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Final Report

Rookery Island Productivity for Priority Waterbird Species

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Executive Summary

Waterbird rookery islands on the Texas coast are quickly disappearing and managers are putting significant resources towards their rehabilitation. There are > 300 rookery islands in the state and managers will have to prioritize islands that have the best potential to increase waterbird nesting populations. However, information on actual reproductive performance of waterbirds is rarely collected and often is limited to a small geographic area. Therefore, we used rotor drones to photograph the nests of four species of waterbirds (Reddish Egret, Tricolored Heron, Great Egret, and Black Skimmer) at 20 rookeries in the Coastal Bend region of Texas throughout the 2023 nesting season at approximately weekly intervals. Photographs were subsequently analyzed to determine the productivity of the four target species in different rookeries. The specific objectives are to (1) estimate productivity of four priority species and (2) test for differences in productivity across island types. We documented the fates of 1,378 nests of our four study species (*n* = 413 Black Skimmer, *n* = 167 Reddish Egret, *n* = 402 Great Egret, and *n* = 396 Tricolored Heron). We estimated daily nest survival for each of the four study species and converted to overall nest survival rate based on observation period and nest stage for our wading bird species. Brood size at fledging was also collected for each successful nest. We then used generalized linear models (GLMs) to analyze the factors affecting nest survival across and among species of our focal wading bird species. Wading bird nest survival pooled across nest

stages was relatively high for all species; however, there was variation among species and colonies. Tricolored Heron had the highest overall nest survival ($\bar{x}$ = 0.90), followed by Great Egret ($\bar{x}$ = 0.85), and Reddish Egret ($\bar{x}$ = 0.82). Nest survival for our focal wading bird species was consistently lower during the incubation stage than the nestling stage. In contrast to the wading bird species, Black Skimmer overall nest survival was low ($\bar{x}$ = 0.70) and was characterized by very high variation among colonies. Brood size at fledging was moderately high and varied by species and colony. All top models (ΔAICc < 2) explaining variation in nest survival of all species pooled across colonies contained the terms island area and nest substrate type, with higher survival on smaller islands and higher survival for nests in trees followed by shrub, and herbaceous substrates, respectively. The top models of factors affecting nest survival of Tricolored Heron across colonies also contained the terms island area and nest substrate type, with higher survival on smaller islands and higher survival for nests in shrub followed by herbaceous, and tree substrates, respectively. The important factors affecting nest survival were the same for the Reddish Egret and Great Egret in that only the full model, containing the terms island size and nest substrate type, was plausible and carried the majority of weight of evidence. Reddish Egret had higher nest survival on smaller islands and higher survival for nests in trees followed by shrub, and herbaceous substrates, respectively, whereas Great Egret had higher nest survival on medium and large islands and higher survival for nests in herbaceous followed by tree, and shrub, respectively. This study shows that our study species on the Texas coast had relatively high productivity compared to other studies. However, we also showed that among our focal species, the lowest values were consistently for the Reddish Egret and Black Skimmer, two species of special management concern. Our results support the management focus on these two species and suggest there is something different about the ecology of these species relative to the others that nest sympatrically in their colonies. The effect of island size on productivity parameters supports the increasing focus of coastal managers on rehabilitating coastal colony islands, and the effect of nest substrate type on productivity parameters identified a knowledge gap in understanding the vegetation dynamics and succession on colony islands.

Introduction

Waterbird rookery islands are being eroded by ship traffic, storms, and rising seas, leading managers to begin putting significant resources toward rookery island rehabilitation. Their efforts are guided by the Texas Colonial Waterbird Survey, an annual statewide effort to document the location and size of colonial waterbird rookeries. However, there is no corresponding information on how many fledglings these rookeries produce (i.e., productivity), which is a key component of their conservation value. With roughly 300 rookery islands on the Texas coast, agencies will not have enough funds to intensively manage all rookery islands. Nor do all islands have the same potential to increase waterbird nesting populations. Some rookeries initiate every year but repeatedly fail, whereas others seem to consistently produce fledglings, although the numbers have rarely been measured. Information to help prioritize islands that have the greatest potential to sustain waterbird populations based on actual reproductive performance of birds is urgently needed to guide the selection of islands for restoration and to focus scarce resources used for management of rookery islands on the most beneficial islands.

Therefore, we initiated a project to measure with rotor drones, the productivity of four species of waterbirds (Reddish Egret [*Egretta rufescens*], Tricolored Heron [*Egretta tricolor*], Great Egret [*Ardea alba*], and Black Skimmer [*Rynchops niger*]) at colonies along the Texas coast. Reddish Egret, Tricolored Heron and Black Skimmer are high priority conservation species, and the Great Egret is a designated indicator for the health of the Gulf of Mexico. The specific objectives are to (1) estimate productivity of four priority species and (2) test for differences in productivity across island types.

Methods

Monitoring Over the course of the 2023 breeding season, researchers used a rotor drone (DJI Matrice 300 RTK) to photograph the nests of the four focal species of waterbirds at 20 rookeries in the Coastal Bend portion of Texas (Table 1), throughout the nesting season at approximately weekly intervals.

Our data collection consisted of three processes: (1) image collection (systematic capture of images from drone surveys), (2) post-processing of images (creation of intermediate products such as orthomosaics), and (3) image interpretation (collection of data on species identification, nest numbers, and individual nest progress).

During (1) image collection, nesting surveys were conducted with a commercially available quadcopter drone (DJI Matrice 300 RTK paired with DJI DII RTK Ground station) paired with a 61.0-megapixel RGB camera (DJI P1) operated by the PhD Graduate Student, launched from the boat or a similar stable surface, and operated using a remote controller. The maximum wind speed a DJI Matrice 300 RTK is safely rated to fly at 53.9 kph. To ensure the safety of researchers and the drone, the drone was only operated when wind speeds, at the altitude missions are flown (50 m), were below 50 kph. Weather projections were accessed before each survey using a third-party app (UAV Forecast), and if the wind exceeded maximum wind speed of DJ Matrice 300 RTK, surveys were called off.

We selected a "home base" ≥ 100 m from the nearest nest to launch the drone while conducting drone transect surveys. We then programmed the drone to photograph the transect using a using a drone mapping app specifically created for the quadcopter drone used in this study (DJI Pilot 2). This app allows the user to dictate settings relevant to the study (% front and side overlap, altitude, camera angle, etc.). The drone then flew to an altitude of 50 m and captured images of the transect at intervals with the appropriate overlap (88% front overlap and 88% side overlap). The drone continued capturing images until it recorded the entire transect. Each image captured with the drone was included metadata which includes: the date and time when the image was collected, the make, model, and focal length of the camera, the onboard GPS latitude and longitude, the yaw angle of the drone, and the yaw, pitch, and roll angle of the camera gimbal.

Upon completion of the survey, we imported images to Agisoft Metashape for post-processing (2). Once images were imported into the post-processing software, the PhD Graduate Student scanned through all images captured during the survey and removed images that were blurry or might otherwise compromise the resolution of processed images. We then aligned Images. Camera alignment finds the camera position and orientation for each photo and builds a sparse point cloud model. Researchers specified that images were aligned at the highest resolution ("highest") attainable by the post-processing software used in this study (Agisoft Metashape). The key point limit, which sets the maximum number of feature points considered as the post-processing software matches photos together, was set to 40,000, and the tie point limit, which is the maximum number of points that the post-processing software will match between photos, was set to 4,000. The tie point and key point limit used in this study are values recommended by Agisoft for projects that focus on landscape imagery. When surveying sites with higher canopy cover, a greater proportion of the key points and tie-points selected by post-processing software are unusable due to few observations between images in the survey caused by reduced visibility of objects observed between and underneath the canopy. To mitigate negative effects of canopy cover on resulting orthomosaics, we set the key point limit to 80,000 and tie point limit was set to 8,000 in surveys conducted in colonies with high canopy cover.

Once images were aligned, we reran any images that failed to align through alignment again. Images that fail to align often do not contain points which can be "tied" to neighboring images (common if images are taken of water surrounding waterbird breeding colonies). We reran images through alignment until they were successfully aligned. If images failed to align after repeated attempts, we removed these images from further analysis.

After camera alignment, we processed the sparse cloud and image tie points generated through camera alignment into a dense cloud and depth maps. To decrease blurriness from the use of uncertain image tie points, we set the "Quality" (image resolution scale) to medium and "Depth Filtering" to mild, which eliminates outliers in the dense point cloud (i.e., uncertain image tie-points) to more accurately construct depth maps. We then rectified Depth maps into a Digital Elevation Models (DEM), and "stitched" DEMs into orthomosaic images.

After images were run through post-processing software and "stitched" into orthomosaic images, the PhD Graduate Student conducted Photo Interpretation (3). We identified and tracked waterbird nests were through photointerpretation using Agisoft Metashape's orthomosaic window feature. Upon constructing an orthomosaic image, we systematically searched the nest transect in a grid pattern at a scale of 1:12.5. We distinguished active nests following Sardà-Palomera et al. (2011). We tracked nests throughout the season, and a record of whether a nest was detected, bird species, stage of nesting, contents, nestling age, and fate was recorded. After looking through every image containing a nest, we used the image with the clearest view of the contents of a nest and highest resolution to record bird species, nestling age, contents, and fate. Because orthomosaic images used in this study were produced by stitching together individual images captured using a seventy-eight-degree angle, it was not always possible to positively distinguish birds below the canopy as being on nests when using the orthomosaic image alone. Instead, due to the angle of the image and the amount and location of canopy cover over a nest, there were several instances in which we only observed the back of a bird and not an actual nest. We labeled these nests as probable nests and placed a georeferenced "reference marker" directly over the location of a suspected nesting bird. We then selected a reference marker of the probable nest using the function "Filter Photos by Marker" in Agisoft Metashape. This function automatically selects every photo containing a referenced marker, and automatically zooms to the same magnification in every image. We examined every image containing a referenced marker to confirm whether the bird was on a nest from an individual image captured during the survey.

We used the contents of a nest observed through drone transect surveys to determine nest stage. We classified nests as being in the incubation or nest-building stage until nestlings were visible in an image of a particular nest. We classified nests as being in the nestling stage when chicks were observed in a nest. Wading birds were considered "fledged" at 14 ± 2 days old when they could no longer be associated with a specific nest. Black Skimmers were considered fledged at ~ 1 week old when they form creches. Because Black Skimmers were usually only tracked until their first observation with nestlings, it was not possible to estimate nestling survival for this species. Thus, for the Black Skimmer, we estimated survival for all nest stages pooled.

To determine the age of nests, we tracked nests from the initial date they were observed. If a nest was abandoned or had failed before chicks were observed, we marked the initial date the nest was observed as day zero. We then added the number of days in-between subsequent surveys to its initial age. If a nestling was confirmed to a nest, we marked the date of the survey and used the date to back-calculate the age of the nest. Given the resolution of the imagery, there were instances in which it was difficult to positively ascribe a nestling to a certain age. Thus, nestlings were marked as 0 days old during their first observation, and the age of the nest was back-calculated based on incubation periods for each species (Reddish Egret $\bar{x}$ = 26 days, Holderby et al. 2012; Tricolored Heron $\bar{x}$ = 22 days, Frederick and Collopy 1988b; Great Egret $\bar{x}$ = 25 days, Weise 1975; Black Skimmer $\bar{x}$ = 23 days, Erwin 1977). If the age of a nest in previous surveys was ascribed to a negative number because of back-calculating, we marked the initial date the nest was detected as 0 days old. This may occur if nestlings were not observed in a nest until they are several days old and/or the initial date a nest was first detected and tracked was close to the date the first egg was laid. We tracked all nests until the date each was determined to have reach fledging, or if chicks had left the nest and could no longer be tracked using drone surveys, we marked the nest as successful, and it was no longer tracked in subsequent surveys.

We also recorded the area in m^2 for each colony and the substrate type that each nest was constructed on. Substrate type was included as a variable in this project due to its importance for wading bird and skimmer breeding biology. Nesting substrate has been found to be an important variable for predicting the number of wading bird nests (Chastant et al. 2017) and for the productivity of several species (Parsons 2003), and nesting substrate and nesting substrate color have been found to be important for egg camouflage, vegetation control, and reproductive success of Black Skimmers (Mallach and Leberg, 1999, Owen and Pierce, 2013). The land area for each colony was derived from a dataset collected by the Geospatial Team of the Texas

General Land Office which delineated land area for every rookery island on the Texas coast (Chaney et al. 2005, Gao 2020). The substrate type each nest was constructed on was determined through photointerpretation using Agisoft Metashape's orthomosaic window feature. When viewing an individual nest, the observer would zoom to a level of magnification high enough to determine if a nest was constructed on herbaceous, shrub, tree, ground, or sand substrate. To ensure the substrate type of each nest was recorded accurately, the observer went through every plant referenced in the Colonial Waterbird and Rookery Management Plan and used these plants to determine the species of plant each nest was constructed on, unless a nest was constructed on the ground or in sand. Substrate types included ground, white sand, dark sand, herbaceous, shrub, and tree. A nest would be considered on the ground if a nest was constructed in an area without plants and not on the sand.

Analysis All analyses were done in program R (R Development Core Team 2022, version 4.2.0). To account for biases in nest survival estimates resulting from variation in the initial nest ages at monitored nests, daily nest survival (proportion of nests that fledge ≥ one nestling) was calculated using logistic exposure models (Shaffer 2004, Baranski and Cook 2021). Generalized linear models were fitted with a log-link distribution function. The model estimates daily nest survival rate. Daily nest survival rate was converted to overall nest survival rate by exponentiating daily survival rate by the length of the survey or nest stage periods. To obtain overall nest survival rate of individual nest stages, daily nest survival rate was exponentiated to the appropriate interval lengths for each nest stage, by species (see above). To obtain overall nest survival rate across all nest stages, daily nest survival rate was exponentiated to the total interval length that each species was monitored. Great Egret nests were typically monitored until they were 50 days old, Tricolored Heron and Reddish Egret nests were typically monitored until they were 45 days old, and Black Skimmers were monitored until they entered the nestling stage (29 days old). Separate models were developed for the nestling and incubation periods because there are clear differences in survival rates between the two nest stages. Appropriate interval lengths for incubation and nestling periods were used for each species (see above). Mean brood size at fledging was calculated from the subset of nests for which we detected chicks within the age classes we defined as fledging for each species as described above.

We also used generalized linear models (GLMs) with a Binomial log-link function and error distribution to analyze the factors affecting nest survival (Harrison et al. 2018). We accounted for variation among nests within each colony by specifying a nested random effects structure where nest ID was nested within colony. Nest survival was a binomial dependent variable (nest survived or failed since previous survey), and nest substrate type (herbaceous, shrub, tree, ground, white sand, dark sand), island size class (small: 0 – 10,000 m^2, medium: 10,000 – 25,000 m^2, large: 25,000 – 50,000 m^2, extra-large: > 50,000 m^2), bird species (Reddish Egret, Tricolored Heron, Great Egret, Black Skimmer), and stage of nesting (incubation, nestling) were treated as categorical predictors in the model.

The GLMs were constructed and analyzed using the lme4 package for program R (R Development Core Team 2022, version 4.2.0) using a model-selection framework to examine *a priori* hypotheses that island size, nest substrate type, and stage of nesting affected survival (Table 2). Separate GLMs were run for individual species across colonies, and for all species pooled, across colonies. ΔAICc values were calculated for each of the candidate models to reflect differences from the best candidate model (i.e., the model with the lowest AICc). Candidate models were then ranked based on ΔAICc values to choose a set of "top models" that were all plausible given the data if ΔAICc < 2. The relative support of candidate models was calculated by scaling models according to their AICc weight of evidence (Burnham and Anderson 2002). To demonstrate the level of effect each parameter had on survival, we constructed a odds ratio forest plot with 95% CI.

Separate GLMs were not constructed or tested for Black Skimmers because unlike our other study species, Black Skimmers leave the nest within one week of hatching and join creches, leaving researchers unable to identify and track nests beyond this date. Additionally, all Black Skimmers in the study nested on white sand, precluding us from testing for differences in Nest Substrate Type.

Results

During the 2023 waterbird breeding season, we conducted a total of 193 surveys of 20 colonies from 21 March through 23 August. We surveyed the seven colonies in the Corpus Christi area 14 to 19 times between 21 March and 25 July. The seven colonies in the Lavaca and Matagorda areas were surveyed 12 to 18 times, between 25 March and 23 August. Of the seven colonies in the Matagorda area, only three colonies were observed with nesting birds during the 2023 breeding season, thus only three colonies were regularly surveyed with the drone. The six colonies in the Galveston area were surveyed eight to 11 times between 27 April and 6 July. Of the six colonies in the Galveston area, only five colonies were observed with nesting birds during the 2023 breeding season. Thus, only five colonies were regularly surveyed with the drone. Differences regarding the start and end date of surveys between breeding colonies and regions were a result of the date at which permits were received and the nesting period of each species. We conducted an impressive 193 colony surveys containing 266 transect subsamples throughout the 2023 breeding season. If a colony was too large to survey completely during each survey, we subsampled random transects throughout the colony, and surveyed throughout the season.

We documented the fates of 1,378 nests of our four study species (n = 167 Reddish Egret, n = 396 Tricolored Heron, n = 402 Great Egret, and n = 413 Black Skimmer; Table 3). We estimated daily nest survival for each of the four study species and converted to overall nest survival rate based on observation and nest stage period. Because wading birds have been found to have clear differences in survival rates between the incubation and nestling nest stages, separate models were developed for the nestling and incubation periods for these species. Overall nest survival across the entire survey period was also calculated for wading birds across all nest stages.

Wading bird nest survival pooled across nest stages was relatively high for all species; however, there was variation among species and colonies. Tricolored Heron had the highest overall nest survival ($\bar{x}$ = 0.90, 95% CI [0.88, 0.91]; Fig 1), but also exhibited high variation among colonies (range across colonies 0.78 to 0.94). Great Egret exhibited relatively high overall nest survival pooled across nest stages ($\bar{x}$ = 0.85, 95% CI [0.83, 0.87]; Fig 1), with large variation among colonies (range 0.74 to 0.95 across colonies; Fig. 1). Reddish Egret exhibited the lowest overall survival across nest stages of the wading bird species ($\bar{x}$ = 0.82, 95% CI [0.78, 0.85]; Fig 1), and exhibited the greatest degree of variation in nest survival among colonies (range across colonies 0.63 to 1.0; Fig. 1).

Nest survival for our focal wading bird species was consistently lower during the incubation stage than the nestling stage. However, even during the incubation stage, nest survival was moderately high. Tricolored Heron had highest survival during incubation ($\bar{x}$ = 0.85, 95% CI [0.82, 0.87], range 0.73-0.93 across colonies) followed by Great Egret ($\bar{x}$ = 0.80, 95% CI [0.76, 0.83], range 0.69-0.84 across colonies) and Reddish Egret ($\bar{x}$ = 0.76, 95% CI [0.70, 0.81], range 0.62-1.0 across colonies; Fig. 2).

Tricolored Heron and Great Egret had very high and similar nest survival during the nestling stage of the wading birds with little variation across colonies (Tricolored Heron $\bar{x}$ = 0.98, CI [0.96, 0.99]; Great Egret $\bar{x}$ = 0.96, CI [0.94, 0.98]; Fig. 3). Reddish Egret nest survival was slightly lower than the other wading bird species but still high during the nestling stage ($\bar{x}$ = 0.96, 95% CI [0.92, 0.99], range across colonies 0.92 to 1.0; Fig. 3).

In contrast to the wading bird species, Black Skimmer overall nest survival was low (Fig. 4; $\bar{x}$ = 0.70, 95% CI [0.67, 0.73]), and was characterized by very high variation among colonies (range across colonies 0 to 0.87). Several colonies in which Black Skimmers were monitored (Chester Island, Rubbersnake Island, Shamrock Island; Fig. 4) were characterized by complete colony collapse, with few if any nests fledging chicks. Other colonies had relatively high nest survival with most nests fledging chicks (Chocolate Bayou, Rabbit Island; Fig. 4).

Brood size at fledging was moderately high and varied by species and colony (Fig.5). Among the wading birds, Tricolored Heron had the largest brood size ($\bar{x}$ = 2.26, *n* = 257, 95% CI [2.19, 2.34], range across colonies 2.20-2.60; Fig. 5) followed by the Great Egret ($\bar{x}$ = 2.03, *n* = 262, 95% CI [1.96, 2.10]; range across colonies 1.88 – 2.22; Fig. 5). Reddish Egret had the lowest brood size of the focal wading bird species ($\bar{x}$ = 1.89, *n* = 93, 95% CI [1.76, 2.02]; range across colonies 1.00-2.22; Fig. 5). However, Black Skimmer, our ground-nesting species, had the lowest brood size at fledging of any species ($\bar{x}$ = 1.65, *n* = 166, 95% CI [1.56, 1.75]; Fig.5).

Our analysis of factors affecting nest survival of all species pooled across colonies resulted in two competitive top models (Table 4). All top models (ΔAICc < 2) explaining variation in nest survival contained the terms island area and nest substrate type (Table 4.), with higher survival on smaller islands and higher survival for nests in trees followed by shrub, and herbaceous substrates, respectively (Fig. 6). These models supported two of our four *a priori* hypotheses. Differences among the top models were due to inclusion of nest substrate type (Table 4.). Island size, nest substrate type, bird species, and stage of nesting were included in the best candidate models (ΔAIC > 2.00). Our second-most supported model (ΔAICc = 1.96) was similar to our top model and lacked a term for nest substrate type. Because our top two models were found to have ΔAICc < 2, 95% CIs of model-averaged parameters (β) were computed as odds ratios as β ± 1.96 (SE) (Fig. 6). None of the fixed effects used in the best fitting model overlapped 0, suggesting that these terms had useful predictive value (Burnham and Anderson 2002). However, because the best fitting model had one additional parameter and only a slightly lower AICc score than the second-best fitting model (Best fitting model AICc = 3101.1, second-best fitting model AICc = 3103.1, Table 4.) with little improvement in deviance, the CI of the regression coefficient was examined to determine if inclusion of nest substrate was really warranted. Although nest substrate type did not have 95% CIs that overlapped zero, the CIs were close to, or larger, than the coefficient estimates. This implies that nest substrate type is a "pretending variable" and its addition did not improve the model fit over the second-best fitting model (Anderson 2010). Whereas bird species and stage of nesting were included in our top models, these differences were expected and treated as uninteresting covariates (Table 4).

The top models of factors affecting nest survival of Tricolored Heron across colonies (Table 5) was similar to those of the models for all species pooled. All top models explaining variation in nest survival of Tricolored Heron nesting on the Texas coast, USA, contained the terms island area and nest substrate type (Table 5.), with higher survival on smaller islands and higher survival for nests in shrub followed by herbaceous, and tree substrates, respectively (Fig. 7). However, the second-best model did not have a term for nest substrate type and showed only a small drop in model performance. A comparison of the top two models showed that nest substrate was a "pretending variable" (Table 5) and therefore the second-best model was preferred, as was the case for the models of all species pooled.

The important factors affecting nest survival were the same for the Reddish Egret and Great Egret in that only the full model was plausible and carried the most weight of evidence. The top models contained terms for both Nest Substrate Type and Island Size. Nest survival also differed by stage of nesting, but again those differences were expected (Tables 6 and 7). We found that Reddish Egret had higher nest survival on smaller islands and higher survival for nests in trees followed by shrub, and herbaceous substrates, respectively (Fig. 8). Whereas Great Egret had higher nest survival on medium and large islands and higher survival for nests in herbaceous followed by tree, and shrub substrates, respectively (Fig. 9).

Discussion

We found a clear difference between survival estimates for the incubation and nestling stages of our three wading bird study species (Reddish Egret, Tricolored Heron, Great Egret). All three species received very high overall nest survival during the nestling stage (Fig. 3), and lower overall nest survival during the incubation stage, across colonies (Fig. 2). These findings were reinforced with the results of GLMs focused on each species (Fig. 4-6). Overall survival for Reddish Egret during the nestling stage (0.92 - 1.0; Fig. 3) was higher than overall survival during the incubation stage (0.62 - 1.0; Fig. 2) for all but one colony (West Bay Bird Island A). Overall survival for Great Egret during the nestling stage (0.84 - 1.0; Fig. 3) was greater than overall survival during the incubation stage, across colonies (0.69 - 0.94; Fig. 2). Overall survival for Tricolored Heron during the nestling stage (0.90 - 1.0) was higher than overall survival during the incubation stage, across colonies (0.73 - 0.93). The stark difference between nest survival in the incubation and nestling stages was also noted for the Tricolored Heron in the Everglades (Frederick and Collopy 1989). Also, Baranski and Cook (2021) found that nestling success (83% - 100%) was higher than incubation success (61% - 95%) across species and colonies for Great Egret, White Ibis (*Eudocimus albus*), Wood Stork (*Mycteria americana*), Roseate Spoonbill (*Platalea ajaja*), Snowy Egret, Great Blue Heron (*Ardea herodias*), Little Blue Heron (*Egretta caerulea*), Tricolored Heron, and Black-crowned Night-Heron (*Nycticorax nycticorax*) in the Greater Everglades.

Overall Tricolored Heron nest survival (0.90) was the highest of any of our study species and higher than other published estimates, both from the Greater Everglades [0.57 in Frederick (1993) and 0.75 for small herons pooled in Baranski and Cook (2021)] Few other studies have examined nest survival for the Tricolored Heron, largely due to the difficulty in identifying and tracking dark-colored herons that nest under the canopy (Frederick et al. 1993) and because of a reluctance to disturb colonies on a weekly basis to check on individual nest fates.

Our estimate of overall Great Egret nest survival (0.85) was the second highest survival estimate among our study species. Herring et al. (2010) reported a daily nest survival rate of 0.981 for Great Egrets in the Everglades, whereas our overall nest survival rate converted to daily nest survival was 0.997. McInnes (2011) estimated overall survivorship of Great Egret nests in the San Fracisco Estuary to be 78 ± 0.4%, and Neinavaz et al. (2013) found overall survival of Great Egret nests in a mangrove swamp in Iran to be only 0.49. Neinavaz et al. (2013) may be an outlier and the estimate artificially low due to the presence of invasive rodent species.

Our estimate of overall Reddish Egret nest survival (0.82) was the lowest survival estimate among our wading bird study species. However, our estimates are similar to those in Holderby et al. (2012), who estimated overall survival using the Mayfield method in the Laguna Madre of Texas to be 0.85 ± 0.054 (*n* = 171). Collins et al. (2021) estimated daily nest survival rate of Reddish Egret in Southwestern Louisiana to be 0.979 (± 0.003 SE), compared to our daily nest survival of 0.996 (converted from overall nest survival).

Our estimate of overall Black Skimmer nest survival (0.70; converted to daily nest survival = 0.998) was the lowest survival estimate among all our study species. Additionally, Black Skimmer was our only study species to experience complete or near-complete colony abandonment at several colonies (Fig. 4). These estimates were similar to those reported in previous colonies. Brooks et al. (2014) estimated daily nest survival rate of Black Skimmers at three separate sites in South Carolina, USA to range between 0.938 - 0.975. Owen and Pierce (2013) reported that daily nest survival rate of Black Skimmers at several colonies in Louisiana, USA ranged between 0.803 - 0.992. Dinsmore (2008) did not estimate daily nest survival rate but noted that disturbance and other factors resulted in colony abandonment of several colonies of Black Skimmers, as we observed.

Although this study was not able to identify the cause for most nest failures, we have anecdotal evidence for the cause of failure for nests at two colonies. Rubbersnake Island (Marker 103-117 Spoil [NM 207-221]) experienced complete colony abandonment between two weekly visits and after a floating cabin that had blown onto the island was removed. We know that based on the large tracks left on the island, heavy machinery was brought onto the island to remove the cabin, likely resulting in what we believe would have been significant human-caused disturbance. At our Chocolate Bayou colony, we observed an individual with an unleashed dog walking within a large aggregation of Black Skimmer nests. Cameras on the island for a study conducted by Coastal Bend Bays & Estuaries Program showed that the same individual returned often, sometimes staying on the island throughout the night (D. Newstead, CBBEP, pers. comm).

We found that variation in waterbird nest survival was related to stage of nesting, bird species, island size, and nest substrate type (Table 4). Whereas other studies have found differences in nest survival between nest stages (e.g., Parsons et al. 2001) and among waterbird species (e.g., Ritenour et al. 2022), we found that nest survival was also related to island size and nest substrate type, with higher survival on smaller islands and higher survival for nests in trees followed by herbaceous, and shrub substrates, respectively (Fig. 6). Previous studies have suggested that smaller islands have higher nest survival than do larger islands because of lower predation rates (Brzeziński et al. 2018, Ringelman et al. 2012) and higher resource availability due to fewer competitors (Lachman 2019, Owen and Pierce 2013). Nesting substrate has been found to be an important predictor variable for Black Skimmer nest survival (Matthews 1995), with lower nest survival on dark substrate and substrate without shell (Mallach and Leberg 1999). Nesting substrate has been found to be an important variable for predicting nest site selection for wading birds, with greater selection for *Salix* (Chastant et al. 2017) and *Phragmites* (Parsons 2003). Nest survival for wading birds varied by species, with Tricolored Heron and Reddish Egret having higher survival in shrub and herbaceous substrates and lower survival in tree substrates (Fig. 7, Fig. 9; see below), and Great Egret having higher survival in herbaceous and trees substrates, and lower survival in shrub substrates (Fig. 8).

Through our species-focused GLM models we found that variation in nest survival for the Great Egret and Reddish Egret was related to stage of nesting, island size, and nest substrate type (Table 6 and Table 7). Great Egret were found to have higher survival on medium and large islands, and higher survival for nests in herbaceous substrate followed by tree, and shrub, respectively (Fig. 8). In contrast, the Reddish Egret was found to have higher survival on small islands, and higher survival for nests in tree substrate followed by shrub and herbaceous, respectively (Fig. 9). Nest survival of Tricolored Heron was found to be related to stage of nesting and island size (Table 5). Nest survival was highest on small islands, and higher for nests in shrub, herbaceous, and tree substrates, respectively (Fig. 7).

Conclusions and Recommendations

This study shows that our study species on the Texas coast had relatively high productivity compared to other studies. However, we also showed that among our focal species, the lowest values were consistently for the Reddish Egret and Black Skimmer, two species of special management concern. Our results support the management focus on these two species and suggest there is something different about the ecology of these species relative to the others that nest sympatrically in their colonies. Our anecdotal observations of human disturbance as a possible cause of nest failure open the possibility that maybe these two species are more susceptible to human disturbances than are other species. Likewise, the effects of island size on productivity parameters supports the increasing focus of coastal managers on rehabilitating coastal colony islands. This habitat is key to maintaining the relatively high productivity that coastal birds in Texas experienced in 2023. Finally, the effects of nest substrate type on productivity parameters identified a knowledge gap in understanding the vegetation dynamics and succession on colony islands. There is very little information on how to maintain or achieve particular mixes of succession habitat on islands that are the key to maintain a diverse breeding waterbird community.

Tables

Table 1. Waterbird rookery islands included in the Rookery Island for Productivity Waterbird Species Project. Coordinates are in WGS84 Coordinate System.

Colony	Coordinates	
Shamrock Island	27.75801	-97.17144
Pita Island / Humbolt Channel - L	27.602784	-97.286915
Pita Island / Humbolt Channel - B	27.592643	-97.264529
Pita Island / Humbolt Channel - D	27.595394	-97.270506
Marker 103-117 Spoil (NM 207-221) - A	27.285477	-97.404962
Chester Island (Sundown Island)	28.451493	-96.346714
Mouth of Chocolate Bayou Peninsula	28.583043	-96.608634
Lavaca Spoil - A	28.617176	-96.562664
Lavaca Spoil - B	28.6142	-96.56245
Lavaca Spoil - C	28.609905	-96.562492
Lavaca Spoil - D	28.607004	-96.562106
Lavaca Spoil - E	28.599477	-96.562022
Dickinson Bay Island - A	29.468202	-94.945394
Dickinson Bay Island - B	29.4669	-94.941932
West Bay Bird Island - A	29.095172	-95.14143
West Bay Bird Island - B	29.098013	-95.141294
North Deer	29.286742	-94.924148
Down Deer Island	29.290685	-94.926992
South Baffin Bay Island - B	27.243424	-97.414599
South Baffin Bay Island - A	27.246876	-97.41406

Table 2. Variables used to test hypotheses regarding the degree to which environmental, colony, and nest site variables influence productivity.

Explanatory Variable	Description
Substrate Type	Whether a substrate a nest is constructed in is classified as woody, herbaceous, shrub, or ground
Stage of Nesting (SN)	Whether a nest is in the Nest Building (NB), Incubation (I), Nestling (N), or Post Fledging (PF) stage
Bird Species (SPP.)	The species of waterbird occupying a nest
Colony Size Class (CSC)	Whether a colony is placed into small, medium, large, and extra-large categories

Table 3. The mean number of observations per a nest, among colonies, for Black Skimmer, Great Egret, Reddish Egret, and Tricolored Heron; SD represents standard deviation; SE represents Standard Error.

Colony	Species	n	Mean Obs. per Nest[a]	SD	SE
Chester	Black Skimmer	44	2.27	0.58	0.09
Chocolate Bayou	Black Skimmer	249	4.19	1.04	0.07
Rabbit	Black Skimmer	43	4.54	0.95	0.15
Rubbersnake	Black Skimmer	22	1.73	0.45	0.09
Shamrock	Black Skimmer	55	4.03	0.99	0.13
Colonies Pooled	Black Skimmer	413	3.89	1.24	0.1
Central Pita	Great Egret	1	3	0	0
Chester	Great Egret	38	4.87	1.73	0.28
Chocolate Bayou	Great Egret	26	5.5	1.55	0.3
Dickinson A	Great Egret	46	4.07	1.54	0.22
East Pita	Great Egret	17	7.71	1.74	0.42
Lavaca Spoil	Great Egret	105	4.9	1.9	0.19
North Deer	Great Egret	33	3.73	1.21	0.21
Pita	Great Egret	61	5.93	1.83	0.23
Rubbersnake	Great Egret	2	2	0	0
Shamrock	Great Egret	37	6.32	1.79	0.29
West Bay Bird Island	Great Egret	36	5.64	1.55	0.26
Colonies Pooled	Great Egret	402	5.2	1.96	0.1
Central Pita	Reddish Egret	21	6.19	1.94	0.42
Chester	Reddish Egret	11	3.73	2.34	0.71
Chocolate Bayou	Reddish Egret	1	6	0	0
East Pita	Reddish Egret	33	4.58	2.4	0.42
North Deer	Reddish Egret	1	3	0	0
Pita	Reddish Egret	36	5.81	2.26	0.38
Rubbersnake	Reddish Egret	1	2	0	0
Shamrock	Reddish Egret	53	5.17	1.67	0.23
West Bay Bird Island	Reddish Egret	10	5.8	0.87	0.28
Colonies Pooled	Reddish Egret	167	5.23	2.13	0.17
Central Pita	Tricolored Heron	20	5.7	1.82	0.41
Chester	Tricolored Heron	53	5.26	1.84	0.25
Chocolate Bayou	Tricolored Heron	17	5	1.46	0.35
Dickinson A	Tricolored Heron	76	5.71	1.58	0.18
East Pita	Tricolored Heron	8	5.13	1.76	0.43
Lavaca Spoil	Tricolored Heron	72	5.54	1.62	0.19
North Deer	Tricolored Heron	33	5.55	1.83	0.32
Pita	Tricolored Heron	19	6.58	1.31	0.3
Shamrock	Tricolored Heron	44	5.39	1.81	0.27
West Bay Bird Island	Tricolored Heron	54	5.54	2.05	0.28
Colonies Pooled	Tricolored Heron	396	5.55	1.77	0.09
Colonies Pooled	Species Spooled	1378	4.91	1.85	0.15

[a] Mean Obs. Per Nest is the mean number of surveys in which nests of a species were detected by colony and all colonies pooled.

Table 4. Factors affecting nest survival of Reddish Egret, Tricolored Heron, Great Egret, and Black Skimmer along the Texas Coast, USA, 2023.

Model	AIC_c	W_i	Number of Parameters	Delta
Fate ~ Island Area Class[a] + Nest Stage[b]	3183.7	0	2	82.6
Fate ~ Island Area Class + Nest Stage + Substrate Type[c]	3120.9	0	3	19.73
Fate ~ Island Area Class + Species[d] + Nest Stage	3103.1	0.276	3	1.93
Fate ~ Island Area Class + Species + Nest Stage + Substrate Type	3101.1	0.724	4	0

[a]Island Area Class denotes the size of a waterbird colony placed into small (< 10,000 m^2), medium (10,000 – 50,000 m^2), large (50,000 – 100,000 m^2), and extra-large (> 100,000 m^2) categories.
[b]Stage allows for independent estimation of the Incubation and Nestling Nest Stages.
[c]Substrate Type denotes if a nest was constructed on herbaceous, shrub, tree, ground, white sand, or dark sand substrate.
[d]Species denotes whether a nest belongs to a Tricolored Heron, Reddish Egret, Great Egret, or Black Skimmer.

Table 5. Factors affecting nest survival of Tricolored Heron along the Texas Coast, USA, 2023.

Model	AIC_c	W_i	Number of Parameters	Delta
Fate ~ Island Area Class + Nest Stage	772.2	0.295	2	1.74
Fate ~ Island Area Class + Nest Stage + Substrate Type	770.5	0.705	3	0

Table 6. Factors affecting nest survival of Reddish Egret along the Texas Coast, USA, 2023.

Model	AIC_c	W_i	Number of Parameters	Delta
Fate ~ Island Area Class + Nest Stage	405.3	0.021	2	7.65
Fate ~ Island Area Class + Nest Stage + Substrate Type	397.6	0.979	3	0

Table 7. Factors affecting nest survival of Great Egret along the Texas Coast, USA, 2023.

Model	AIC_c	W_i	Number of Parameters	Delta
Fate ~ Island Area Class + Nest Stage	854.4	0.008	2	9.73
Fate ~ Island Area Class + Nest Stage + Substrate Type	844.6	0.992	3	0

Figures

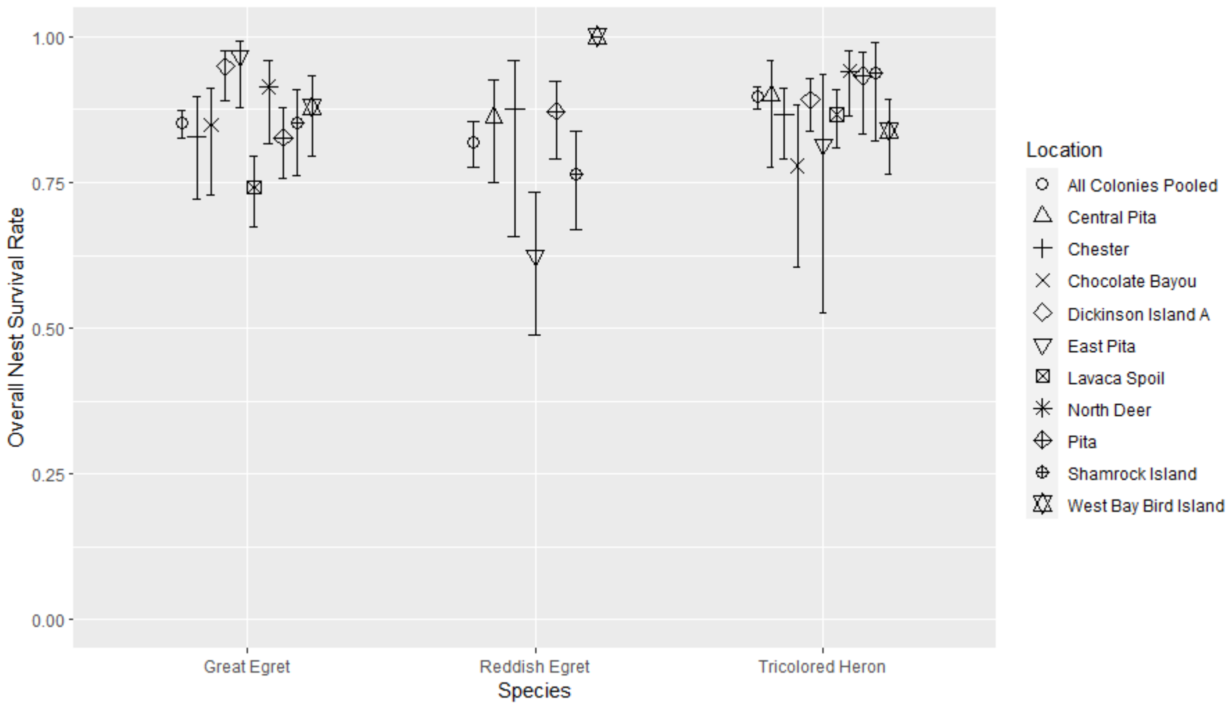

Figure 1. Overall nest survival rate (± 95% CI) of nests for three waterbird species (Great Egret, Reddish Egret, Tricolored Heron), across nest stages, among individual colonies, and across all colonies (all colonies pooled).

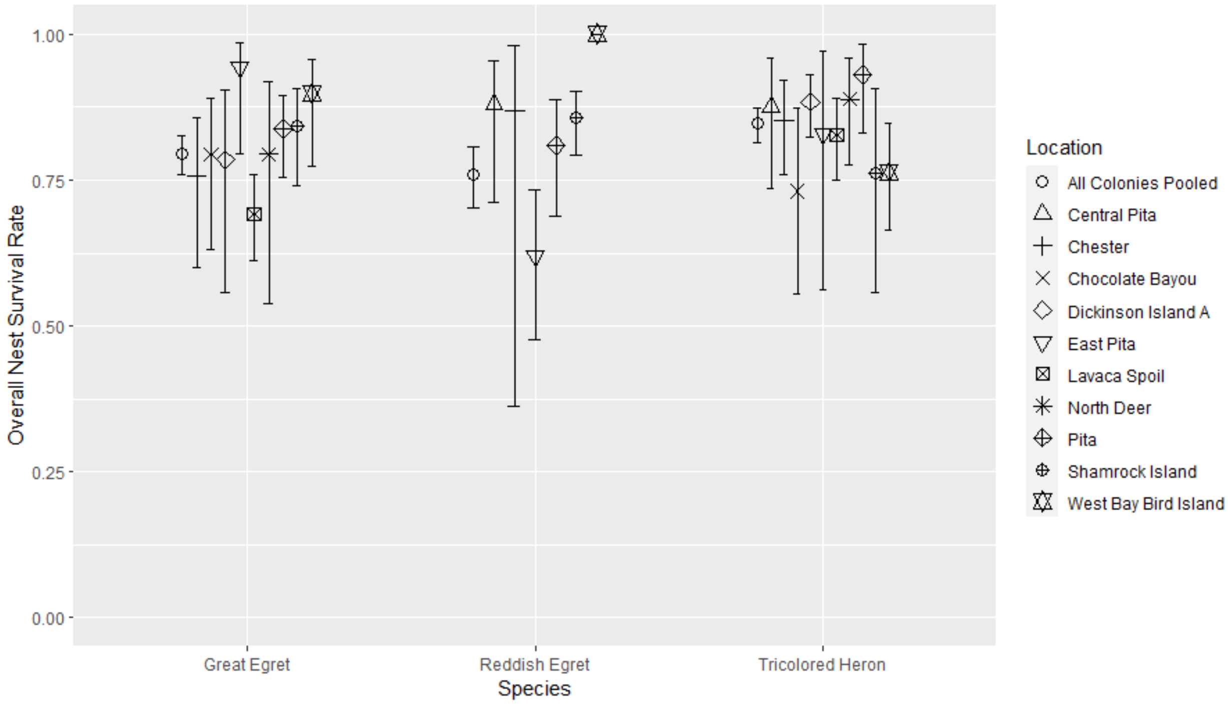

Figure 2. Overall nest survival rate (± 95% CI) of nests for three waterbird species (Great Egret, Reddish Egret, and Tricolored Heron) during the incubation period, among individual colonies, and across all colonies (all colonies pooled).

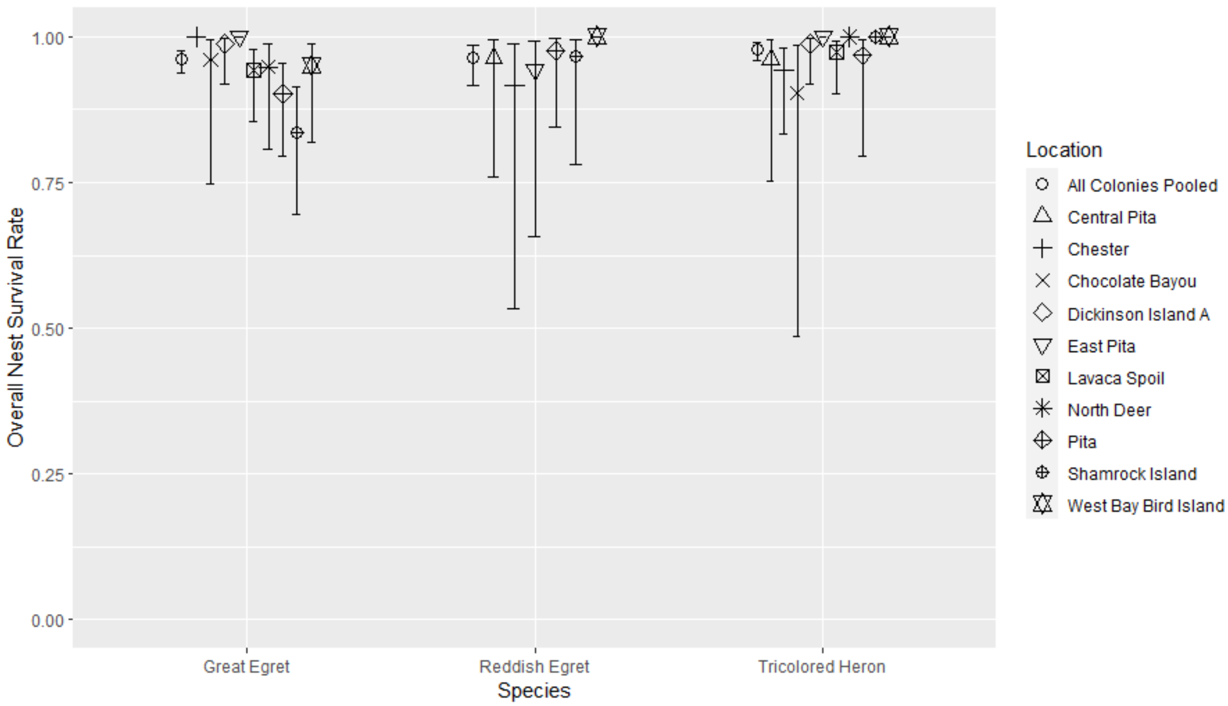

Figure 3. Overall nest survival rate (± 95% CI) of nests for three waterbird species (Great Egret, Reddish Egret, Tricolored Heron) during the nestling period, among individual colonies, and across all colonies (all colonies pooled).

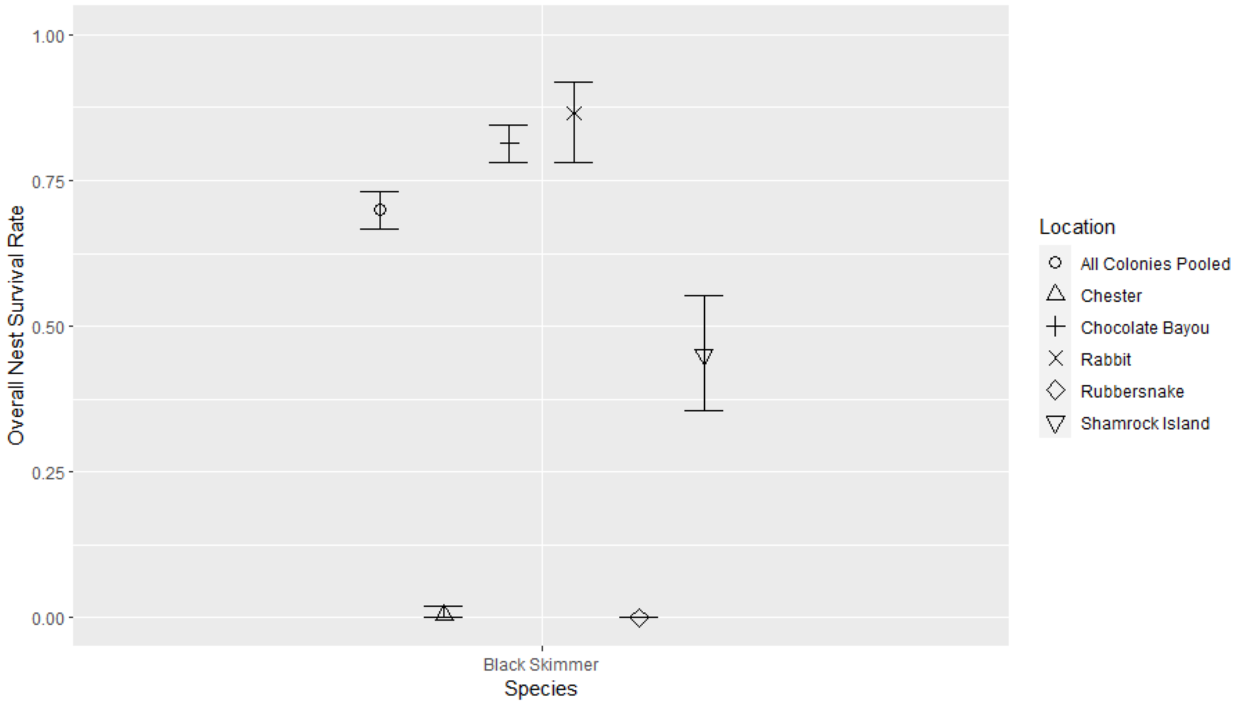

Figure 4. Overall nest survival rate (± 95% CI) of Black Simmer nests, across nest stages, among individual colonies, and across all colonies (All Colonies Pooled).

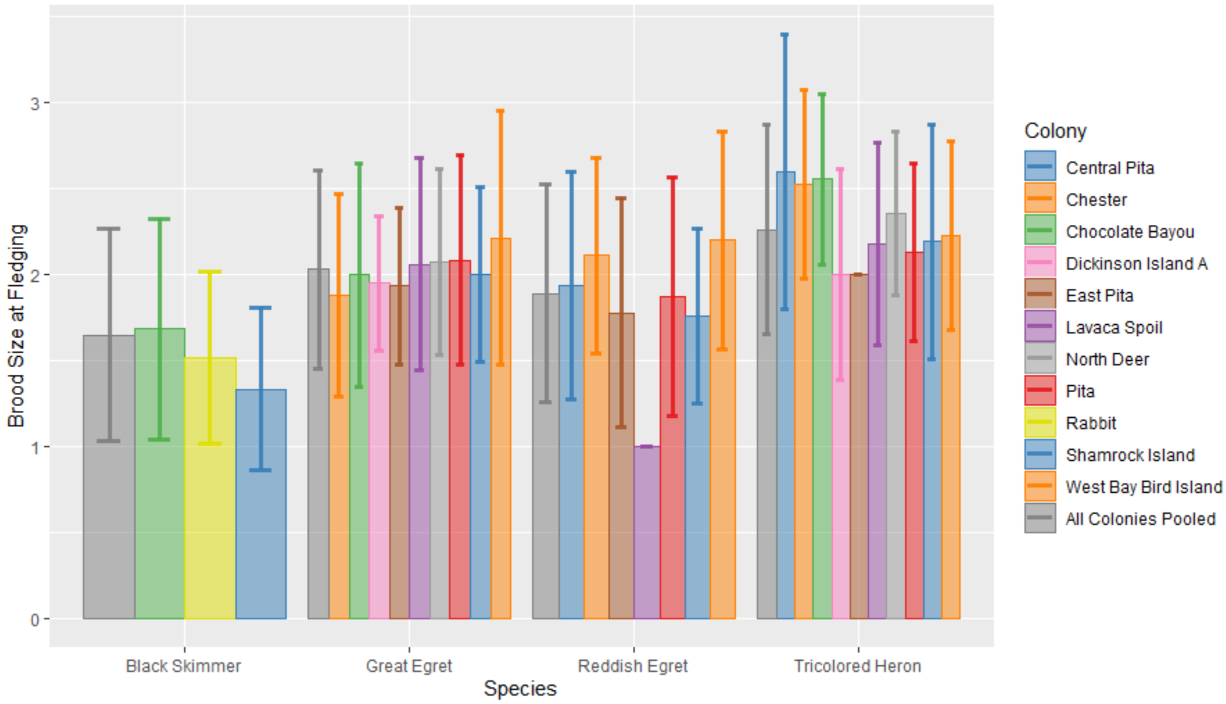

Figure 5. Mean Brood size at Fledging (± SD) of nests for four waterbird species (Black Skimmer, Great Egret, Reddish Egret, Tricolored Heron) among individual colonies; mean (± SD) brood size at fledging of nests for Black Skimmer; mean (± SD) brood size at fledging of nests for Reddish Egret; mean (± SD) brood size at fledging of nests for Tricolored Heron.

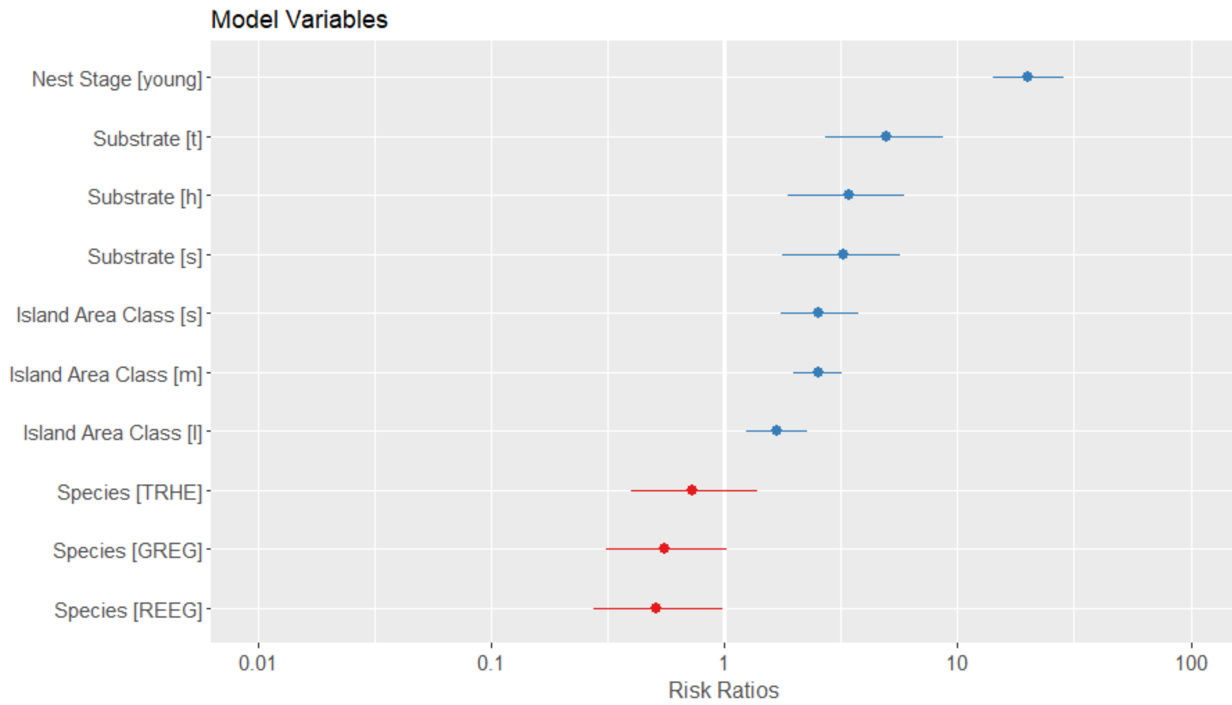

Figure 6. Standardized Regression Coefficients (β) (± 95% CI) for the top fitting GLM of waterbird nest survival across all species and colonies pooled. Variables are placed in descending order of their effect on the response variable (nest survival). Model terms include (Nest_Stage[young]) Nestling Nest Stage, (Substrate [t]) nest constructed on a tree, (Substrate [h]) nest constructed on a herbaceous plant, (Substrate [s]) nest constructed on a shrub, (Island_Area_Class[s]) islands with an area < 10,000 m^2, (Island_Area_Class[m]) islands with an area between 10,000 – 25,000 m^2, (Island_Area_Class[l]) islands with an area between 25,000 – 50,000 m^2, (Species[TRHE]) Tricolored Heron, (Species[GREG]) Great Egret, and (Species[REEG]) Reddish Egret.

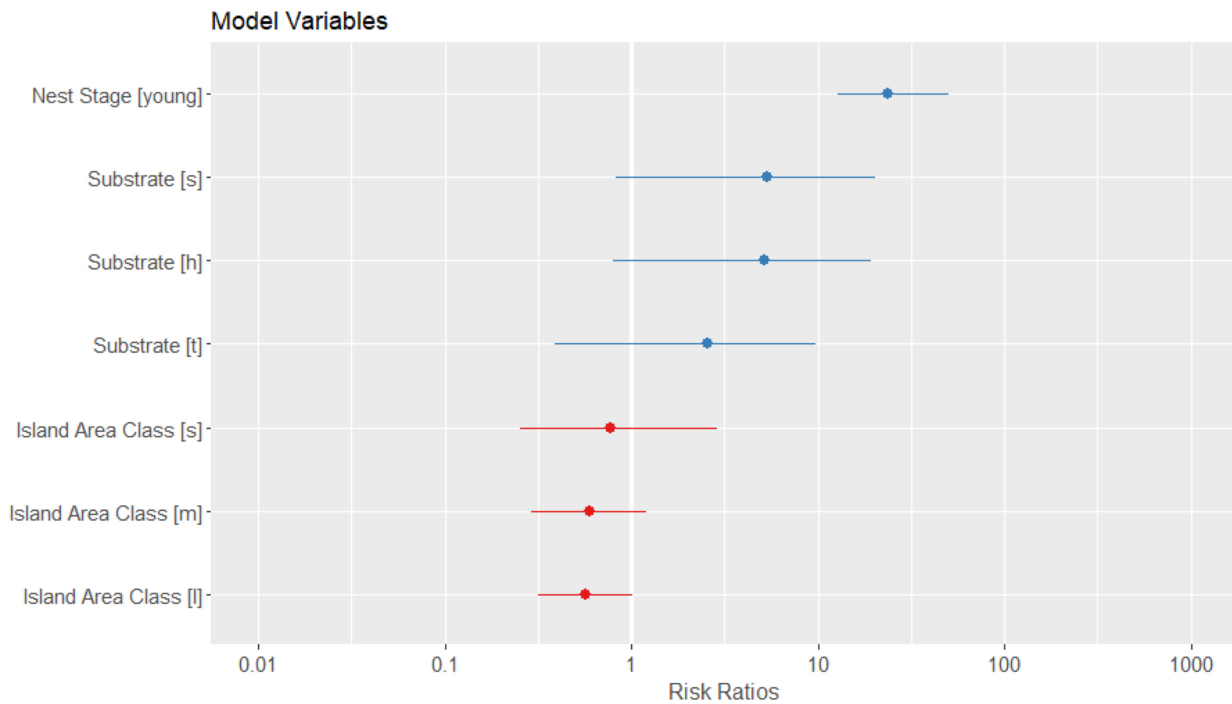

Figure 7. Standardized Regression Coefficients (β) (± 95% CI) for model averaged GLMs (AICc < 2.0) for the top fitting GLM model of Tricolored Heron nest survival, across colonies. All variables are placed in descending order of their effect on the response variable (survival). Model terms include: (Nest_Stage[young]) Nestling Nest Stage, (Substrate [t]) nest constructed on a tree, (Substrate [s]) nest constructed on a shrub, (Island_Area_Class[s]) islands with an area < 10,000 m^2, (Island_Area_Class[m]) islands with an area between 10,000 – 25,000 m^2, (Island_Area_Class[l]) islands with an area between 25,000 – 50,000 m^2.

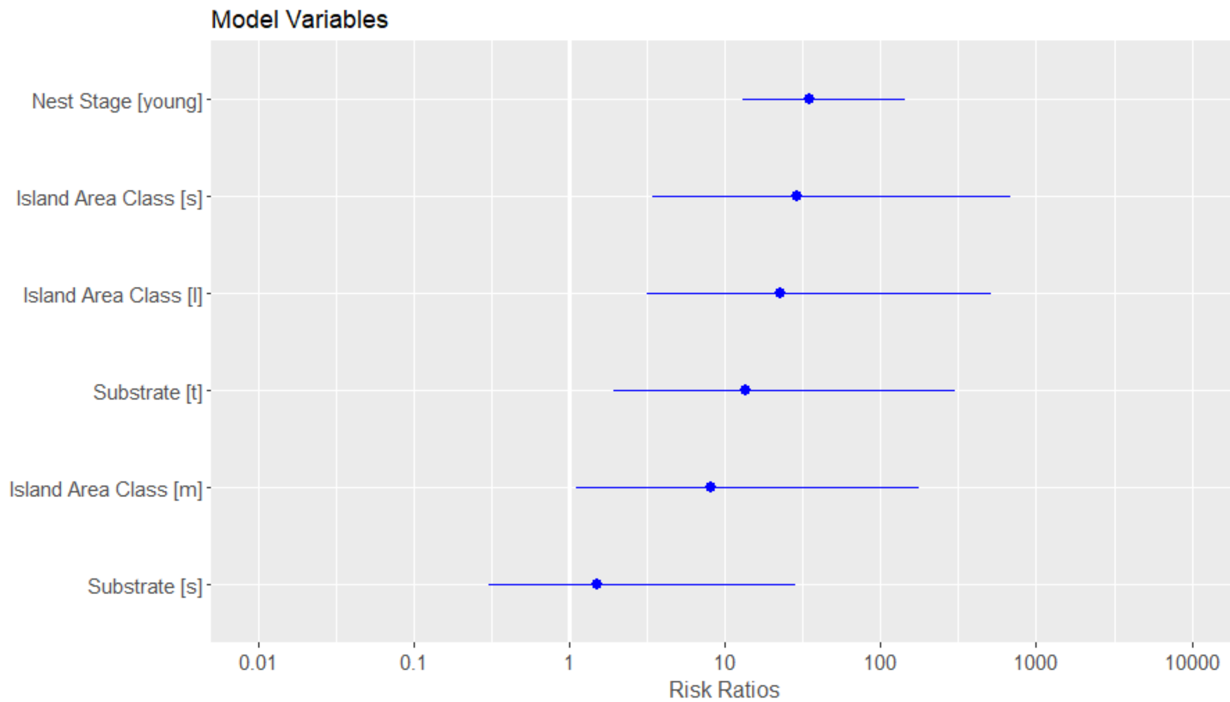

Figure 8. Standardized Regression Coefficients (β) (± 95% CI) for the top fitting GLM of Reddish Egret nest survival, across colonies. All variables are placed in in descending order of their effect on the response variable (survival). Model terms include: (Nest_Stage[young]) Nestling Nest Stage, (Substrate [t]) nest constructed on a tree, (Substrate [s]) nest constructed on a shrub, (Island_Area_Class[s]) islands with an area < 10,000 m^2, (Island_Area_Class[m]) islands with an area between 10,000 – 25,000 m^2, (Island_Area_Class[l]) islands with an area between 25,000 – 50,000 m^2.

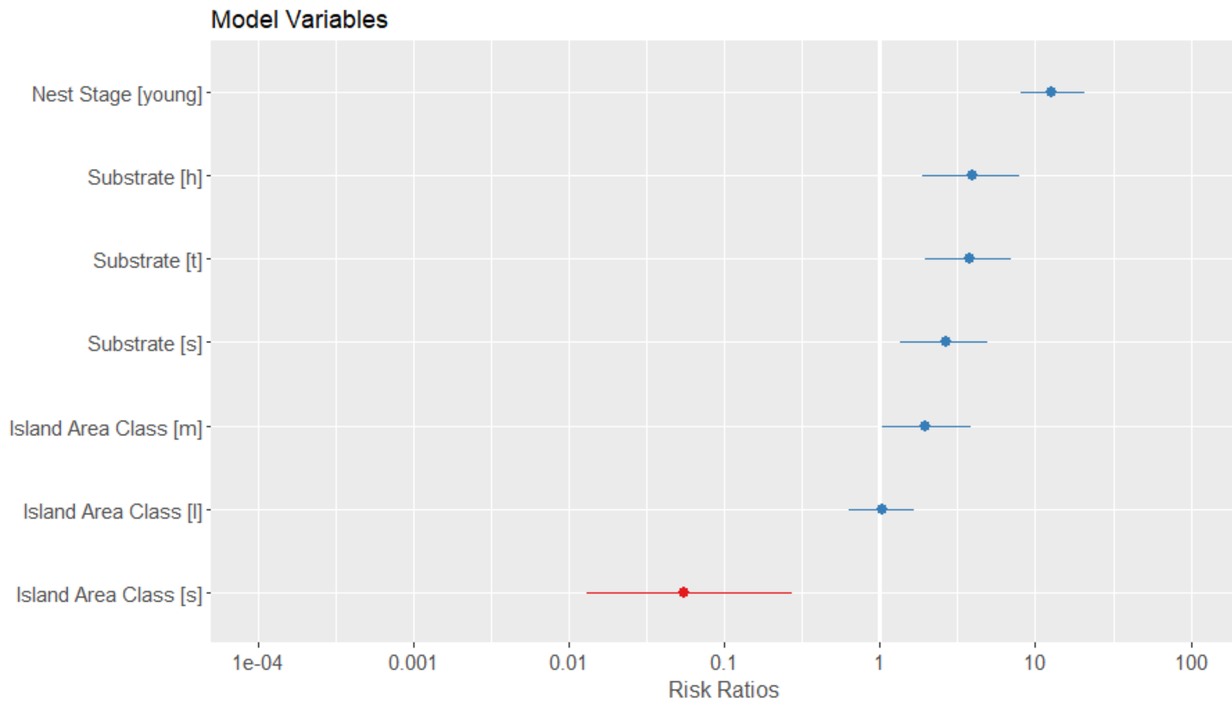

Figure 9. Standardized Regression Coefficients (β) (± 95% CI) for the top fitting GLM of Great Egret nest survival, across colonies. All variables are placed in in descending order of their effect on the response variable (survival). Model terms include: (Nest_Stage[young]) Nestling Nest Stage, (Substrate [t]) nest constructed on a tree, (Substrate [h]) nest constructed on a herbaceous plant, (Substrate [s]) nest constructed on a shrub, (Island_Area_Class[s]) islands with an area < 10,000 m^2, (Island_Area_Class[m]) islands with an area between 10,000 – 25,000 m^2, (Island_Area_Class[l]) islands with an area between 25,000 – 50,000 m^2.

Literature Cited

Baranski, M., and M. Cook. (2016). South Florida Wading Bird Report. South Florida Water Management District, West Palm Beach, USA.

Brooks, G. L., Sanders, F. J., Gerard, P. D., and P. G. R. Jodice. (2014). Daily survival rate for nests of Black Skimmers from a core breeding area of the southeastern USA. The Wilson Journal of Ornithology 126:443-450.

Brzeziński, M., Chibowski, P., Gornia, J., Górecki, G., and A. Zalewski. (2018). Spatio-temporal variation in nesting success of colonial waterbirds under the impact of a non-native invasive predator. Oecologia 188:1037-1047.

Chaney, A. H., and G. W. Blacklock. (2005). Colonial Waterbird and Rookery Island Management Plan. Coastal Bend Bays & Estuaries Program, Corpus Christi, TX.

Chastant, J. E., Petersen, M. L., and D. E. Gawlik. (2017). Nesting substrate and water-level fluctuations influence wading bird nesting patterns in a large shallow eutrophic lake. Hydrobiologia 788:371-383.

Collins, S. A., Selman, W., Green. M. C., and W. T. Strong. (2021). Reproductive ecology and nest success of Reddish Egret (*Egretta rufescens*) on a natural marsh island in southwestern Louisiana, USA. Waterbirds 44:1-12.

Dinsmore, S. J. (2008). Black Skimmer nest survival in Mississippi. Waterbirds 31:24-29.

Erwin, R. M. (1977). Black Skimmer breeding ecology and behavior. The Auk 94:709-717.

Frederick, P. C., and M. W. Collopy. (1989a). Researcher disturbance in colonies of wading birds: effects of frequency of visit and egg-marking on reproductive parameters. Colonial Waterbirds 12:152-157.

Frederick, P. C., & Collopy, M. W. (1989b). Nesting success of five ciconiiform species in relation to water conditions in the Florida Everglades. The Auk 106:625-634.

Frederick, P. C. (1993). Wading bird nesting success in the water conservation areas of the Everglades, 1993. Report for the U.S. Army Corps of Engineers, Jacksonville, FL.

Frederick, P. C., Spalding, M. G., and G. V. N. Powell. (1993). Evaluating methods to measure nestling survival in Tricolored Herons. Journal of Wildlife Management 57:34-41.

Gao, D. (2020). Bird Rookeries (GLO). Texas General Land Office. Accessed 2024. http://tinyurl.com/TXrookeriesmap

Harrison, X. A., Donaldson, L., Correa-Cano, M. E., Evans, J., Fisher, D. N., Goodwin, C. E. D., Robinson, B. S., Hodgson, D. J., and R. Inger. (2018). A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 6:e4794.

Herring, G., Gawlik, D. E., Cook, M. I., and J. M. Beerens. (2010). Sensitivity of nesting Great Egrets (*Ardea alba*) and White Ibises (*Eudocimus albus*) to reduced prey availability. The Auk 127:660-670.

Holderby, Z., Simper, W., Geary, B., and M. C. Green. (2012). Potential factors affecting nest initiation date, clutch size, and nest success in the plumage dimorphic Reddish Egret. Waterbirds 35: 437-442.

Lachman, D. A. (2019). Behavioral and environmental factors affecting nest site selection and nest survival in a colonial nesting waterbird. Master's thesis. University of Idaho, Moscow, USA.

Mallach, T. J., and P. L. Leberg. (1999). Use of dredged material substrates by nesting terns and Black Skimmers. Journal of Wildlife Management 63:137-146.

Matthews, C. D. (1995). Effects of substrate on hatching success in Black Skimmers, *Rhynchops niger*, at the Hampton Roads Bridge-Tunnel, Hampton, Virginia. Dissertation. College of William & Mary, Williamsburg, USA.

McInnes, A. J. (2011). Reproductive performance of Great Egrets (*Ardea alba*) at High Island, Texas. Master's Thesis. Texas A&M University, College Station, USA.

Neinavaz, E., Barati, A., Brown, J. L., Etezadifar, F., and B. Emami. (2013). Effects of nest characteristics and Black Rat *Rattus rattus* on daily survival rates of Great Egret *Ardea alba* nests in mangrove forest in the Hara Biosphere Reserve, the Persian Gulf. Wildlife Biology 19:240-247.

Owen, T. M., and A. R. Pierce. (2013). Hatching success and nest site characteristics of Black Skimmer (*Rhynchops niger*) on the Isles Dernieres Barrier Island Refuge, Louisiana. Waterbirds 36:342-347.

Parsons, K. C., Schmidt, S. R., and A. C. Matz. (2001). Regional patterns of wading bird productivity in northeastern U.S. estuaries. Waterbirds 24:323-330.

Parsons, K. C. (2003). Reproductive success of wading birds using *Phragmites* marsh and upland nesting habitats. Estuaries 26:596-601.

Parsons, K. C., and T.L. Master. (2020). Snowy Egret (*Egretta thula*), version 1.0. Birds of the World (ed. Poole, A. F., and F. B. Gill). Cornell Lab of Ornithology, Ithaca, USA.

Ringelman K. M., Eadie, J. M., and Ackerman, J. T. (2012). Density-dependent nest predation in waterfowl: the relative importance of nest density versus nest dispersion. Oecologia 169:695-702.

Sardà-Palomera, F., Bota, G., Viñolo, C., Pallarés, O., Sazatornil, V., Brotons, L., and S. Gomáriz. (2011). Fine-scale bird monitoring from light unmanned aircraft systems. Ibis 154:177-183.

Shaffer, T. L. (2004). A unified approach to analyzing nest success. Ornithology 121:526-240.

Ritenour, K., King, S. L., Collins, S., and M. D. Kaller. (2022). Factors affecting nest success of colonial nesting waterbirds in southwest Louisiana. E

Wiese, J. H. (1976). Courtship and pair formation in the Great Egret. The Auk 93:709-724.