.S. Department of Navy began surveying moorhens at Hagoi Wetland on Tinian in 1998 to monitor population trends of the species (Appendix I). The Hagoi Wetland was divided into north and south ponds (Figure 3) which were surveyed separately for 20 minutes from a fixed point at each pond, thus a total of 40 minutes was spent sampling for moorhens at Hagoi Wetland. From November 1998 through December 2007, population surveys were conducted at

Hagoi approximately once per month, and north and south pond counts were recorded separately. In 2008 and 2009, moorhen surveys were conducted quarterly, and only total counts for the combined north and south ponds were recorded. From 2010 through 2014, surveys were again conducted each month, with north and south pond data recorded separately. A total of 147 monthly counts and nine quarterly counts were conducted over the 16-year time series. Numbers of adults detected were recorded, and wetland vegetation was searched for nests. For each nest, age of the nest was estimated and number of eggs recorded. Data on nests and eggs were not considered in this report.

### **Data quality assessment and control**

Raw data was compared to the electronic version on a line-by-line basis to correct transcription errors. After line-by-line proofing was completed, individual data sets were spot-checked for errors following methods described in Camp *et al.* (2011). Less than 1% of spot-checked records contained errors; therefore no further proofing actions were taken. Copies of the field sheets and digital data will be archived according to USGS standards.

### **Trend Assessment**

Preliminary analyses revealed that the relatively short length (i.e., limited number of years) of the monthly and quarterly time series for all four species precluded modeling the inter-annual variation as a time series, or using hierarchical models to combine the monthly and quarterly surveys. Instead we chose a single month to assess trends across years. Efficient trend assessment relies upon index counts with relatively little error variation (variation that is not due to actual changes in population abundance, such as observation error or count differences due to inter-annual changes in behavior). In order to facilitate trend detections, we chose the month with the greatest median count (in general larger counts have smaller relative variation), narrowest inter-quartile range (a direct measure of variation), and smallest error bars (indicating fewer outlying values; Figure 5).

We further restricted the candidate months for selecting among the moorhen counts to September through December, when their habitat was less likely to be dry, and the birds more active, based on a summary of data collected between July 1994 and August 1995 (USFWS 1996), findings by Takano and Haig (2004) and consultation with Annie Marshall (USFWS, pers. comm.). We chose the following months to assess trends: brown booby—June; masked booby—January; red-footed booby—March; and moorhen—September. We filled in surveys for target months with incomplete or missing data by substituting the nearest complete survey. To assess if our selection of a specific month influenced interpretation of trend we estimated the trend for each month and plotted the results; a quasi-sensitivity analysis (Figure 6; Appendix II). A visual inspection of the plots show that there was negligible evidence the preferred month influenced the trend outcomes.

We assessed change in population counts by two methods—ordinary log-linear regression and a log-linear state-space model. We defined trend as the long-term, overall directional change in abundances following Urquhart and Kincaid (1999). Urquhart and Kincaid (1999:405) state that population counts “may deviate substantially from strict linearity” yet “we can detect trend by seeking linear trend without ever asserting that detected trend is linear.” Under this definition a trend may experience annual perturbations and appear non-linear, but still be detectable with linear models. Populations differ from year-to-year, vary over short periods, and go through cycles. We therefore assessed trends of both the log-linear regression and state-space models



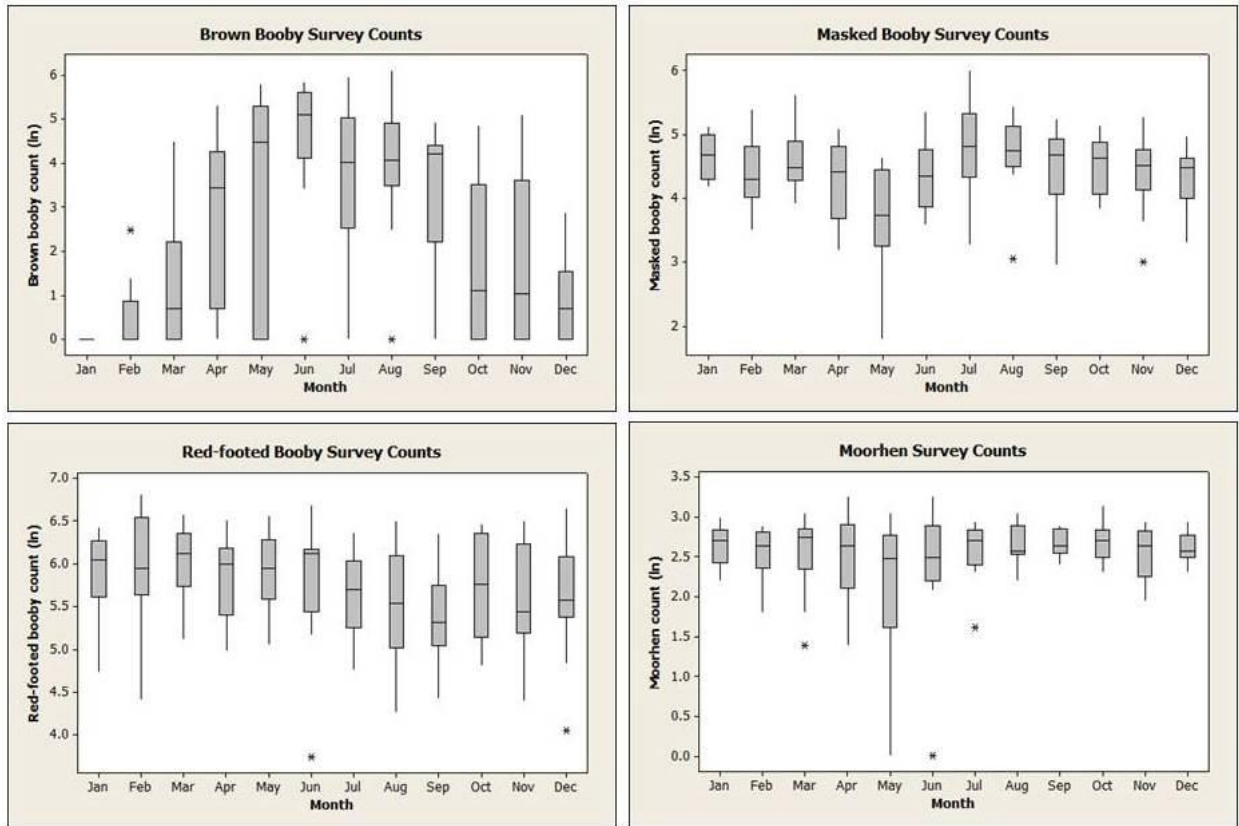


Figure 5. Boxplots showing variability in brown booby (upper left panel), masked booby (upper right panel), red-footed booby (lower left panel) and moorhen (lower right panel) counts by month. Data were pooled across years. The bottom and top of the box are the first and third quartiles, the band inside the box is the median (second quartile), the vertical lines (i.e., whiskers) are the dispersion of the counts and are calculated as the inter-quartile range of the minimum and maximum quartile values times 1.5, and the stars are outlier counts.

in an equivalency test framework to distinguish between ecologically and statistically significant changes, and to differentiate between negligible and insignificant trends (Camp *et al.* 2008).

Linear trends through a time series of counts can be used to assess trajectories of populations, helping to make sense of what is often noisy data. A weakness of using a linear regression model to assess trend is that linear regression assumes all of the observed deviations from the model are due to *observation error* (random deviations in the observed index count from the “true” value) and that the slope is constant across the time series (Dennis *et al.* 2006). Preliminary analyses indicated that counts in populations did not follow a straight line, but rather showed peaks and troughs superimposed upon a longer-term trend. Most common in the four species was a peak in index counts around 2005-2006, followed by a decline.

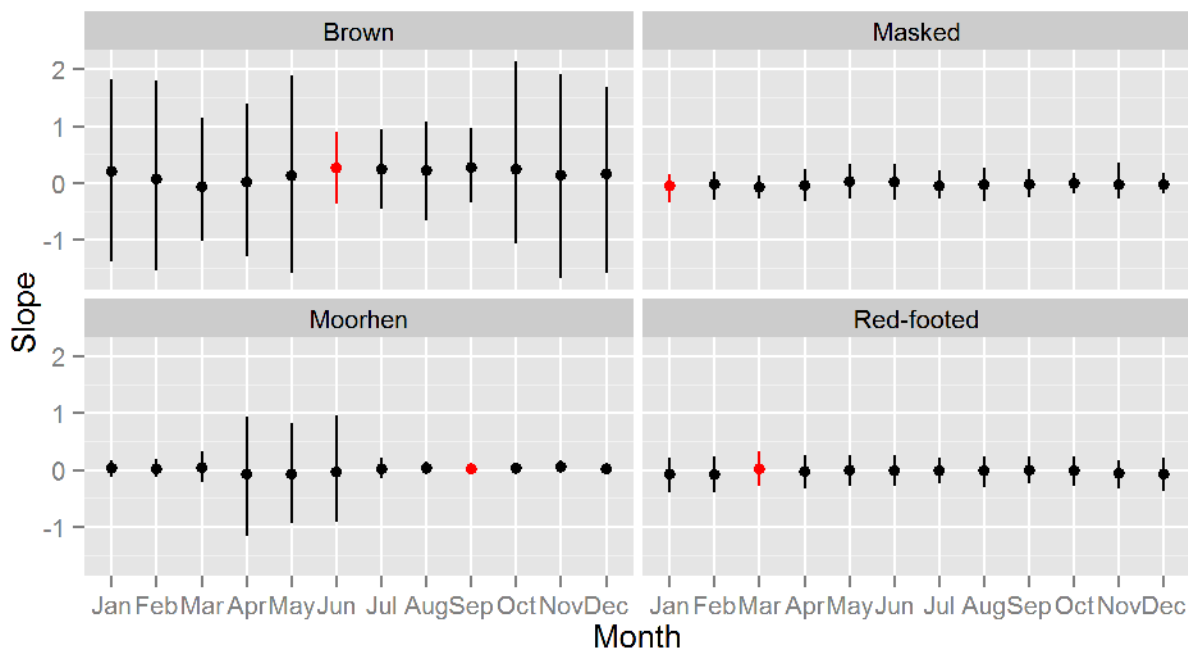


Figure 6. Plots of preliminary trends by month for each species. Monthly estimates are median slope (dot) and variance (bars), with the preferred month colored red. Overlap of the preferred month estimates with all month values indicates that the choice of month to represent an annual index does not affect the interpretation.

In the context of a linear model this variation is termed *process error*, meaning deviations in the observed index count that are due to changes in the “true” value (the actual population of birds) departing from the linear model. These departures could be due to any of a number of possible effects, which we discuss below. The presence of process error, though, violates a fundamental assumption of simple linear regression (that all error is observation error). Therefore we do not consider using log-linear regression models to assess trends to be a viable approach, but we conducted the simple linear regression analysis for comparison with other approaches.

State-space models decompose the linear model error into its process and observation components (Humbert *et al.* 2009, Knape *et al.* 2011). This partitioning allows for assessment of trend based only on the “biologically real” process variation. State-space models are inherently autoregressive, because the population in a given year is always assumed to depend on the population size in the previous year. Year-to-year population changes are realizations of a long-term growth rate with annual variation due to environmental (e.g., sea surface temperature and lake water level) and demographic (e.g., variation in clutch size) stochasticity. Modeling the long-term trend as a stochastic parameter allows for variation in the year-to-year slope across the time series, which can provide improved annual count estimates and long-term trends (Dennis *et al.* 2006, Knape 2008, Knape *et al.* 2011).

### *Model diagnostics*

Model diagnostics were conducted on counts from the preferred month to assess the assumptions of linear models (Appendix III). The counts were fitted with a traditional least-squares model using simple linear regression in R (R version 3.0.3; 2014-03-06; R Core Team 2014). The R language 'LearnBayes' library (Albert 2012) was used to sample from the joint posterior distribution of the slope (beta) and variance (sigma) following model diagnostics procedures in Maindonald and Braun (2006). Histograms of the simulated posterior draws of the regression coefficients and error standard deviation were plotted and inspected visually to ascertain deviations from a normal distribution.

Outliers were also identified using Bayesian residuals and visually inspected. Few counts were identified as outliers for any species, nor did the outliers occur at either the first or last observations in each series. Outlier values were retained and the resulting trend is conservative because the associated variance is wider than if the outliers were dropped (i.e., implying lower statistical power).

Because autocorrelation in a time series results in the error terms being dependent upon each other and underestimated, temporal autocorrelation in annual indices was assessed with the 'acf' function in R, and AIC procedures were used to select the lag autocorrelation that removed serial correlation where present.

Diagnostic plots indicated little to no evidence of unequal variances or non-normality in the residuals from the linear model of annual count time series for the four species. The posterior medians of the regression parameters slope and variance were similar in value to the ordinary regression estimates, and the histograms of simulated draws from the marginal posterior distributions appeared approximately normally distributed. AIC statistics indicated that an independence model was appropriate for all species except for red-footed booby, where a first-order autoregressive error model was more appropriate. Trends for species for which the independence model was appropriate were assessed with a log-linear model. The red-footed booby trend was estimated with a modified log-linear regression model to account for temporal autocorrelation using a single lag-1 regression (AR1) model (Ives *et al.* 2010).

#### *State-space model*

Following the methods in Kéry and Schaub (2012) we fit a log-linear state-space model of each species, using counts as the response. Models were run in Stan (a probabilistic programming language implementing Bayesian statistical inference) from an R environment using the 'rstan' package (Stan Development Team, 2014). For the log-normal model a value of 0.01 was added to all zero counts. Models were run with four chains using a 2,000 iteration warm-up, which was discarded before collecting an additional 4,000 runs for each chain. Maximum  $\hat{R}$  (the Gelman-Rubin convergence statistic, Gelman *et al.* 2004) in the final models was  $< 1.1$ , indicating convergence. The posterior distribution of the slope was then interpreted as described below in trend interpretation.

The mean slope ( $\bar{\beta}$ ) of the log-transformed response was modeled with a normal prior of standard deviation 25, which is uninformative on the log-scale of population counts. Standard deviation of the mean ( $\sigma_{\beta}$ ) was modeled with a uniform prior between 0 and 20. Beginning with the second year of the time series, the log of the index value at time  $t+1$  ( $\log N_{t+1}$ ) was modeled as the index value at time  $t$  plus a random slope drawn from a normal distribution with a mean and variance of the generated priors.

$$\log N_{t+1} = \log N_t + \text{Normal}(\bar{\beta}, \sigma_{\beta}^2)$$

Environmental covariates (see below) were incorporated in the state-space model as an additive term with coefficient ( $b_1$ ) times the difference in the covariate value ( $Z_{t+1} - Z_t$ ); the model equation becomes

$$\log N_{t+1} = \log N_t + \text{Normal}(\bar{\beta}, \sigma_{\beta}^2) + b_1 * (Z_{t+1} - Z_t)$$

Observation error standard deviation ( $\sigma_{obs}$ ) was drawn from a uniform prior ranging from 0 to 20, also uninformative on the log-scale index values. The log of each year's observed index ( $\log Y_t$ ) was then modeled as a normal distribution.

$$\log Y_t \sim \log \text{Normal}(N_t, \sigma_{obs}^2)$$

Process error ( $\sigma_{proc}^2$ ) was measured on the same scale as observation error by calculating the variance of the difference between each year's actual  $\log Y$  and the previous year's  $\log Y$  plus the mean slope (i.e., the variance of  $\log Y_{t+1} - (\log Y_t + \bar{\beta})$ ), omitting the first year. We recorded means and 95% credible intervals of  $\sigma_{obs}^2$ , the percent of total observation error ( $\frac{\sigma_{obs}^2}{\sigma_{obs}^2 + \sigma_{proc}^2}$ ),  $\bar{\beta}$ , and  $\log Y$ .  $\hat{R}$  convergence statistics were calculated for all model parameters. Any model with an  $\hat{R}$  value greater than 1.1 (due to the failure of a chain to converge with the others) was re-run. Maximum  $\hat{R}$  in the final models was 1.04, indicating convergence. The posterior distribution of  $\bar{\beta}$  was then interpreted as described below in trend interpretation.

#### *Environmental covariates*

Seabirds dispersing in search of food are strongly associated with sea surface temperatures (SST) and SST gradients (O'Hara *et al.* 2006). Further, tropical booby species are sensitive to changes in SST, which may indirectly affect seabird behavior such as time spent roosting, foraging at sea, timing of breeding and whether an individual breeds during a given year (Cubaynes *et al.* 2011). Thus, SST may affect seabirds' availability to be counted during surveys. Data from weather-station buoys located within 250 km of FDM were not available; one was defunct, and comprehensive data were not available for 1997–2014. Interpolated SST data from NOAA were available at 1°C / 1.0 degree latitude x 1.0 degree longitude resolution. This rather small difference in SST temperature, relative to changes in counts, was not sufficient to provide meaningful information to the model. We used a multivariate ENSO index obtained from the National Oceanic and Atmospheric Administration (NOAA) website ([http://www.cpc.ncep.noaa.gov/products/analysis\\_monitoring/ensostuff/ensoyears.shtml](http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml)) as a potential predictor of seabird counts. The correlation between monthly Southern Oscillation Index data (SOI) for the period 1 January, 1996, through 1 October, 2014, and counts was assessed with varying lag between ENSO measurements and seabird counts from 0 to 24 months. Correlation was relatively low and varied by species (Figure 7). Maximum correlation was found at a lag of 20 months for brown booby (Pearson's correlation;  $r = 0.21$ ), 19 months for masked booby ( $r = 0.32$ ), and 7 months for red-footed booby ( $r = 0.41$ ). Based on these estimates, SOI was examined as a potential covariate in evaluating booby trends.

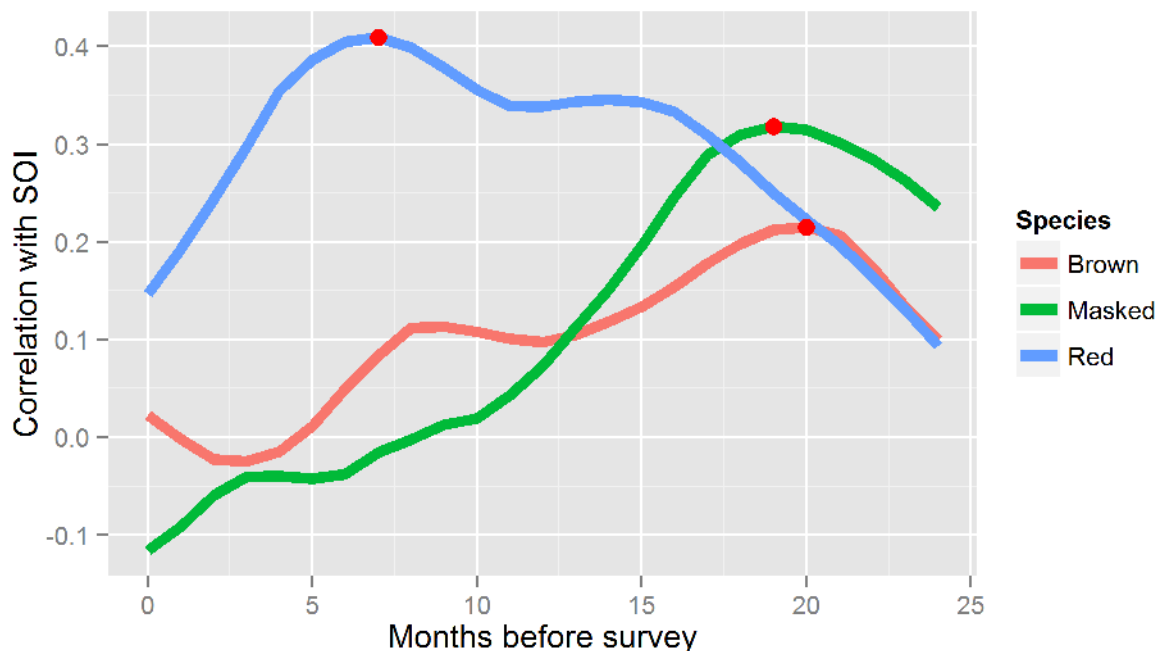


Figure 7. Graph depicting correlation between Southern Oscillation Index and bird counts. Numbers of months prior to survey with greatest correlation are indicated by red dot.

Moorhen use of the Hagoi Wetland is strongly associated with water levels (USFWS 1984; Annie Marshall, USFWS, pers. comm.). A water level gauge was installed on South Pond; the water level was not consistently recorded and in September 2004 the gauge was knocked over, while at other times it appeared to be covered in mud. As a surrogate to water levels, we acquired precipitation data from the NOAA station GHCND:CQC00914874 on Tinian (location 15.00000°, 145.63333°) from the NOAA Climate Data Online webpage (<http://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:CQC00914874/detail>). Daily precipitation from 1 January 1997, through the end of the data series on 31 October 2012, was retrieved.

We investigated the correlation between rainfall and water levels, to see if rainfall data could be used as a surrogate for the often-missing water level data. We modeled cumulative rainfall prior to the survey period over a range of 0 to 180 cumulative days of rain. Maximum correlation between cumulative precipitation and water levels was achieved with a 121 day lag (Pearson's correlation: 0.86; Figure 8). Linear regression of water level against the 121-day cumulative precipitation was significant ( $t = 9.77$ ,  $df = 35$ ,  $P < 0.001$ ); thus, while based on a relatively small sample, we concluded the relation between cumulative rainfall and water level was strong enough to consider cumulative rainfall as a potential predictor of moorhen counts.

There are some limitations to NOAA station weather data: it ends in October 2012 and moorhen surveys continue. More importantly it is incomplete; during the 16 year period retrieved, 30 months had no data available. Consequently 121 days of cumulative rainfall was only available for 7 of the 15 years used for the moorhen trends assessment. Even reducing the accumulation period to 30 days (where correlation rises sharply, see Figure 8) only allows for calculating cumulative rainfall in 10 of the 15 years. Additionally, omitting years without a cumulative



rainfall covariate leaves one year and two year gaps in the time series, greatly reducing the power of a state-space model to detect a trend. For these reasons we did not further pursue cumulative rainfall as a potential predictor.

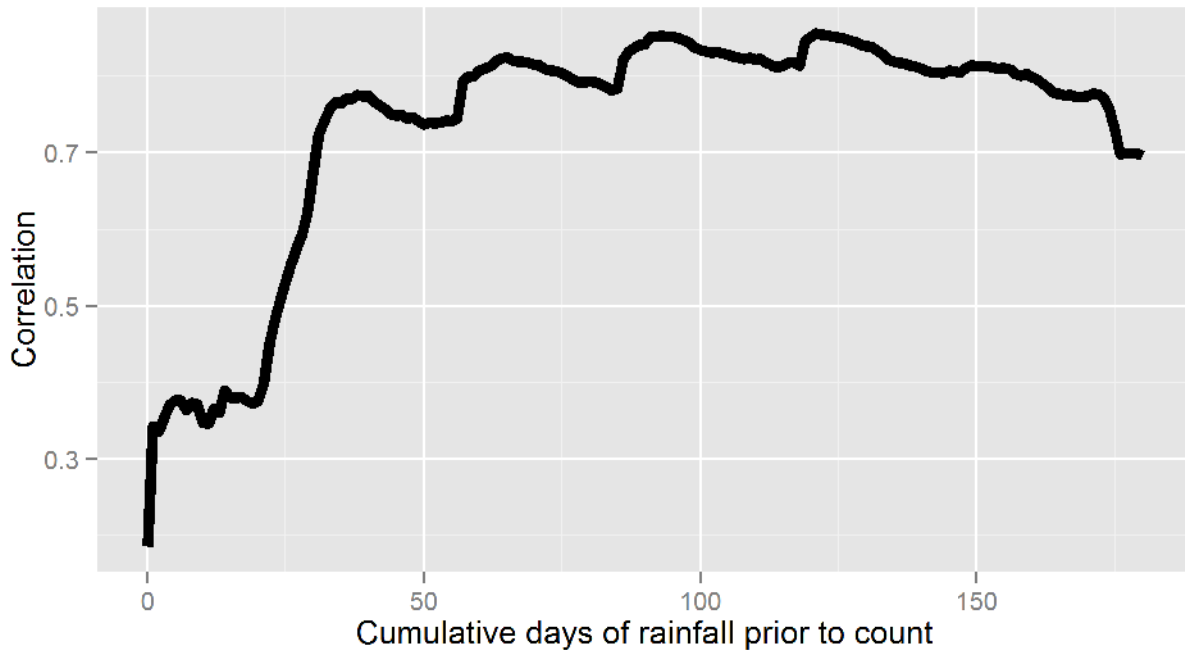


Figure 8. Graph depicting Pearson’s correlation (y-axis) between cumulative precipitation over a varying time span (x-axis) and recorded Hagoi Wetland water level. Maximum correlation was achieved with 121 days cumulative precipitation.

#### *Trend interpretation*

For the state-space models we interpreted the posterior distribution of the slopes using relevant threshold levels—equivalency testing—in a *post hoc* context to differentiate between inconclusive and biologically meaningful trends (Camp *et al.* 2008). Applied in a Bayesian framework, the posterior distribution of the slope provides the probability of each of the three trend outcomes (increasing, decreasing, or neutral population trend) as well as a measure of uncertainty in the estimated slope.

Meaningful trends were differentiated from ecologically negligible or statistically non-significant trends by applying a rate of change of 25% over 25 years to define threshold levels of change to the logarithm of the mean slope: declining ( $< -0.0119$ ); negligible ( $-0.0119$  to  $0.0093$ ); or increasing ( $> 0.0093$ ) (Camp *et al.* 2010). We categorized the strength of evidence for a trend based on the posterior odds (also called Bayes factors) as weak, moderate, strong, or very strong. Based on the posterior probabilities ( $P$ ) evidence was weak if  $P < 0.5$ ; moderate if  $0.5 \leq P < 0.7$ ; strong if  $0.7 \leq P < 0.9$ ; and very strong if  $P \geq 0.9$ . In cases where the posterior odds

provided weak evidence among all three trend categories (i.e., decreasing, negligible, and increasing trends), we interpreted the trend to be inconclusive. We concluded that a population was stable given strong or very strong evidence of a negligible trend.

## RESULTS

### Seabird trends

During the 159 counts conducted between February 1997 and August 2014 a total of 8,786 brown booby, 15,878 masked booby, and 57,304 red-footed booby were recorded. The numbers detected during each count ranged from 0 to 447 for brown booby, 6 to 404 for masked booby, and 42 to 915 for red-footed booby. Counts averaged  $55.26 (\pm 87.67 \text{ SD})$  for brown booby,  $99.86 (\pm 59.06)$  for masked booby, and  $360.40 (\pm 184.75)$  for red-footed booby.

The 95% credible intervals in state-space models that included covariates for the coefficient of the effect of SOI bracketed zero for all three booby species, implying there is not a significant relationship between the SOI of a single month and booby counts (brown booby 95% credible interval (CI)  $-0.17$ – $-0.34$ ; masked booby  $-0.24$ – $-0.37$ ; and red-footed booby  $-0.42$ – $-0.65$ ). Using the simplified state-space models, there was a relatively strong difference in the median counts by month for brown booby, but median monthly counts of masked and red-footed booby were less variable (Figure 5). Brown booby counts during the 18 surveys in June, the preferred month for assessing trends, were conducted 13 times yielding a total of 2,014 detections with a mean count of  $154.92 (\pm 115.21)$  and a range of 0 to 348 birds. Masked booby counts during January, the preferred month for assessing trends, were conducted 11 times yielding a total of 1,234 detections with a mean count of  $112.18 (\pm 37.89)$  and a range of 65 to 168 birds. Red-footed booby counts during March, the preferred month for assessing trends, were conducted 13 times yielding a total of 5,573 detections with a mean count of  $148.69 (\pm 148.78)$  and a range of 167 to 721 birds. Surveys during the preferred months that were missing were filled in by substituting the nearest complete survey, and the summary statistics are presented in Figure 5.

There is evidence that brown booby counts have increased between 1997 and 2014 (Figure 9); however, the ostensible lack of fit to the data (trend line does not overlay the counts from 2009–2014) and extremely wide CI make this outcome suspect (Table 1). With the wide CI we conclude this to be an inconclusive result with the counts ranging between 0 and 400. There is an apparent fluctuating pattern in masked booby counts of about 50 to 200 birds (Figure 10) with declines between 1997 and 1999 that held relatively steady until 2004 before increasing through 2007. The counts then declined through 2010 and have increased slightly to the end of the time series in 2014. This fluctuating pattern is reflected in the trends assessment which resulted in moderate evidence (55.7%) that masked booby counts have decreased between 1997 and 2014, and weak evidence of negligible or increasing trends (Table 1; Figure 10). The fluctuating pattern was amplified in the red-footed booby counts with counts varying between about 100 to 750 birds (Figure 9). However, the length of each trajectory appears about the same as for the masked booby. Red-footed booby counts initially increased between 1997 and 1998 and then declined until 2000 before increasing through 2005. At that point, the counts declined until 2010 and then increased to the end of the time series. Similarly to masked booby trends, there is moderate evidence (54.6%) of a long-term decline in red-footed booby counts with weak evidence of either a negligible or increasing trend (Table 1; Figure 11).

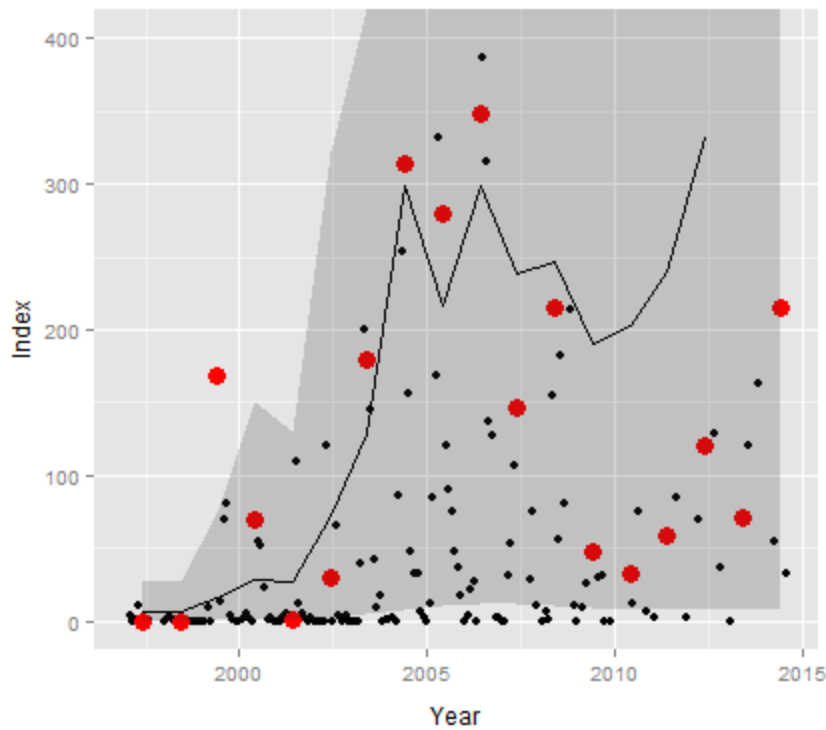


Figure 9. Brown booby trend in counts and evidence of trend based on state-space model. The black dots are count data collected between 1997 and 2014, red dots are the counts during the preferred month for assessing trends, the trend is represented by the black line, and the 95% credible interval trend uncertainty is the shaded region which extends beyond the index range displayed.

### Moorhen trends

A total of 2,111 moorhen were recorded during the 156 counts conducted between November 1998 and January 2014. The counts ranged from 0 to 26 moorhen detections, with an average of 13.53 ( $\pm$  4.68) detections. Median counts varied little by month (Figure 5), and September was chosen as the preferred month to assess trends. September surveys were conducted 14 times during the 16 year period. During September a total of 200 moorhen were detected with a mean count of 14.29 ( $\pm$  2.43) and a range of 10 to 18 detections. Surveys during the preferred months that were missing were 'filled in' by substituting the nearest complete survey, and the summary statics are presented in Figure 5.

Common moorhen counts at the Hagoi Wetland on Tinian varied slightly with moderate evidence of a general long-term increasing trend of a few birds between 1998 and 2014 (Figure 12). There was moderate evidence (68.1%) of an increasing trend in moorhen counts and weak evidence of either declining or negligible trends (Table 1; Figure 12).

Table 1. Trends in count indices on Farallon de Medinilla and Tinian Island, Mariana Islands. Trends for brown, masked and red-footed booby species were assessed during 1997–2014. Trends for the Mariana common moorhen were assessed during 1998–2014. The ecological relevance of a trend was based on a 25% change in counts over 25 years, corresponding to an annual rate of change with a threshold lower bound of  $\phi_l = -0.0119$  and upper bound of  $\phi_U = 0.0093$ .  $P$  is the Bayesian posterior probability of a trend, where evidence was weak if  $P < 0.5$ ; moderate if  $0.5 \leq P < 0.7$ ; strong if  $0.7 \leq P < 0.9$ ; and very strong if  $P \geq 0.9$ .

Species	Slope ( $\hat{\beta}$ ) $\pm$ SE	95% credible interval	Interpretation <sup>1</sup>	Posterior probability		
				Declining $\hat{\beta} < \phi_l$	Negligible $\phi_l < \hat{\beta} < \phi_U$	Increasing $\hat{\beta} > \phi_U$
brown booby	0.264 $\pm$ 0.266	(-0.290–0.805)	Non-significant	0.144	0.010	0.846
masked booby	-0.027 $\pm$ 0.101	(-0.242–0.162)	Non-significant	0.557	0.100	0.340
red-footed booby	-0.006 $\pm$ 0.114	(-0.230–0.225)	Non-significant	0.527	0.076	0.397
Mariana common moorhen	0.025 $\pm$ 0.043	(-0.062–0.116)	Non-significant	0.132	0.186	0.681

<sup>1</sup> If the 95% credible interval brackets zero, the trend is non-significant



Figure 10. Masked booby trend in counts and evidence of trend based on state-space model. The black dots are count data collected between 1997 and 2014, red dots are the counts during the preferred month for assessing trends, the trend is represented by the black line, and the 95% credible interval trend uncertainty is the shaded region.



Figure 11. Red-footed booby trend in counts and evidence of trend based on state-space model. The black dots are count data collected between 1997 and 2014, red dots are the counts during the preferred month for assessing trends, the trend is represented by the black line, and the 95% credible interval trend uncertainty is the shaded region.

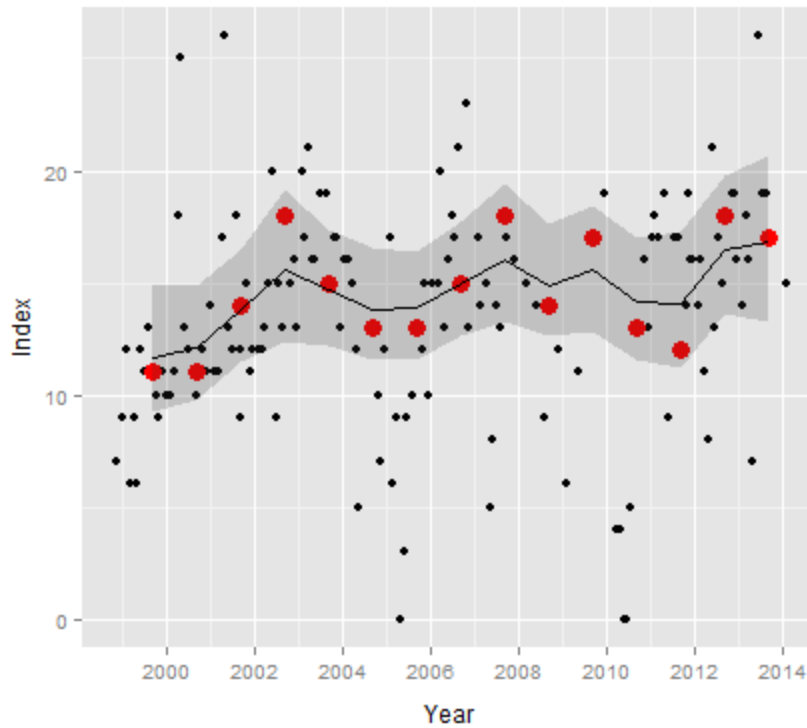


Figure 12. Mariana common moorhen trend in counts and evidence of trend based on state-space model. The black dots are count data collected between 1998 and 2014, red dots are the counts during the preferred month for assessing trends, the trend is represented by the black line, and the 95% credible interval trend uncertainty is the shaded region.

## DISCUSSION

All of the credible intervals (CI) are very wide and for each of the four species all CIs bracket zero. For example, the transformed brown booby CI ranges from a population that is declining by 0.75 to increasing by 2.23 birds counted per year. There is some evidence that masked and red-footed booby have declined while brown booby and moorhen have increased, but the general conclusion is that, for all four species, the length of the time series and the relative noisiness of the counts preclude definite conclusions about long-term population trends; i.e., the results are non-significant. As an example, in the brown booby trends the standard error is larger than the median slope, which results in a coefficient of variation  $> 100\%$ , and the other species have even larger coefficients of variation. These coefficients of variation far exceed the desired levels of  $< 25\%$  or even intermediate levels of  $25\text{-}50\%$  (Gibbs 2000), yielding little information about population patterns and trends.

The observed wide CIs are the result of a variety of known and unknown sources of variation in bird counts. Variability in environmental, biological and sampling processes all contribute to variation in the number of birds counted (the index) and the relationship between the numbers of birds counted and bird abundance.

To a greater or lesser extent, there appears to be an underlying fluctuation in the counts for all species that appears as an increasing and declining pattern. Environmental factors, such as El Niño Southern Oscillation, Pacific Decadal Oscillation, and global climate change, can influence sea-surface temperature that in turn affects food availability resulting in fluctuations in seabird abundance (Grémillet and Boulinier 2009). The FDM booby populations also experience frequent perturbations from severe storms occurring in the Mariana archipelago, which may result in population cycles as the birds suffer widespread nest failure followed by an increase back to carrying capacity. Furthermore it is well documented that long-lived species experience long-term population cycles (Pianka 1970), particularly seabirds (Schreiber and Schreiber 1985). Although we found that booby counts were correlated to Southern Oscillation Index, the relationship was not significant. Further, the correlation was relatively weak, never exceeding about  $r = 0.4$  for red-footed booby and much weaker for the other two booby species. Biologically one might expect the SOI relationship with booby abundance to follow an annual or bi-annual cycle, while we looked at the relationship for 7, 19, and 20 months—lags without apparent biological justification. However, we chose those lags as providing the maximum correlation with counts and did not find a significant result. Any other lag would have an even less significant relationship. Strong ENSO effects can inhibit successful breeding (Cubaynes *et al.* 2011) and it is possible a stronger relationship between ENSO and booby abundance could be detected by incorporating breeding data into future modeling efforts. Alternatively, boobies could be relocating to nearby islands due to nest disturbance during naval training exercises or resulting fires that alter habitat (Lusk *et al.* 2000).

The numbers of Mariana common moorhen at Hagoi Wetland are known to fluctuate in response to water levels, which are dependent on precipitation (U.S. Department of Navy. 2013b). The water level gauge on South Pond was not consistently recorded and in September 2004 it was knocked over. Since then the gauge appeared to be covered in mud. As a surrogate to water levels, we acquired precipitation data from a nearby weather station. Although we found a significant correlation between water level and precipitation over the previous 121 days, available rainfall data was too sparse to test as a potential predictor of moorhen counts. The relationship between rainfall and water level is complicated and variable; water level in a pond is an integrative measure of rain in the recent and longer-term past, complicated by the rate of rainfall (single, intense events vs. diffuse long-term events). An accurate relationship between rainfall and pond level would depend upon a hydrologic flow model. Therefore, if water level is to be directly considered as a covariate with moorhen count an accurate gauge would need to be maintained and water levels at the time of survey recorded consistently.

The biology of brown, masked, and red-footed booby species proved difficult for the aircraft survey counts necessary at FDM. Populations of the three booby species have high intra- and inter-annual variability throughout their range (Harrison 1990), which inherently lends itself to difficulties when assessing population trends. Conducting quarterly surveys on FDM risks the chance of missing the breeding period for survey counts, which is the preferred time for collecting count data (Chardine, No date; K. Courtot, USGS, pers. comm.). Brown, masked, and in particular, red-footed boobies spend large portions of daylight hours foraging and may not be included in daytime counts (Weimerskirch *et al.* 2005, Young *et al.* 2010). Aerial nest counts could serve as a viable addition to current survey methods as it is a population size metric that is not confounded by bird availability such as foraging activities (K. Courtot, USGS, pers. comm.). Furthermore, booby populations are strongly affected by food resources and availability of nesting habitat (Young *et al.* 2010) and such data may be important to include in modeling efforts.

One limitation of our analyses is that the trends are based on counts, an index serving as a proxy for actual abundance. Variations in the count series presumably track changes in populations as they respond to environmental variation. However, the underlying assumption of indices is that bird detection probability is invariant over the entire time series (Rosenstock *et al.* 2002). This assumption can be relaxed if variation in detectability is substantially less than the variation in population size, magnitude of trend sought, and detectability is independent of population size (Johnson 2008). In this case we must assume that detectability rates are similar across time and space.

There have been changes in the habitat, including vegetation growth in and around Hagoi Wetland (U.S. Department of Navy. 2013b), and, although not directly documented, changes in vegetation on FDM that influence bird detectability. In addition to changes in habitats, weather conditions during each survey influence detectability resulting in variation in detectability. Counts may also be affected by consistency in sampling and data processing; differences in aptitude and training in counters and helicopter pilots, observer turnover, and sampling intensity and effort (see for example Sauer *et al.* 1994, Kendall *et al.* 1996). Trends based on the simple indices may thus be misleading, and the direct-count based indices could be improved by accounting for variation in detectability (Johnson 2008).

### **Sampling implications**

If future surveys are conducted, they could be improved by standardizing sampling protocols, conducting observer training, and implementing a data processing and validation procedure. Estimator variability was not reduced for either the booby species or moorhen using SOI or precipitation data. Having a better understanding of the environmental variables directly influencing bird numbers, and collecting those data may help reduce estimator variability allowing greater chance of trend detection. These covariates could include sampling conditions such as time of day, cloud cover, visibility, background noise levels, vegetation, and water levels. Recording nesting phenology of the booby species may help identify the optimal month(s) used for trend assessment. Although some of these are already collected, procedures should be implemented to standardize and collect the measures consistently. A binary metric such as incubating/brooding presence could be recorded to determine whether seabirds are breeding. Alternatively, photogrammetry methods could be used for nest count surveys to be used both for estimating changes in booby populations and to monitor breeding.

Disturbances to seabirds caused by naval training activities could alter survey results. If these disturbances influence breeding behavior or nest attendance then recording the number of post-military maneuvers days could help reduce count variability and in turn, improve population trend estimates. Lusk *et al.* (2000) reported boobies to have flushed for 15+ minutes as a helicopter flew over the island. Determining the numbers of birds flushed as a result of surveying from a helicopter may also reduce count variability.

Using index counts to estimate abundance requires a measure of the detection probability to account for birds that are not detected (Anderson 2001, Thompson 2002). Methods do exist to calculate detection probabilities and convert indices to direct population measurements of occupancy and abundance (Thompson *et al.* 1998, Anderson 2001), but the information needed to do so currently is not collected during the FDM seabird and Hagoi Wetland moorhen surveys. Calculating the detection probability to calibrate indices into abundance estimates requires some form of replicated sampling either by repeat counts or with repeated measures of distances to detected birds—either as part of a continuing survey methodology or applied later



as a correction factor derived from an intensive repeat survey (Camp *et al.* 2014). Other methods of determining detection probability rely upon the identification of individual birds. Mark-resight methods use leg bands to identify either individual birds or at least provide a measure of the proportion of unmarked birds in the population.

Greenwood *et al.* (1994) states that monitoring is more than surveillance; a monitoring program is a program of repeated surveying with clearly defined objectives, assessment to baseline parameters, standardized field and analytical methods, and a mechanism to implement actions. The primary objective of monitoring seabirds on FDM and moorhens at Hagoi Wetland on Tinian is to detect trends. Although we have not conducted a formal evaluation of the monitoring program, our analyses elucidate limitations and provide insight for the improvement and design of any future programs (Cochran 1977).

### **ACKNOWLEDGEMENTS**

This project was funded by the U.S. Navy, COMPACFLT and the U.S. Geological Survey-Pacific Island Ecosystems Research Center. We thank the field biologists and pilots who collected the bird survey data. We thank Devin Leopold, at Stanford University, for analytical assistance, and Michelle Reynolds and Karen Courtot, at USGS- Pacific Island Ecosystems Research Center, for discussions on seabird behavior. This report was improved by comments from Karen Courtot and Lindsay Young.

### **LITERATURE CITED**

- Albert, J. 2012. LearnBayes: Functions for Learning Bayesian Inference. R package version 2.12. <http://CRAN.R-project.org/package=LearnBayes>.
- Anderson, D. R. 2001. The need to get the basics right in wildlife field studies. *Wildlife Society Bulletin* 29:1294–1297.
- Camp, R. J., K. W. Brinck, E. H. Paxton, and C. Leopold. 2014. Monitoring Hawaiian waterbirds: evaluation of sampling methods to produce reliable estimates. Hawaii cooperative studies unit Technical Report HCSU-049. [http://hilo.hawaii.edu/hcsu/documents/HCSU\\_TR49\\_Camp\\_Monitoring\\_waterbirds.pdf](http://hilo.hawaii.edu/hcsu/documents/HCSU_TR49_Camp_Monitoring_waterbirds.pdf).
- Camp, R. J., T. K. Pratt, C. Bailey, and D. Hu. 2011. Landbirds vital sign monitoring protocol – Pacific Island Network. Natural Resource Report NPS/PACN/NRR—2011/402. National Park Service, Fort Collins, Colorado, USA.
- Camp, R. J., N. E. Seavy, P. M. Gorresen, and M. H. Reynolds. 2008. A statistical test to show negligible trend: Comment. *Ecology* 89:1469–1472.
- Chardine, J. W. No date. Basic guidelines for setting up a breeding seabird monitoring program for Caribbean countries. Retrieved 7 Nov 2014: [www.scscb.org/working\\_groups/resources/chardinepaper.pdf](http://www.scscb.org/working_groups/resources/chardinepaper.pdf).
- Cochran, W. G. 1977. *Sampling techniques*. Third edition. John Wiley & Sons, New York, NY, USA.

- Cubaynes, S., P. F. Doherty, E. A. Schreiber, and O. Gimenez. 2011. To breed or not to breed: a seabird's response to extreme climatic events. *Biology Letters* 2011(7):303–306. DOI: 10.1098/rsbl.2010.0778.
- Dennis, B., J. M. Ponciano, S. R. Lele, M. L. Taper, and D. F. Staples. 2006. Estimating density dependence, process noise, and observation error. *Ecological Monographs* 76:323–341.
- Engbring, J., F. L. Ramsey, and V. J. Wildman. 1986. Micronesian forest bird survey, 1982: Saipan, Tinian, Aguijan, and Rota. U.S. Fish and Wildlife Service, Honolulu, HI.
- Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. *Bayesian data analysis, second edition*. Chapman & Hall. New York, NY, USA.
- Gibbs, J. P., 2000. Monitoring populations. Pages 213–252 in L. Boitani and T. K. Fuller, editors. *Research techniques in animal ecology: Controversies and Consequences*. Columbia University Press, New York, USA.
- Greenwood, J. J. D., S. R. Baillie, and H. Q. P. Crick. 1994. Long-term studies and monitoring of bird populations. Pp. 343–364 in R. A. Leigh and A. E. Johnston (editors). *Long-term experiments in agricultural and ecological sciences*. CAB International, Wallingford, UK.
- Grémillet, D., and T. Boulinier. 2009. Spatial ecology and conservation of seabirds facing global climate change: a review. *Marine Ecology Progress Series* 391:121–137.
- Harrison, C. S. 1990. *Seabirds of Hawaii: Natural History and Conservation*. Cornell University Press, Ithaca, NY, USA. 288 pg.
- Humbert, J-Y, L. S. Mills, J. S. Horne, and B. Dennis. 2009. A better way to estimate population trends. *Oikos* 118:1940–1946.
- IUCN [International Union for the Conservation of Nature]. 2013. IUCN Red List of Threatened Species. Version 2013.1. Available at: <[www.iucnredlist.org](http://www.iucnredlist.org)> (September 2013).
- Ives, A. R., K. C. Abbott, and N. L. Ziebarth. 2010. Analysis of ecological time series with ARMA(p,q) models. *Ecology* 91:858–871.
- Johnson, D. H. 2008. In defense of indices: the case of bird surveys. *Journal of Wildlife Management* 72:857–868.
- Kendall, W. L., B. G. Peterjohn, and J. R. Sauer. 1996. First-time observer effects in the North American Breeding Bird Survey. *Auk* 113:823–829.
- Kéry, M., and M. Schaub. 2012. *Bayesian Population Analysis Using WinBUGS*. Academic Press, Waltham, USA.
- King, W. B. 1985. Island birds: will the future repeat the past? Pages 3–15 in Moors, P. J., editor. *Conservation of island birds*. International Council for Bird Preservation Technical Publication No. 3. Cambridge, UK.
- Knape, J. 2008. Estimability of density dependence in models of time series data. *Ecology* 89:2994–3000.

- Knape, J., N. Jonzén, and M. Sköld. 2011. On observation distributions for state space models of population survey data. *Journal of Animal Ecology* 80:1269–1277.
- Liu, Z., and L. Fischer. 2006. Commonwealth of the Northern Mariana Islands vegetation mapping using very high spatial resolution imagery: methodology. U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Forest Health Protection, McCellan, CA.
- Lusk, M. R., P. Bruner, and C. Kessler. 2000. The avifauna of Farallon de Medinilla, Mariana Islands. *Journal of Field Ornithology* 71:22–33.
- Maindonald, J., and J. Braun. 2006. *Data Analysis and Graphics Using R—an example-based approach*. Cambridge University Press, Cambridge, UK.
- Naval Base Guam, Public Works Dept. Environmental. 2013. Fiscal Year 2012 Annual Report. Wildlife Surveys on Military Leased Lands, Farallon de Medinilla, CNMI.
- Naval Base Guam, Public Works Dept. Environmental. 2014. Fiscal Year 2013 Annual Report. Wildlife Surveys on Military Leased Lands, Farallon de Medinilla, CNMI (Draft Report).
- O’Hara, P. D., K. H. Morgan, and W. J. Sydeman. 2006. Primary producer and seabird associations with AVHRR-derived sea surface temperatures and gradients in the southeastern Gulf of Alaska. *Deep Sea Research Part II: Topical studies in oceanography* 53:359–369.
- Pianka, E. R. 1970. On r and K selection. *American Naturalist* 104:592–597.
- R Core Team. 2014. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0, URL <http://www.R-project.org/>.
- Rosenstock, S. S., D. A. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: current practices and an alternative. *Auk* 119:46–53.
- Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American Breeding Bird Survey. *Auk* 111:50–62.
- Schreiber, R. W., and E. A. Schreiber. 1984. Central Pacific seabirds and the El Niño southern oscillation: 1982 to 1983 perspectives. *Science* 225:713–716.
- Stan Development Team. 2013. Stan: A C++ Library for probability and sampling, version 2.2.0. URL <http://mc-stan.org/>.
- Stattersfield, A. J., M. J. Crosby, A. J. Long, and D. C. Wege. 1998. Endemic bird areas of the world: priorities for biodiversity conservation. BirdLife Conservation Series No. 7. Cambridge: BirdLife International.
- Takano, L. L., and S. M. Haig. 2004. Distribution and abundance of the Mariana subspecies of the common moorhen. *Waterbirds* 27:245–250.
- Thompson, S. K. 2002. *Sampling*, 2<sup>nd</sup> edition. John Wiley & Sons, Inc., New York, NY.

- Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, San Diego, CA.
- U.S. Department of Navy. 2013a. Final Integrated Natural Resources Management Plan for Joint Region Marianas. Prepared under contract N40192-10-R-9915.
- U.S. Department of Navy. 2013b. Final Wetlands Management Plan for the Mariana Common Moorhen Integrated Natural Resources Management Plan for Joint Region Marianas. Prepared under contract N40192-10-R-9915.
- U.S. Fish and Wildlife Service. 1984. Determination of endangered status for 7 birds and 2 bats of Guam and Northern Mariana Islands. Federal Register 49(167):33881–33885.
- U.S. Fish and Wildlife Service. 1991. Recovery plan for the Mariana common moorhen (*Gallinule*), *Gallinula chloropus guami*. USFWS, Portland, OR.
- U.S. Fish and Wildlife Service. 1996. Characteristics of Mariana common moorhens and wetland habitats within the US Dept. of the Navy's Military Lease Area and Exclusive Military Use Area on the island of Tinian, CNMI, July 1994–August 1995. Prepared for the U.S. Dept. of Navy, Pacific Division NAVFACENCOM. USFWS, Honolulu, HI.
- U.S. Fish and Wildlife Service. 2005. U.S. Regional seabird conservation plan, Pacific region. USFWS, Portland, OR.
- U.S. Fish and Wildlife Service. 2010. Final Biological Opinion for the Mariana Islands Range Complex (MIRC), Guam, and the Commonwealth of the Northern Mariana Islands 2010–2015.
- Urquhart, N. S. and T. M Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics 4:404–414.
- Vogt, S. 2009. Micronesian Megapode (*Megapodius laperouse laperouse*) Surveys on Farallon de Medinilla, Commonwealth of the Northern Mariana Islands. Unpublished report submitted to U.S. Department of Navy.
- Vogt, S. R., and L. L. Williams. 2004. *Common Flora and Fauna of the Mariana Islands*. Laura L. Williams and Scott R. Vogt, USA.
- Weimerskirch, H., M. Le Corre, S. Jaquemet, and F. Marsac. 2005. Foraging strategy of a tropical seabird, the red footed booby, in a dynamic marine environment. Marine Ecology Progress Series 288:251–261.
- Young, H. S., S. A. Shaffer, D. J. McCauley, D. G. Foley, R. Dirzo, and B. A. Block. 2010. Resource partitioning by species but not sex in sympatric boobies in the central Pacific Ocean. Marine Ecology Progress Series 403:291–301.

## APPENDIX I

Appendix I, Table 1. Farallon de Medinilla (FDM) seabird counts, raw data.

Year	Month	Day	Masked booby	Brown booby	Red-footed booby
1997	Feb	21	218	4	281
	Mar	4	275	0	452
	Mar	20	212	1	630
	Apr	No survey	–	–	–
	May	17	22	10	462
	May	27	43	0	460
	Jun	No survey	–	–	–
	Jul	19	110	0	244
	Aug	2	86	1	259
	Sep	No survey	–	–	–
	Oct	No survey	–	–	–
	Nov	No survey	–	–	–
Dec	No survey	–	–	–	
1998	Jan	NA	146	0	527
	Feb	NA	74	2	915
	Mar	20	144	2	721
	Apr	1	88	0	609
	May	No survey	–	–	–
	Jun	No survey	–	–	–
	Jul	No survey	–	–	–
	Aug	No survey	–	–	–
	Sep	NA	119	0	289
	Oct	NA	102	0	587
	Nov	NA	194	0	659
	Dec	30	92	0	559
1999	Jan	28	65	0	313
	Feb	27	110	0	427
	Mar	25	95	9	426
	Apr	27	40	0	400
	May	25	27	196	345
	Jun	No survey	–	–	–
	Jul	26	404	13	212
	Aug	30	110	69	71
	Sep	27	124	80	92
	Oct	25	122	3	293
	Nov	27	134	1	189
	Dec	29	88	0	264
2000	Jan	22	78	0	454
	Feb	22	52	1	300

	Mar	27	71	5	237
	Apr	24	24	2	221
	May	22	30	0	165
	Jun	23	36	70	200
	Jul	24	80	56	299
	Aug	28	109	51	203
	Sep	25	147	23	189
	Oct	23	132	1	122
	Nov	25	91	2	252
	Dec	26	81	0	185
2001	Jan	22	108	0	275
	Feb	26	33	0	265
	Mar	19	70	2	381
	Apr	23	41	5	218
	May	28	41	0	157
	Jun	25	77	1	174
	Jul	22	102	109	310
	Aug	27	166	12	261
	Sep	24	56	5	278
	Oct	29	58	2	236
	Nov	27	62	0	153
	Dec	17	105	2	250
2002	Jan	27	87	0	275
	Feb	25	68	0	282
	Mar	22	50	0	403
	Apr	22	40	0	249
	May	25	30	120	306
	Jun	24	57	30	472
	Jul	26	73	0	361
	Aug	25	158	65	442
	Sep	25	108	3	200
	Oct	26	55	0	319
	Nov	25	20	4	169
	Dec	16	32	0	333
2003	Jan	27	68	0	113
	Feb	24	56	0	320
	Mar	24	73	0	498
	Apr	21	132	40	565
	May	9	70	200	603
	Jun	23	45	180	353
	Jul	28	205	145	478
	Aug	25	231	42	449
	Sep	21	70	9	170

	Oct	27	83	18	171
	Nov	16	62	0	192
	Dec	15	71	1	259
2004	Jan	19	73	1	421
	Feb	16	73	2	507
	Mar	21	86	0	503
	Apr	26	83	86	486
	May	9	104	254	527
	Jun	21	115	314	393
	Jul	26	124	156	171
	Aug	26	119	48	140
	Sep	19	138	32	319
	Oct	23	92	33	397
	Nov	20	102	7	517
	Dec	16	102	2	603
2005	Jan	24	133	0	528
	Feb	28	92	12	694
	Mar	28	85	90	623
	Apr	25	100	204	673
	May	23	102	332	712
	Jun	20	127	279	804
	Jul	25	123	121	581
	Aug	22	118	90	407
	Sep	18	161	75	577
	Oct	24	131	48	647
	Nov	17	98	37	670
	Dec	12	145	18	771
2006	Jan	23	148	0	610
	Feb	25	169	4	845
	Mar	20	97	21	533
	Apr	27	82	27	458
	May	22	9	0	382
	Jun	26	77	348	455
	Jul	24	205	386	563
	Aug	22	209	315	664
	Sep	25	189	137	364
	Oct	23	171	129	576
	Nov	13	69	2	246
	Dec	12	27	2	285
2007	Jan	22	168	0	621
	Feb	18	51	0	405
	Mar	No survey	–	–	–
	Apr	1	123	31	380

	Apr	27	139	53	317
	May	21	84	106	381
	Jun	25	117	147	481
	Jul	28	141	300	257
	Aug	20	172	447	644
	Sep	24	107	67	203
	Oct	NA	112	29	336
	Nov	13	128	75	504
	Dec	10	104	11	343
2008	Jan	No survey	–	–	–
	Feb	25	141	0	705
	Mar	24	125	6	249
	Apr	21	164	134	415
	May	19	87	155	548
	Jun	23	212	251	575
	Jul	28	382	56	358
	Aug	18	91	182	249
	Sep	22	107	81	211
	Oct	No survey	–	–	–
	Nov	17	85	0	214
	Dec	15	92	11	125
2009	Jan	26	160	0	302
	Feb	No survey	–	–	–
	Mar	16	88	9	167
	Apr	20	40	25	146
	May	No survey	–	–	–
	Jun	No survey	–	–	–
	Jul	21	26	47	121
	Aug	17	21	30	122
	Sep	21	19	35	83
	Oct	20	46	0	144
	Nov	No survey	–	–	–
	Dec	15	42	0	57
2010	Jan	No survey	–	–	–
	Feb	No survey	–	–	–
	Mar	No survey	–	–	–
	Apr	No survey	–	–	–
	May	25	6	33	181
	Jun	No survey	–	–	–
	Jul	12	43	12	116
	Aug	No survey	–	–	–
	Sep	28	58	75	136
	Oct	No survey	–	–	–



	Nov	16	38	7	182
	Dec	No survey	-	-	-
2011	Jan	No survey	-	-	-
	Feb	11	61	2	82
	Mar	No survey	-	-	-
	Apr	No survey	-	-	-
	May	No survey	-	-	-
	Jun	24	100	58	471
	Jul	No survey	-	-	-
	Aug	No survey	-	-	-
	Sep	20	122	85	154
	Oct	No survey	-	-	-
	Nov	No survey	-	-	-
	Dec	19	83	2	250
2012	Jan	No survey	-	-	-
	Feb	No survey	-	-	-
	Mar	No survey	-	-	-
	Apr	25	75	70	220
	May	No survey	-	-	-
	Jun	19	37	121	42
	Jul	No survey	-	-	-
	Aug	No survey	-	-	-
	Sep	11	47	129	314
	Oct	No survey	-	-	-
	Nov	28	91	37	286
	Dec	No survey	-	-	-
2013	Jan	No survey	-	-	-
	Feb	26	118	0	364
	Mar	No survey	-	-	-
	Apr	No survey	-	-	-
	May	31	70	71	383
	Jun	No survey	-	-	-
	Jul	No survey	-	-	-
	Aug	20	96	121	219
	Sep	No survey	-	-	-
	Oct	No survey	-	-	-
	Nov	25	113	163	81
	Dec	No survey	-	-	-
2014	Jan	No survey	-	-	-
	Feb	No survey	-	-	-
	Mar	No survey	-	-	-
	Apr	10	89	55	445
	May	No survey	-	-	-

Jun	3	62	215	455
Jul	No survey	-	-	-
Aug	28	79	33	155

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Appendix I, Table 2. Tinian moorhen counts, raw data.

Year	Month	Day	Moorhen	Comments
1998	Nov	2	7	
	Dec	No survey	–	
1999	Jan	4	9	
	Jan	27	12	
	Feb	26	6	
	Mar	No survey	–	
	Apr	7	9	
	Apr	25	6	Only north pond searched
	May	29	12	
	Jun	28	11	
	Jul	31	13	
	Aug	27	11	
	Sep	30	10	
	Oct	28	9	
	Nov	24	11	
	Dec	No survey	–	
	2000	Jan	3	10
Jan		26	10	
Feb		No survey	–	
Mar		2	11	
Mar		31	18	
Apr		26	25	
May		23	13	
Jun		26	12	
Jul		28	11	
Aug		31	10	
Sep		29	11	
Oct		26	12	
Nov		30	11	
Dec		29	14	
2001		Jan	25	11
	Feb	No survey	–	
	Mar	1	11	
	Apr	4	17	
	Apr	26	26	
	May	31	13	
	Jun	27	12	
	Jul	26	18	
	Aug	29	9	
	Aug	30	12	
Sep	27	14		

	Oct	No survey	–	
	Nov	1	15	
	Nov	29	11	
	Dec	19	12	
2002	Jan	30	12	
	Feb	28	12	
	Mar	27	13	
	Apr	25	15	
	May	24	20	
	Jun	27	9	Only south pond searched
	Jul	24	15	
	Aug	28	13	
	Sep	25	18	
	Oct	30	15	
	Nov	27	16	
	Dec	18	13	
2003	Jan	28	20	
	Feb	26	17	
	Mar	26	21	
	Apr	23	16	
	May	21	16	
	Jun	25	19	
	Jul	30	15	
	Aug	27	19	
	Sep	24	15	
	Oct	29	17	
	Nov	18	17	
	Dec	17	13	
2004	Jan	21	16	
	Feb	18	16	
	Mar	24	15	
	Apr	28	12	
	May	13	5	Survey lasted only 10 min, south pond
	Jun	NA	–	
	Jul	28	13	
	Aug	NA	–	
	Sep	22	13	
	Oct	27	10	
	Nov	17	7	
	Dec	14	12	
2005	Jan	26	17	
	Feb	24	6	
	Mar	30	9	

	Apr	27	0	
	May	25	3	
	Jun	22	9	
	Jul	27	10	
	Aug	24	13	
	Sep	21	13	
	Oct	26	12	
	Nov	14	15	
	Dec	14	10	
2006	Jan	25	15	
	Feb	28	15	
	Mar	22	20	
	Apr	26	13	
	May	24	16	
	Jun	28	18	
	Jul	26	17	
	Aug	23	21	
	Sep	22	15	
	Oct	29	23	
	Nov	15	13	
	Dec	NA	–	
2007	Jan	No survey	–	
	Feb	1	17	
	Feb	22	14	
	Mar	NA	–	
	Apr	4	15	
	May	7	5	Only south pond searched
	May	23	8	Only south pond searched
	Jun	28	14	
	Jul	No survey	–	
	Aug	1	13	
	Aug	22	18	
	Sep	27	17	
	Oct	No survey	–	
	Nov	No survey	–	
	Dec	1	16	
2008	Jan	NA	–	
	Feb	NA	–	
	Mar	1	15	
	Apr	NA	–	
	May	23	14	
	Jun	NA	–	
	Jul	NA	–	

	Aug	1	9	
	Sep	25	14	
	Oct	NA	-	
	Nov	NA	-	
	Dec	1	12	
2009	Jan	NA	-	
	Feb	1	6	
	Mar	NA	-	
	Apr	NA	-	
	May	20	11	
	Jun	NA	-	
	Jul	NA	-	
	Aug	1	17	
	Sep	NA	-	
	Oct	NA	-	
	Nov	NA	-	
	Dec	17	19	
2010	Jan	NA	-	
	Feb	NA	-	
	Mar	18	4	Only south pond searched
	Apr	21	4	Only south pond searched
	May	27	0	Only south pond searched
	Jun	17	0	
	Jul	14	5	
	Aug	NA	-	
	Sep	2	13	
	Oct	NA	-	
	Nov	18	16	
	Dec	21	13	
2011	Jan	20	17	
	Feb	10	18	
	Mar	17	17	
	Apr	21	19	
	May	26	9	Only south pond searched
	Jun	NA	-	
	Jul	14	17	
	Aug	25	17	
	Sep	22	12	
	Oct	27	14	
	Nov	8	19	
	Nov	30	16	
	Dec	21	16	
2012	Jan	NA	-	

	Feb	8	14	
	Mar	1	16	
	Mar	29	11	
	Apr	26	8	
	May	24	21	
	Jun	20	13	
	Jul	25	17	
	Aug	22	15	
	Sep	12	18	
	Oct	No survey	–	
	Nov	8	19	
	Nov	29	19	
	Dec	20	16	
2013	Jan	31	14	
	Feb	No survey	–	
	Mar	3	18	
	Mar	28	16	
	Apr	24	7	Only south pond searched
	May	NA	–	
	Jun	26	26	
	Jul	26	19	
	Aug	21	19	
	Sep	19	17	
	Oct	NA	–	
	Nov	NA	–	
	Dec	NA	–	
2014	Jan	29	15	

## APPENDIX II

Appendix II, Table 1. The Bayesian posterior probability values used in the quasi-sensitivity analyses for brown, masked, and red-footed booby survey data from Farallon de Medinilla during 1997–2014, and the Mariana common moorhen survey data at Hagoi Wetland on Tinian Island during 1998–2014. Median slope with 95% credible intervals are presented.

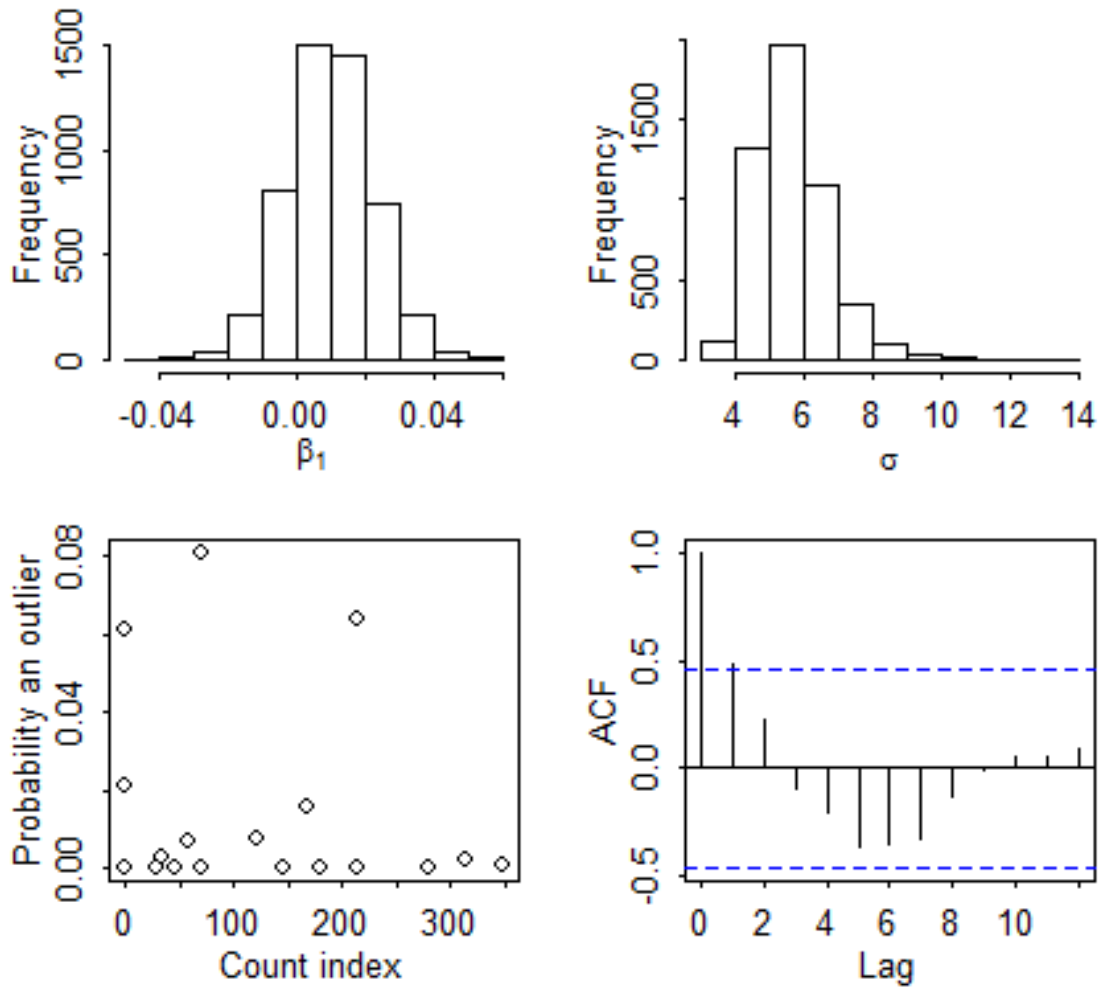
Species	Month	Median slope	Slope 2.5% CI	Slope 97.5% CI
brown booby	Jan	0.243	-1.380	1.817
	Feb	0.034	-1.540	1.799
	Mar	-0.081	-1.022	1.154
	Apr	0.015	-1.278	1.398
	May	0.143	-1.581	1.903
	Jun	0.271	-0.290	0.805
	Jul	0.247	-0.454	0.950
	Aug	0.213	-0.646	1.091
	Sep	0.274	-0.328	0.963
	Oct	0.190	-1.066	2.143
	Nov	0.134	-1.671	1.924
	Dec	0.164	-1.588	1.698
masked booby	Jan	-0.025	-0.242	0.162
	Feb	-0.009	-0.282	0.200
	Mar	-0.074	-0.266	0.130
	Apr	-0.041	-0.323	0.241
	May	0.023	-0.265	0.331
	Jun	0.009	-0.291	0.331
	Jul	-0.053	-0.271	0.226
	Aug	-0.022	-0.323	0.262
	Sep	-0.019	-0.258	0.246
	Oct	-0.013	-0.187	0.187
	Nov	-0.047	-0.263	0.363
	Dec	-0.023	-0.178	0.171
red-footed booby	Jan	-0.064	-0.382	0.227
	Feb	-0.084	-0.388	0.232
	Mar	-0.020	-0.230	0.225
	Apr	-0.028	-0.313	0.252
	May	-0.010	-0.288	0.272
	Jun	-0.024	-0.284	0.273
	Jul	-0.017	-0.223	0.215
	Aug	-0.015	-0.298	0.249
	Sep	-0.004	-0.232	0.246
	Oct	-0.019	-0.269	0.233



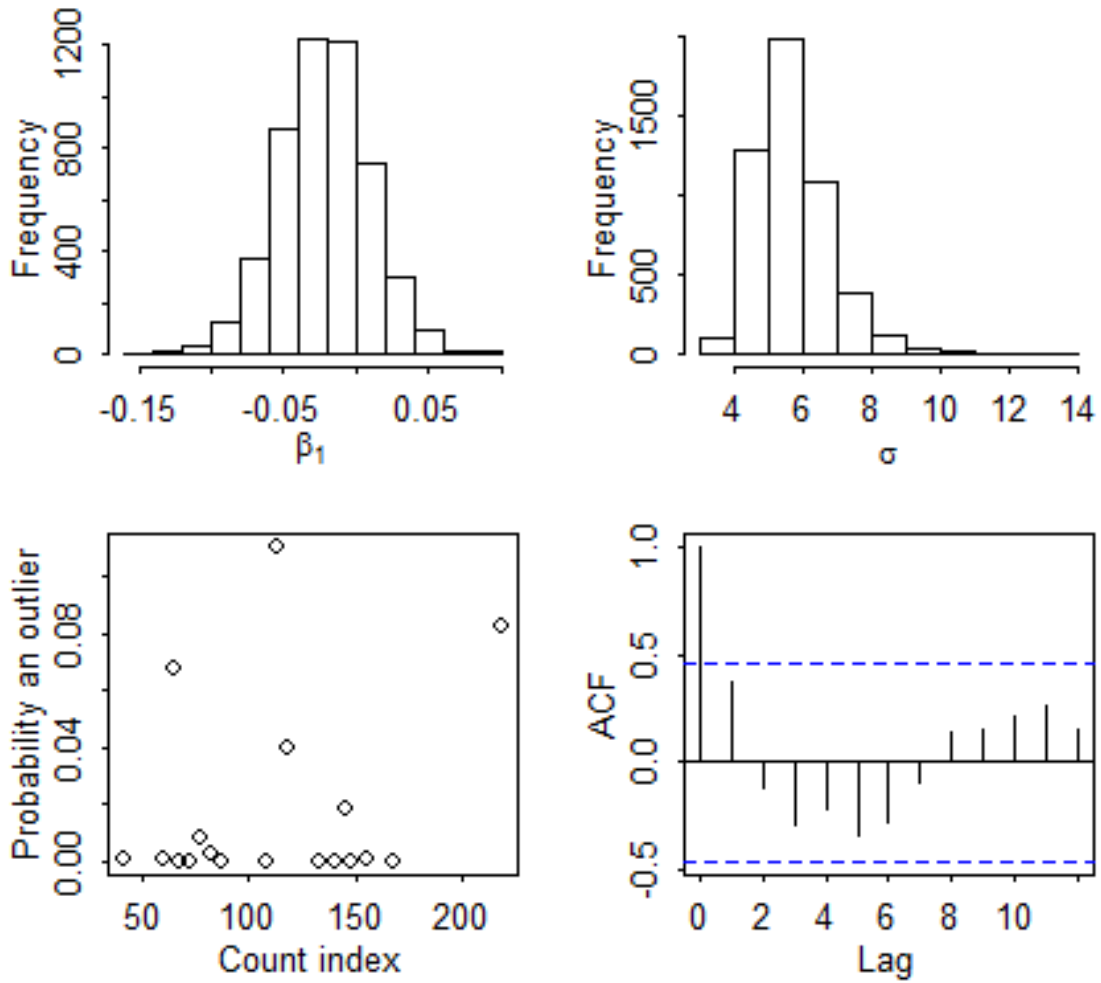
	Nov	-0.055	-0.313	0.171
	Dec	-0.066	-0.366	0.223
Mariana common moorhen	Jan	0.027	-0.111	0.171
	Feb	0.023	-0.126	0.195
	Mar	0.035	-0.204	0.331
	Apr	-0.058	-1.166	0.932
	May	-0.073	-0.935	0.829
	Jun	-0.043	-0.912	0.963
	Jul	0.018	-0.143	0.210
	Aug	0.023	-0.084	0.150
	Sep	0.024	-0.062	0.116
	Oct	0.029	-0.068	0.134
	Nov	0.050	-0.048	0.167
	Dec	0.025	-0.044	0.090

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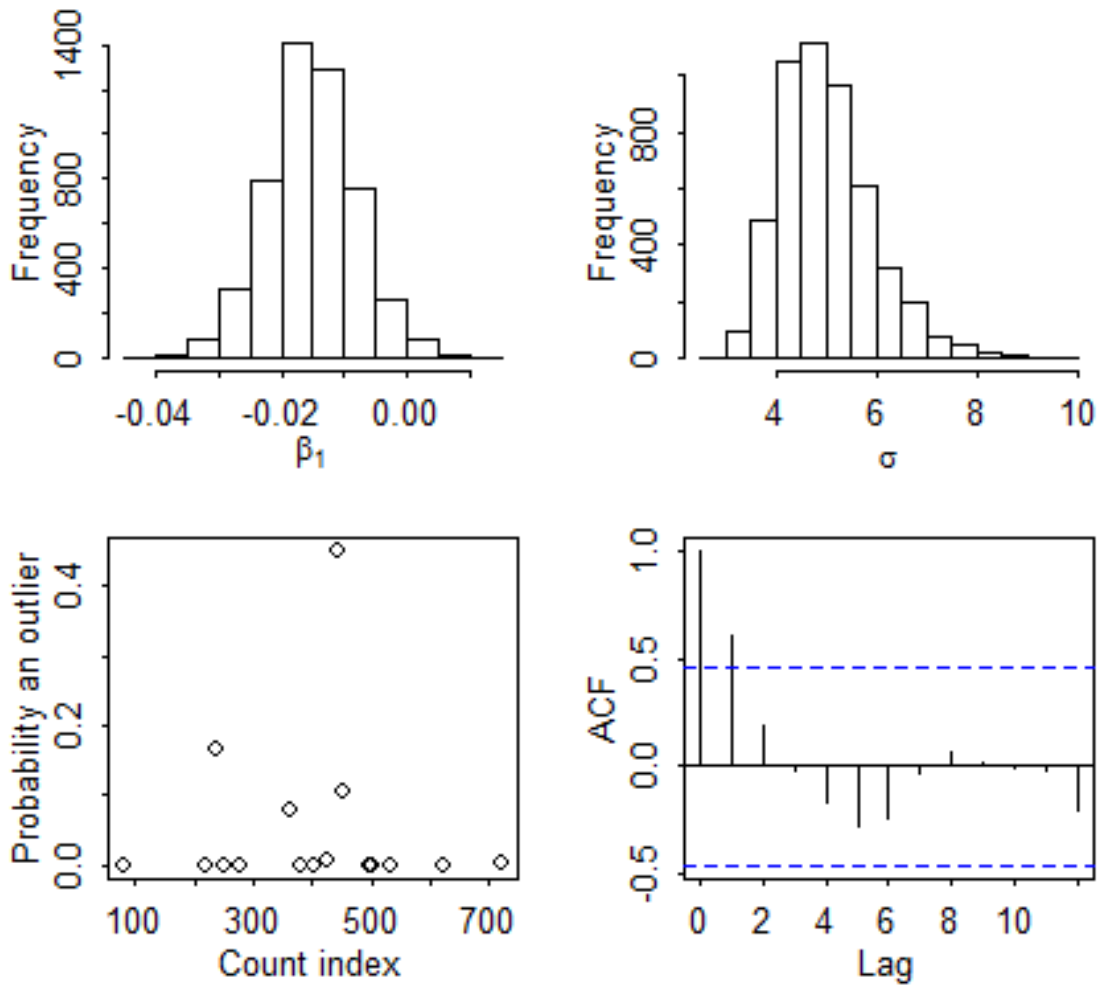
### APPENDIX III



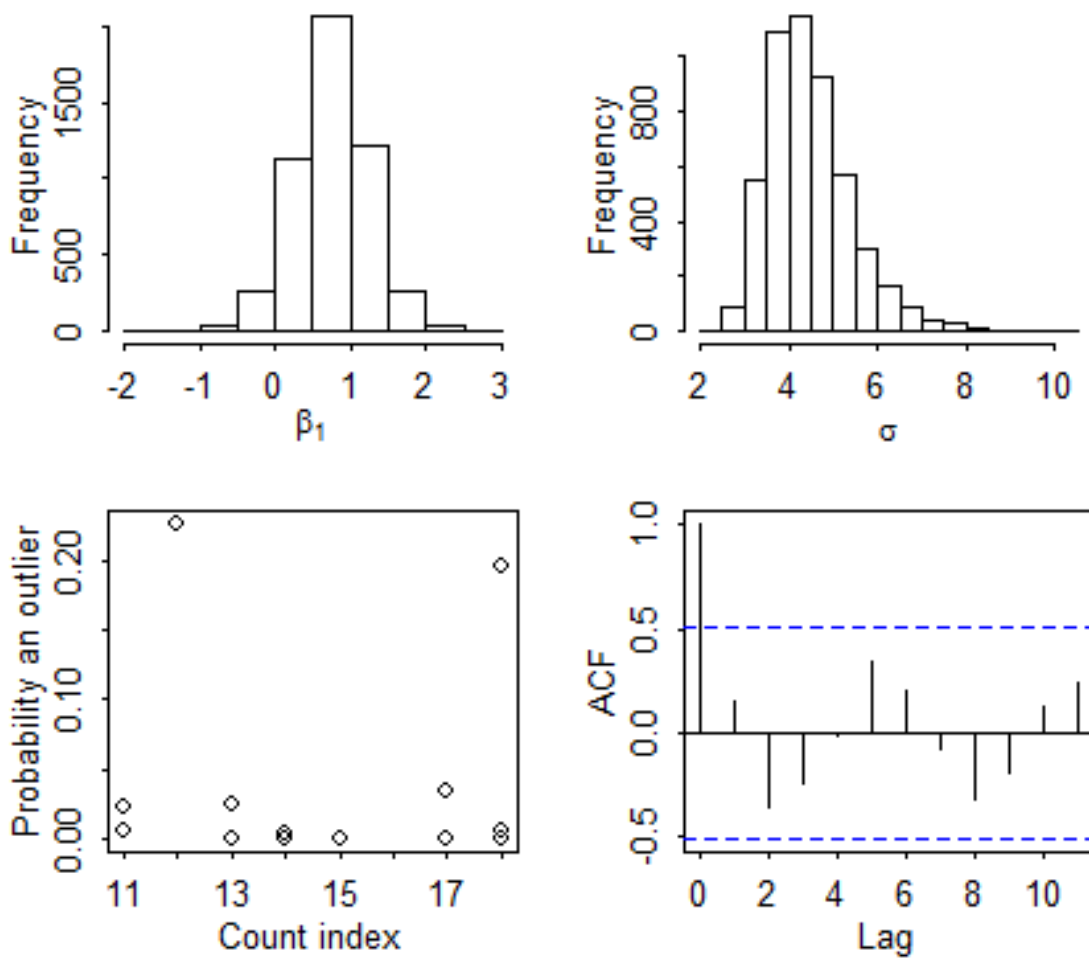
Appendix III, Figure 1. Brown booby diagnostic analyses to assess regression model assumptions: top panels display slope and standard deviation residuals, respectively; lower left panel displays the probability that a given count value is an outlier; and lower right panel displays autocorrelation (ACF: autocorrelation function).



Appendix III, Figure 2. Masked booby diagnostic analyses to assess regression model assumptions: top panels display slope and standard deviation residuals, respectively; lower left panel displays the probability that a given count value is an outlier; and lower right panel displays autocorrelation (ACF: autocorrelation function).



Appendix III, Figure 3. Red-footed booby diagnostic analyses to assess regression model assumptions: top panels display slope and standard deviation residuals, respectively; lower left panel displays the probability that a given count value is an outlier; and lower right panel displays autocorrelation (ACF: autocorrelation function).



Appendix III, Figure 4. Mariana common moorhen diagnostic analyses to assess regression model assumptions: top panels display slope and standard deviation residuals, respectively; lower left panel displays the probability that a given count value is an outlier; and lower right panel displays autocorrelation (ACF: autocorrelation function).