NEST SITE SELECTION OF AMERICAN OYSTERCATCHERS (*HAEMATOPUS PALLIATUS*) ON THE UPPER TEXAS COAST WITH COMMENTS ON FIELD SEXING TECHNIQUES

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

ABSTRACT

The American Oystercatcher, hereafter oystercatcher, is a shorebird species of high conservation concern that requires intertidal shellfish beds for breeding and wintering habitat. Considerable attention has been paid to obtaining site-specific productivity data and determining factors contributing to their reproductive success on the Atlantic coast; however no data exists for populations along the Texas coast. I monitored breeding oystercatchers on the upper Texas coast and discovered 58 and 83 nests during 2011 and 2012, respectively. During 2011 productivity was 0.78 based on 36 chicks fledging from 46 breeding pairs. During 2012, productivity was 0.21 based on 10 chicks fledging from 48 breeding pairs. Oystercatchers in Texas nested in 4 types locations: 52% of nests (n=74) were on emergent shell island, 37% (n=53) on the periphery of colonial waterbird rookery islands, 6% on shell spits connected to the mainland at low tide (n=8), and 5% on the mainland (n=7). The most common plants at oystercatcher nests on the Texas coast were sea purselane (*Sesuvium portulacastrum*), Carolina wolfberry (*Lycium carolinianum*), saltwort (*Batis maritima*), and sea ox eye daisy (*Borrichia frutescens*). I investigated nest site selection at two scales, microhabitat at the nest site and landscape scale at the presumed territory. I measured the same variables at nests and at randomly selected unused locations within the study area and then performed logistic regression to determine if oystercatchers were selecting nest

locations non-randomly. Fifteen percent of nests surveyed were on shell substrate with no vegetation whereas overall, nests averaged 30% live vegetative cover. There was no significant difference between the amount of live vegetation (df= 147, r^2<0.001, p=0.874) or shell (df= 147, r^2=0.002, p=0.602) at nest locations and random locations. There was also no significant effect of the amount of vegetation (df= 73, r^2=0.093, p=0.078) or shell (df= 73, r^2=0.093, p=0.220) at nest locations on the likelihood of fledging.

At the landscape scale, I used a geographic information system (GIS) to measure elevation, the percent shell, rock or sand substance within territories, and distance to nearest oyster reefs, beach access points, urban landcover and the intracoastal waterway. I used these relationships to parameterize a model that predicts the presence of oystercatcher nests on the Texas coast. The best-supported logistic regression model illustrated that oystercatchers prefer nesting closer to oyster reefs, urban landcover, and with more shell substrate (*w*=0.44, r^2=0.80). I found a relationship between oystercatcher nest site selection and habitat features, demonstrating that both land formations and urbanization influence oystercatcher nests, and further spatial analysis is suggested. My results suggests that landscape scale spatial analysis of the structure of coastal bays can inform land managers regarding projects aimed at restoring and developing dredge islands and oyster reefs in an effort to support and stabilize oystercatcher populations in rapidly changing coastal ecosystems.

CHAPTER I. NEST SITE SELECTION

Figure 1. Adult American Oystercatcher (*Haematopus palliatus*) painted by Alexandra Munters

One of the central questions in ecology is how organisms select their breeding habitat. It is generally thought that habitat selection is a hierarchical process with selection occurring at multiple spatial scales (Johnson 1980; Hutto 1985; Jones 2001). It is difficult to explore habitat selection by experimentally manipulating habitat, so most studies rely on observational and correlative approaches. In correlative studies, habitat selection is often inferred by comparing measurements of habitat variables taken at used sites with randomly or systematically selected non-use sites. Thus, disproportionate use of particular habitat features is thought to illustrate habitat preference (Jones 2001).

Because habitat selection by individuals determines population-level regional distribution (Sergio *et al.* 2004), I sought to determine which habitat features influence breeding site selection by American Oystercatchers (*Haematopus palliatus*). The primary management option proposed for population stabilization and recovery of American Oystercatchers is to identify the most important habitats and food resources used by oystercatchers both temporally and spatially throughout the species range (Schulte *et al.* 2010).

The American Oystercatcher, hereafter oystercatcher, is a shorebird in the order Charadriiformes that depends on oyster reefs throughout its annual cycle. Oystercatchers use their characteristically long, orange to red bill to feed on bivalves and other marine invertebrates by rapid stabbing to sever the adductor muscle that holds bivalves together (American Oystercatcher Working Group 2012). The narrow feeding niche of oystercatchers restricts their habitat to coastal islands and salt marshes that support intertidal shellfish beds (Tomkins 1954). This species is representative of the issues affecting the vulnerability of all shorebird species, including habitat loss and alteration due to increasing development and recreation, pollution, human disturbance, expanding predator populations, and rising sea-levels resulting from global climate change eliminating small islands for nesting and roosting (American Oystercatcher Working Group 2012; Davis *et al.* 2001; Erwin *et al.* 2001). These threats have led to declines in oystercatcher populations, and subsequent listing as a Species of High Concern in the United States Shorebird Conservation Plan (Brown *et al.* 2001), and as a species of highest regional priority in the Southeast Shorebird Conservation Plan (Hunter *et al.* 2000). Biologists throughout the species' range are monitoring populations and collecting standardized reproductive metrics in order to model demography on multiple scales. Prior to this study, oystercatchers had not yet been monitored in Texas, although Brown *et al.* (2001) reported from aerial surveys a wintering population estimate for the Texas Gulf Coast of 477 ± 78 individuals, which is approximately 5% of the total population of the species in the United States.

Due to their conservation status, recognition of a lack of data for key demographic parameters, and the species' potential as an important bio-indicator of coastal ecosystem health, oystercatchers have attracted research interest on the Atlantic coast of the United States in recent years (Brown *et al.* 2001; Schulte *et al.* 2010). During the breeding season, breeding pairs are highly territorial. Territory sizes range from a few meters of beach shoreline on river island habitat to almost a square kilometer of beach shoreline on barrier island habitat in North Carolina (McGowan *et al.* 2005); nesting density usually increases as habitat becomes more limited (Lauro *et al.* 1992). Oystercatcher nesting habitat ranges from sand and shell beaches, emergent oyster shell spits, dunes, salt marsh, and occasionally rock or other surfaces. Typically, nests are placed non-randomly in areas with little to no vegetation, farther from water, and at higher elevations although substrate is highly variable and dependent upon site type (Lauro and Burger 1989; Toland 1992; Wilke *et al.* 2005; Traut *et al.* 2006).

For oystercatchers, the availability of quality foraging habitat is critical for reproductive success and for chick survival because oystercatchers hatch semi-precocial young that rely on parents for food prior to and after fledging (American Oystercatcher Working Group 2012; Safriel *et al.* 1996; Thibault *et al.* 2010). Generally, food availability often influences the capacity of breeding birds to invest in offspring (e.g.

clutch size, offspring size, nesting attempts; Martin 1987, 1995; Arcese and Smith 1988; Holmes *et al.* 1992; Bolton *et al.* 1993; Nagy and Holmes 2004; Zanette *et al.* 2006; Chalfoun and Martin 2007), whereas nest predation risk primarily influences the probability of nest success. In habitat selection strategies, individuals are differentially affected by these various environmental influences on reproductive success, which may allow alternative strategies to achieve the same net fitness.

As a first step to understanding the species' breeding ecology in Texas, I sought to understand the relationship between coastal habitat and breeding oystercatchers. I studied the distribution of oystercatcher nests with respect to geomorphological features and human infrastructure. This study explores the process of habitat selection for oystercatchers on the Texas Gulf coast at two spatial scales: 1) second order selection, which determines the home range or territory size and, 2) third order selection, which pertains to the usage made of various habitat components within the home range, in this case the nest site (Johnson 1980). The objectives of this study were to determine the types of habitat where oystercatchers nest in Texas and to obtain site-specific productivity data for the birds in Texas.

Additionally, I sought to identify microhabitat and landscape scale predictors of oystercatcher nest site selection. I predicted that oystercatchers would non-randomly select nest locations with less vegetation and more shell substrate. Oystercatchers tend to nest at higher densities and fledge more chicks when they have direct access to foraging areas away from predators (Nol 1989, McGowan *et al.* 2005). Therefore, at the landscape scale, I predicted that oystercatcher nests would be positively associated with habitat at higher elevations and with more shell substrate, positively associated with closer proximity to oyster reefs, and negatively associated with human infrastructure.

METHODS

I monitored oystercatcher nests in East Matagorda Bay, Matagorda County and the western portion of Galveston Bay, Galveston County, on the Texas Gulf coast, USA. The Texas Gulf Coast consists of a network of barrier islands and coastal bays, with bay shoreline covering over 5,300 kilometers (Texas General Land Office). Based on initial surveys and known oystercatcher habitat in other parts of the species' range (American Oystercatcher Working Group *et al.* 2012), an area of potential habitat was delineated for each site. Oyster (*Crassostrea virginica*) reefs are common within the shallow bays of the Texas coast and provide foraging habitat for oystercatchers. Potential nesting habitat included shell rakes, spoil islands, barrier islands, and the mainland. The delineation of this area allowed for comparison between used and unused nest sites within all potential breeding habitats available on a landscape scale.

Between February and July 2011 and 2012, I conducted boat-based surveys of potential breeding habitat on the upper Texas coast. Initial searches by boat and by foot throughout the study sites were for territorial pairs of oystercatchers. Territorial pairs are birds that have selected a territory for nesting, creating scrapes and engaging in agonistic behavior with other oystercatchers.

I monitored breeding pairs of oystercatchers from February-July 2011 and February-July 2012. When birds were located, I determined if a nest was present by observing from offshore and, if needed, by approaching the birds on foot. If I observed breeding behavior (e.g. incubating bird, paired birds, copulation, piping and alarm calls), I carefully searched the area for nests, limiting search time to 15 minutes to minimize disturbance. Males and females of each focal pair were captured with whoosh nets, decoy-noose traps, and box traps at their first territory or nest of the season (McGowan and Simons 2005). Whoosh netting attempts were limited to less than 1 hour whenever possible to minimize disturbance. Once captured, I banded individuals with stainless steel bands and color-coded darvic bands for individual identification in the field. I placed identification leg bands on each bird in accordance with US Geological Survey bird banding laboratory protocols for permanent identification. I measured and recorded the wing chord, bill length, tarsus length and mass of captured individuals. All linear measurements were made using standard calipers and wing rules. Mass was measured with a 1,000 g hanging spring scale.

Following the initial survey, I revisited areas where pairs were observed and captured, but no nest was found in approximately 5-7 days. I located nests within each study site using behavioral observations and systematic searches. I flagged all nests approximately 5-10 meters from the nest and recorded locations with a handheld GPS. I monitored nests every 5-7 days to determine nest fate and sources of failure. I also banded chicks with stainless steel bands and color-coded darvic bands prior to fledging (~35 days of age). Nests were considered successful when ≥1 chick fledged and unsuccessful when the nest produced no fledged chicks. I made every effort to determine the reason for nest loss, including identifying predator tracks in the immediate vicinity of the nest, signs of storm overwash, or signs of human disturbance.

Nest Microhabitat

Upon discovery of nests, or during subsequent nest visits, I used a 1 m^2 PVC quadrat to survey the percentage of live vegetation using 5% increments surrounding the nests, limiting survey time to approximately 10 minutes to minimize nest disturbance. I determined the percent composition of live vegetation, dead vegetation, bare ground, shell, or rock. I also photographed nests with unidentified vegetation with the quadrat in place for later identification of plant species composition. To test if oystercatcher nest sites are placed at random or selectively placed at the micro-habitat scale, I compared the percent cover at actual nest locations to percent cover at a corresponding number of random locations. Random locations were 3, 5, or 7 meters from the nest. The direction (N,E,S,W) and distance of the plot was randomly assigned prior to sampling.

Habitat data from the sampling plots at occupied and randomly-selected locations were averaged and compared to assess selection at the microhabitat scale. I performed logistic regression to determine if the composition of nest microhabitat differed between used and random (unused) locations. Additionally, I used logistic regression to determine if the composition of microhabitat at the nest influenced the probability of fledging success. All statistical analyses were performed within the software package R (R Core Development Team 2008).

Landscape Scale

I also sought to determine nest site selection at landscape scale. I created a GIS layer of nest locations and plotted the locations in ArcMap (version 9.3.1; ESRI, Redlands, CA). This analysis used nests only from West Bay and the southwestern portion of Galveston Bay (Figure 2). The total number of nest locations included two breeding seasons and re-nests for multiple pairs of oystercatchers. To prevent violations of independence and to accurately reflect selection at the territory scale, repeat nests between seasons or within season by pairs on the same territories were excluded from the landscape scale analysis.

I additionally created a layer of an equal number of random locations within the delineated available habitat for oystercatcher nests. Potential available habitat was delineated in ArcMap with a polygon around the entire surveyed boundaries of the study area. I created a 150 meter buffer around all bodies of water within the study area to create a layer representing all habitat which oystercatchers might select for a nest site. The 150 meter buffer size was chosen as the upper limit of distance from water of a nest because the farthest observed oystercatcher nest from water was 128 meters. I used the random point generator in Hawth's Tools extension of ArcGIS (Beyer 2004) to generate random locations within the buffered layer of "available" habitat. I then overlaid nest locations and random locations on multiple geomorphological and human infrastructure layers. These included polygon layers (Texas General Land Office, TGLO) of oyster reefs, the intracoastal waterway, beach access points, and the 2006 National Land Cover Database (NLCD). The NLCD consists of remote sensing imagery data classified into distinct cover types on a 30 x 30 m pixel grid and formatted as GIS files (Homer *et al.* 2004). From the NLCD data I created 3 additional habitat variables. I created a layer of urban development by combining low, medium, and high density developed land, I also created a separate layer representative of all of water in the available habitat. A third layer representing sand shell spit habitat was identical to the NLCD category "barren."

For detailed definitions of the NLCD cover types, see Appendix 1. All of the aforementioned landscape characteristics have the potential to influence oystercatcher nest site selection, hatch, or fledge success. See Table 2 for detailed information on the selection of the landscape characteristics for the analysis.

To obtain values of habitat parameters for nest and random locations, I conducted spatial analyses in ArcMap. I used the Euclidean distance tool to generate raster layers in which each pixel was a distance value from the nearest incidence of the habitat feature of interest. I then used the point-intersect tool in the Hawth's Tools extension to calculate the distance of each nest and random location from the habitat feature. Additionally, I used the thematic raster summary in Hawth's Tools to quantify the percent of sand, shell, or rock substrate within a 50 m area around each of the nest and random locations. The thematic raster summary calculates how much available nesting substrate existed in each presumed breeding territory.

To evaluate the relationship between oystercatcher nest site selection and the landscape data derived from GIS, I performed statistical analyses using software package R. I first performed paired t-tests to determine if differences existed between habitat variables at nest and random locations. I then used logistic regression to model nest site selection. If a habitat variable was not a significant predictor by itself of oystercatcher nest site selection, it was excluded from further analysis. Prior to model selection, I conducted a correlation analysis on all independent variables to assess multicollinearity among the data. I did not include highly correlated variables ($r \geq 0.60$ or $r \leq -0.60$) to avoid inflated standard errors of partial regression coefficients (Zar 1998).

I then combined independent variables that were significant predictors of nest site selection and not strongly correlated to employ information theoretic model selection to rank candidate models by small-sample size corrected Akaike's Information Criterion (AIC_c) and associated Akaike weights (Burnham and Anderson 2002). I ranked all candidate models according to their AIC_c value (Burnham and Anderson 2002) and the best-supported model was the model with the smallest AIC_c value. I additionally calculated Nagelkerke's r^2 to assess the best-supported model's fit to the data. Because only one model received substantial support, parameter estimates and standard errors were calculated for only the best-supported model.

RESULTS

During the 2011 breeding season I monitored 58 nesting attempts, 46 of those nests were first nesting attempts of the season and 12 were re-nests. During 2011, productivity was 0.78 based on 36 chicks fledged from 46 breeding pairs. During 2012, I monitored 83 nesting attempts, 49 of those nests were first nesting attempts of the season and 34 were re-nesting. During 2012, productivity was 0.21 based on 10 chicks fledged from 48 breeding pairs. Clutches were initiated between 25 February and 25 June during 2011 and 2012. Oystercatchers in Texas (2011-2012) nested in 4 main locations: on the periphery of colonial waterbird rookery islands (37%, n=53), on emergent shell islands (52%, n=74), on shell spits connected to the mainland at low tide (6%, n=8), and on the mainland (5%, n=7).

Microhabitat Analysis

I surveyed 74 oystercatcher nest sites and an equal number of random locations within breeding pair territories during the breeding season in 2012 to determine microhabitat composition. Fifteen percent of nests surveyed were on shell substrate with no vegetation while overall, nests averaged 30% live vegetative cover. The most common plants at oystercatcher nests on the Texas coast were Sea purselane (*Sesuvium portulacastrum*), Carolina wolfberry (*Lycium carolinianum*), saltwort (*Batis maritima*), and sea ox eye daisy (*Borrichia frutescens*).

There was no significant difference between the amount of live vegetation (df= 148, r^2<0.001, p=0.874) or shell (df= 148, r^2=0.0024, p=0.602) at nest locations and random locations. I also found no significant effect of the amount of vegetation (df= 74, r^2=0.093, p=0.078) or shell (df= 74, r^2=0.093, p=0.220) at nest locations on the likelihood of fledging.

Landscape Analysis

Although I monitored a total of 141 nests over the two breeding seasons, only 67 nests were used for the landscape scale analysis. These nests represented the first selection of a breeding territory within our study period. All other nests were re-nesting during the same season or the following year within the same territory and would therefore violate assumptions of independence. All of the variables, except for distance to beach access points differed between nests and random locations (Table 3). Univariate logistic regression models also supported this as distance to beach access points was not a significant predictor of nest site selection, so it was excluded from further analysis. None of the remaining variables were significantly correlated with one another (Table 4), so they were all used to build candidate models.

I tested nine candidate models, including a null model and a model containing all of the remaining habitat variables. The best-supported model (w = 0.44) included the variables of distance to oyster reefs, urban landcover, and percent of shell substrate (Table 5). For the best-supported model the Nagelkerke r^2 = 0.8, which indicated a good fit of the model to the data. Oystercatchers nested more closely to oyster reefs, and in areas with more shell substrate, and more closely to urban landcover. Parameter estimates from the best-supported model indicated a positive relationship between oystercatcher nest site selection and the amount of available shell/sand/rock substrate. Parameter estimates for distance to oyster reefs and urban landcover illustrated negative relationships, demonstrating that oystercatchers are less likely to place their nests farther away from those habitat features. Initial exploration of univariate logisitic regression models found that none of the measured landscape-scale habitat variables had a significant effect on the likelihood of fledging, so I did not conduct further model selection analysis.

DISCUSSION

Because of their conservation status, recognition of a lack of data for key demographic parameters, and the species' potential as an important bio-indicator of coastal ecosystem health, oystercatchers have attracted research interest on the Atlantic coast of the United States in recent years (Brown *et al.* 2001; Schulte *et al.* 2010). This research represents the first attempt to examine the breeding ecology of oystercatchers in

Texas. My results confirm that, similar to other parts of the species' range, there is annual variability in productivity. The variability in productivity I observed emphasizes the importance of consistent monitoring, while site to site differences in hatching and fledging success emphasize the need for thorough studies conducted on young from hatching to fledging across different sites (Davis *et al.* 2001).

I found that oystercatchers nest in similar locations in Texas as they do in other parts of their range, although all of our nests were on the bayside of Galveston Island and on islands in the bay; there were few nests on the barrier island itself and no nests were located on the Gulf side. Although the nests I monitored appeared to be placed non-randomly in areas with little to no vegetation, farther from water, and at higher elevations as other research has shown (Lauro and Burger 1989; Toland 1992; Wilke *et al.* 2005; Traut *et al.* 2006), I did not find significant differences between the nest and random sites within the presumed territories. Future studies should explore other elements of the nest microhabitat such as orientation of the island, slope leading up to the nest scrape, and the potential effects from other waterbird species nesting on the same island.

The majority of nests I examined were on islands within the Galveston bay estuary and not on the mainland or densely populated barrier island itself, which supports the finding on the Atlantic coast that oystercatchers are shifting habitat from outer beaches to shell rakes, wrack deposits, sand ridges (NC Wildlife Resources Commission, unpublished; Wilke *et al.* 2005), dredge spoil islands (McGowan *et al.* 2005), or even rooftops in Florida (Douglass *et al.* 2001). Wilke *et al.* (2005) suggested that this shift may be providing relief from increasingly less suitable habitat. The results of my landscape scale analysis demonstrate that oyster reefs and the presence of shell substrate for nesting are important factors in determining how oystercatchers select their nest sites.

Food availability often influences the capacity of breeding birds to invest in offspring (e.g. clutch size, offspring size, nesting attempts; Martin 1987, 1995; Arcese and Smith 1988; Holmes *et al.* 1992; Bolton *et al.* 1993; Nagy and Holmes 2004; Zanette *et al.* 2006; Chalfoun and Martin 2007). Additionally, oystercatchers select habitat with direct access to foraging areas away from predators, which positively influences their reproductive success (McGowan *et al.* 2005). However, this species is very territorial during the breeding season and there is variation in the extent of the territory that adult oystercatchers defend; breeding pairs of oystercatchers can defend feeding territories adjacent to breeding territories, or may defend adjacent territories plus separate feeding territories (Cadman 1979) similar to European Oystercatchers ("resident/leapfrog model"; (Heppleston 1972; Safriel 1985; Ens *et al.* 1992). In this model, parents that traveled a great distance to forage (i.e. leapfrog nests) had less time to attend the nesting territory and spent more time transporting food compared to parents that foraged in areas adjacent to nest sites (i.e. resident nests).

Thibault *et al.* (2010), investigating the resident/leapfrog model for American oystercatchers in South Carolina, found that a difference in the spatial distribution of food to nest sites between two study areas, and the subsequent difference between foraging behaviors is the mechanism underlying the relationship they observed between attendance and brood success. Parental attendance and chick survival were higher in the site with a greater extent of shellfish reefs, which may ultimately affect reproductive success. Similarly, Nol (1989) found that fledging success of oystercatchers in Virginia was positively related to the size of the foraging grounds and the proximity of the foraging grounds to the nesting territory.

Although in this research I took into account the distance from nests to the closest oyster reef, I did not take into account the area of the reef, the depth of the reef during tidal cycles, or explore a metric of how many breeding pairs could be supported per reef area. Therefore, it remains unclear how individual habitat selection influences overall fitness. Future research on Texas's population of oystercatchers could further explore the spatial relationship of breeding territory, foraging territory, and available foraging habitat, and to determine how this relationship mediates parents' effort of provisioning chicks. This would require rigorously monitoring oystercatcher behavior to determine nesting territory size and foraging territory size, and to overlay these territory boundaries on a detailed representation of the available tidal flats and oyster bed coverage.

An unexpected but interesting aspect of our best-supported model is that the parameter estimates for distance to urban landcover suggests a positive relationship between oystercatcher nests and urban development. Human disturbance has been shown to affect the productivity of Black, European, and American Oystercatchers by causing nest abandonment or reduced time spent incubating and foraging, resulting in lower reproductive success (Hockey 1987; Novick 1996; Davis 1999; Leseberg *et al.* 2000; Verhulst *et al.* 2001; McGowan and Simons 2006; Sabine *et al*. 2008). It is plausible that the combination of low, medium, and high density developed landcover into one "urban" category does not accurately reflect how urbanization and human activity might be influencing the birds. It should also be considered that habitat selection does not always positively influence individual fitness, in the case of ecological traps in rapidly changing landscapes (Battin 2004). Furthermore, this study was conducted in a highly urbanized area and no oystercatcher habitat may exist that is not in close proximity to urban landcover. Galveston Bay accounts for the second largest recreational boating industry in the U.S., the second largest port in the U.S., and makes up 40% of the nation's petrochemical production. Unfortunately, coastal development, shoreline erosion, and land subsidence around the bay have resulted in substantial habitat loss (Gilmer *et al.* 2012). These changes have made Galveston Bay increasingly vulnerable to changes in sea level rise and storm surge inundations (Weiss *et al.* 2011). Although the Gulf Coast side of Galveston Island is protected by a seawall, the natural sediment transport system has been altered causing greater downdrift erosion (Feagin *et al.* 2005), and other shoreline measures like geotextile tubes have been implemented to minimize erosion.

Oystercatchers on the upper Texas coast occupy a habitat that is rapidly changing, and the amount of habitat for nesting, roosting, and foraging is at risk to sea-level rise resulting from global climate change. Sea level is predicted to rise between 0.18 m and 0.59 m by 2100 (IPCC 2007; Rahmstorf *et al.* 2007). About half of the total 142 nests observed in this study were located just above sea level, so any change in sea level would result in considerable breeding habitat loss for the species. There are oystercatchers in Galveston Bay now, but how long can that habitat support their population, and how long will that habitat persist?

Since the publication of the original Birds of North American species account in 1994, nearly 30 papers have been published on this species (American Oystercatcher Working Group et al. 2012). Future studies should combine statistical and geospatial analysis techniques with already collected site-specific productivity and survival data to articulate a more precise prediction of how sea level rise would change available habitat and alter the viability of American Oystercatcher populations. For example, the Sea Level Rise Affecting Marshes Model 6 (SLAMM 6) is a spatial model that incorporates different kinds of data to determine how cover types would change and shift inland under rising sea levels and can predict alterations in available habitat for certain species. Aiello-Lammens *et al.* (2011) combined a SLAMM 6 model and a population viability analysis (PVA) to determine how changes in habitat due to rising sea levels would influence the likelihood of Snowy Plover extinction on the Gulf Coast of Florida. They found that sea level rise would cause a decline in suitable habitat and carrying capacity for snowy plovers along the Gulf Coast of Florida, thereby increasing the risk of population decline and subsequent extinction.

Multiple management options have been proposed in the American Oystercatcher species' conservation plan (Schulte *et al.* 2010), including working with the Army Corps of Engineers to create isolated emergent dredge deposit sites while maintaining intertidal shoals and natural inlet function. Members of the working group can use the results of landscape scale spatial analysis to explore how to embark upon restoration projects. Before undertaking restoration projects however, more research is necessary to explore the causes of oystercatcher nest failure in Texas and the relationship between habitat selection and reproductive success to determine if the selection of particular habitats is influencing an individual's fitness within the Texas oystercatcher population.

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Table 1.

Sample means ($\bar{x}$) and standard deviations (SD) for variables measured at American oystercatcher (*Haematopus palliatus*) microhabitat nest plots (n=74) and random plots (n=74), upper Texas coast, 2012. An asterisk (*) indicates that data from nest sites differed significantly from data at random sites (two sample *t*-tests, $P < 0.05$).

	Nest Plots		Random Plots		*P*-value
	$\bar{\chi}$	±SD	$\bar{\chi}$	±SD	
Live Vegetation	29.97%	26.12%	30.84%	40.25%	0.843
Shell	64.34%	28.97%	61.18%	43.68%	0.517

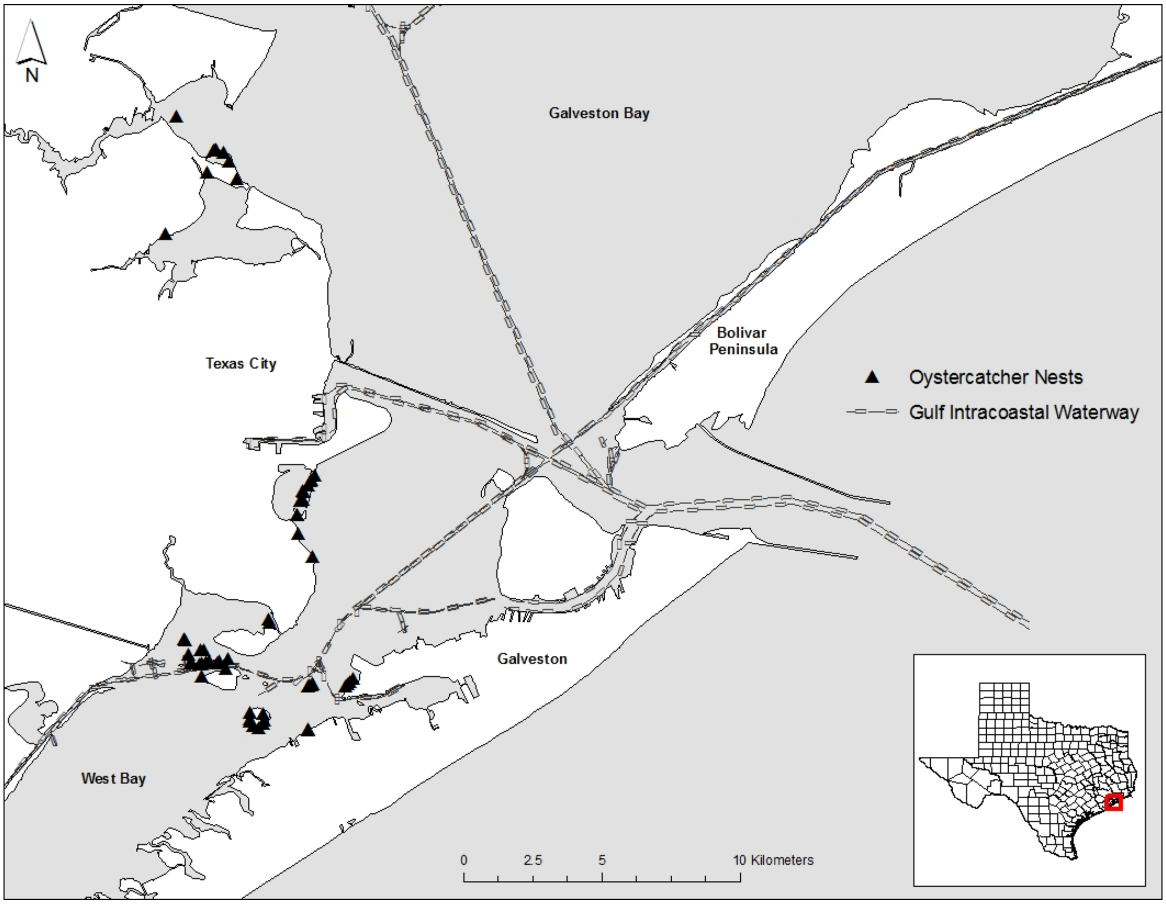

Figure 2. Nest locations of American Oystercatchers on the upper Texas coast, 2011 and 2012

Table 2.

Description of habitat variables used for modeling habitat relationships of American oystercatchers (*Haematopus palliatus*) on the upper Texas coast, 2011 and 2012.

Landscape data acquired in GIS analysis	Unit	Abbreviation	Potential Influence
Distance to oyster reefs	m	Oyster	Species distribution limited by the availability of intertidal shellfish beds for foraging (American Oystercatcher Working Group *et al.* 2012; Tomkins 1954)
Substrate (shell, rock, sand)	%	Shell	Nest scrapes in sandy substrate, shell rakes, or tide rack in marsh habitat (Lauro and Burger 1989; Winn 2000)
Distance to beach access points	m	Beach	Disturbance from human recreational activity and elevated predation from predators augmented by human activities (Sabine *et al.* 2008; Schulte *et al.* 2010)
Elevation	m	Elevation	Nests typically on slightly elevated sites, low nests very susceptible to tidal flooding (American Oystercatcher Working Group *et al.* 2012; Virzi 2008)
Distance to intracoastal waterway	m	GIWW	Disturbance from recreational and commercial boat traffic, increased potential of nest overwash from boat wakes (McGowan and Simons 2006; Thibault 2008)
Distance to Urban Landcover	m	Urban	Lower nest survival and higher chick mortality in sites with high human disturbance (McGowan and Simons 2006; Sabine *et al.* 2008)

Table 3.

Sample means ($\bar{x}$) and standard deviations (SD) for landscape-scale variables measured at American Oystercatcher (*Haematopus palliatus*) nests (n=67) and random locations (n=67), upper Texas coast, 2011 and 2012. An asterisk (*) indicates that data from nest sites differed significantly from data at random sites (two sample *t*-tests, $P < 0.05$).

	Nests		Random		*P*-value
Variable	$\bar{\chi}$	±SD	$\bar{\chi}$	±SD	
Oyster (m)	619.20	554.37	2965.94	2231.87	<0.001*
GIWW (m)	1914.67	2472.54	2242.27	2748.61	0.011*
Beach (m)	9685.30	4929.19	7926.73	5329.36	0.041
Urban (m)	1262.34	473.14	2540.71	2380.15	<0.001*
Elevation (m)	1.29	0.56	2242.27	2748.61	0.008*
Shell substrate (%)	0.60	0.32	0.11	0.28	<0.001*

Table 4.

Correlation coefficients (r) for covariates used in nest-site selection of American oystercatchers (*Haematopus palliatus*) on the upper Texas coast, 2011 and 2012. Covariates with |r|>0.60 were considered to be highly correlated.

Covariate	Oyster	Intrac	Urban	Shell	Elevation
Oyster	1.00	0.535	0.052	-0.366	0.433
Intrac		1.00	-0.070	-0.256	0.160
Urban			1.00	-0.299	-0.029
Shell				1.00	-0.230
Elevation					1.00

Table 5.

Summary of model selection for logistic regression models predicting influence of habitat attributes on nest site selection of American oystercatchers (*Haematopus palliatus*) on the upper Texas coast, 2011 and 2012. Covariates investigated were % shell substrate, distance to oyster reefs, distance to urban landcover, distance to intracoastal waterway, and elevation, and no influence of a covariate (null). Model selection statistics: delta values of Akaike's information criterion corrected for small sample size (ΔAICc0, Akaike weight (*w*), number of parameters, and twice the log likelihood (-2LL). Sample size was 134. Best-supported model is in bold.

Model	ΔAICc	*w*	Number of parameters	-2LL
Shell + Oyster + Urban	**0**	**0.44**	**4**	**62.01**
Shell+ Oyster + Urban + Elevation + Intrac	1.26	0.23	6	58.79
Shell+ Oyster + Urban + Elevation	1.35	0.22	5	61.14
Shell + Oyster + Intrac	4.22	0.05	4	66.23
Shell + Oyster	4.87	0.04	3	69.05
Shell + Oyster + Elevation	6.71	0.02	4	68.72
Oyster	43.2	<0.001	2	109.51
Shell	56.94	<0.001	2	123.25
null	117.37	<0.001	1	185.76

Table 6.

Parameter estimates (β) and standard errors from the best-supported logistic regression model for predicting nest-site selection by American Oystercatchers on the upper Texas coast, 2011 and 2012.

Parameter	β	SE
Distance to oyster reefs	-0.0019	0.0004
% shell substrate	4.9681	1.2182
Distance to urban landcover	-0.0005	0.0002

CHAPTER II: FIELD SEXING TECHNIQUES FOR AMERICAN OYSTERCATCHERS

For species of conservation concern, life history details such as differences between the sexes in resource partitioning to chicks, site fidelity, survivorship, and dispersion, are crucial to creating appropriate recovery plans (Clutton-Brock 1986; Ellegren and Sheldon 1997). However, many shorebirds of the order Charadriiformes are not sexually dimorphic and therefore difficult to sex in the field. American Oystercatchers (*Haematopus palliatus*) are a plumage monomorphic shorebird species that have experienced population declines, and are now listed as a Species of High Concern in the United States Shorebird Conservation Plan (Brown *et al.* 2001). This species demonstrates a life history of paired territorial partnerships in which both sexes share incubation and chick rearing duties. Reliably differentiating the sexes of a pair of territorial oystercatchers without having to collect blood and molecularly sex the birds in the lab would be useful for conservation biologists monitoring this species and studying their territoriality, foraging behavior, and reproductive success.

Although American Oystercatchers are plumage monomorphic, adult females are generally bigger and heavier than adult males (Carlson-Bremer *et al.* 2010). However, in Virginia, South Carolina, and Georgia, there was considerable overlap in weight, bill length, and wing length between males and females (Carlson-Bremer *et al.* 2010). This morphometric overlap can make distinguishing the sex of an adult oystercatcher challenging if only one member of the pair is captured. Another method of sexing adults is checking for cloacal distension immediately following egg-laying. However, this method is only useful if the female is trapped immediately after she has laid eggs.

I sought to shed light on the potential difficulty of sexing adult oystercatchers in the field by examining a feature of American Oystercatchers that they share with other oystercatcher species. A number of oystercatcher species show the presence of iridial depigmentation, or darkened regions within the yellow iris, henceforth termed "eye flecks." In Black Oystercatchers (*Haematopus bachmani*). Guzzetti *et al.* (2008) found the presence of eye flecks in their irises to be a predictor of sex in adult females. Researchers used categories of low, medium, and high eye flecks to classify captured birds in the field. Guzzetti *et al.* (2008) found that for Black Oystercatchers, researchers more frequently correctly identified sex using eye flecks as a diagnostic tool rather than discriminant analysis based on morphological characteristics. Similarly, Kohler *et al.* (2009) found that eye flecks can serve as a reliable indicator of sex for African Black Oystecatchers (*Haematopus moquini*).

I explored the accuracy of determining sex of American Oystercatchers in the field as part of a larger study examining breeding habitat preferences and productivity of the species in Texas. I used morphometric measurements, specifically mass, culmen length, tarsus length, and wing chord, coupled with the presence and severity of eye flecks to sex pairs of oystercatchers in the field. I then used a molecular method to determine sex to confirm the reliability of these diagnostic tools in my assignment of sex in the field to captured birds.

METHODS

I monitored breeding pairs of oystercatchers on the upper Texas coast between February and July, 2011 and 2012. I captured males and females with whoosh nets, decoy-noose traps, and box traps at their first territory or nest of the season (McGowan and Simons 2005). I limited whoosh netting attempts to less than 1 hour whenever possible to minimize disturbance.

Once captured, I banded individuals with stainless steel bands and color-coded darvic bands for individual identification in the field. Identification leg bands were placed on each bird in accordance with US Geological Survey bird banding laboratory protocols for permanent identification. I recorded the wing chord, culmen length, tarsus length and mass of captured individuals. I made all linear measurements using standard calipers and wing rules. I measured mass with a 1,000 g Pesola spring scale. I recorded presence and severity of eye flecks (none, minimal, moderate, severe) and took photographs of the eyes of individuals for further *a posteriori* classification. Based on morphometric measurements and the severity of eye flecks, I assigned sex to both members of captured territorial pairs, with the female as the larger bird with more eye flecks. When only one member of a breeding pair was captured, I used morphometrics and the presence and severity of eye flecks to determine sex. If the amount of eye flecking was indeterminate and the measurements fell in the overlap zone between males and females, then I recorded sex as unknown.

When birds were captured, a maximum of 1 ml of blood was collected by venipuncture of the right brachial vein using a disposable 0.7×25 mm needle and sodium heparinized 3 cc syringe. Samples were immediately aliquoted into 1.5 ml micro centrifuge tubes containing 600 microliters of cell lysis solution. Blood collection tubes were stored in a cooler until transferred into a refrigerator. The whole blood collected was packaged on dry ice and shipped to Oregon State University for genetic determination of sex using polymerase chain reaction (PCR) amplification of the chromo-helicase-DNA binding protein (CHD) gene on avian sex chromosomes Z and W (Zoogen Inc., Davis, California, USA). The PCR product was subjected to electrophoresis through a 2% agaorse gel in 1x TA buffer, and visualized using gel red and UV illumination. The gender of each individual was scored on the basis of the presence (indicates female) or absence of the 110 bp band in the gel following digestion of the PCR product (Fridolfsson and Ellegren 1999).

I used the results of the molecular sex determination to confirm the assignment of sex in the field based on morphometrics and eye flecks. I then examined morphometric and eye fleck differences between the sexes. I imported images of oystercatcher eyes into ImageJ (National Institute of Health, USA), a public domain software program, to quantify the amount of eye flecks. I calculated the area of the iris using the ellipse drawing tool. I then calculated eye fleck area by zooming into the photo and tracing the pixels of black within the iris (See Figure 2). I calculated a proportion for each eye of the eye fleck pixels divided by the total pixels in the iris. To ensure that there was no relationship between the overall size of the bird (mass), and the remaining morphometric measurements I first tested for correlation between the morphometric variables and eye fleck measurements by creating a correlation matrix of r values. I calculated means and standard deviations for each of the variables and t-tests were performed to test for differences between males and females with respect to the proportion of eye flecks, culmen length, tarsus length, wing chord, and body mass.

RESULTS

I captured and sexed molecularly a total of 42 adult oystercatchers. I assigned sex in the field to 34 of the birds captured based on morphometrics and presence and severity of eye flecks. The sex of the remaining 8 birds was left unidentified in the field because of overlap in measurements between the individuals of a captured territorial pair, or only one member of the pair was captured.

The results of the PCR indicated that 18 (43%) were female and 24 (57%) were male. I measured eye flecks using high resolution photographs from 27 of the 42 adults that were molecularly sexed. Twelve (44%) of those birds were female and 15 (56%) were males. A paired t-test indicated that there was no significant difference between the eye fleck proportion in left or right eyes in individual birds ($p=0.85$, $n=27$), so the proportions derived from the left eyes were used for comparison between males and females. The correlation analysis indicated that none of the morphometric variables or eye flecks were significantly correlated (Table 7), so I was able to compare specific morphometric measurements between the sexes. Females had significantly longer culmens than adult males ($P<0.001$) with bill lengths ranging from 85.26-99.6mm, and male culmens ranging from 78.57-95.64mm. Females also had significantly longer wing chords, tarsus lengths, greater mass, and more eye flecks. (Table 8).

DISCUSSION

There was a significant difference between the sexes for all morphometric measurements and amount of eye flecks. Prior to the results of PCR, I used the combination of these indicators in the field to assign sex to the birds before sexing them molecularly and lab results confirmed that my assessments were nearly 100% correct for the birds whose sex I was able to determine in the field.

In Virginia, South Carolina, and Georgia, Carlson-Bremer *et al.* (2010) found considerable overlap in weight, bill length, and wing length between the sexes and concluded that these parameters are unreliable indicators of sex. My results from Texas oystercatchers indicate that all measurements differed significantly between males and females, but I also found a large overlap in morphometric measurements. It was easiest to determine the sex of a breeding pair when I was able to capture both of the birds and could compare their measurements, but more difficult to determine sex if only a single bird was captured whose measurements were close to the overlap between males and females. The results of the molecular sex determination also indicated that one bird I had identified as a male, was actually a female. This is a perplexing finding as this bird's mate was also molecularly sexed to be female. Both members of the pair were captured and I deemed the smaller as a male and larger as a female. The pair has continued to defend breeding and foraging territories and has laid clutches in subsequent breeding seasons and has fledged chicks. This result is unexplained but a contaminated blood sample is the most logical answer. The above results point to the presence of flaws in all manners of sex determination and suggests that a combination of tools be employed.

This research confirms that quantitatively, females have a greater proportion of eye flecks. However, it is not feasible to quantify the amount of eye flecks in the field. Amount of eye flecks can be considered categorically (none, low, medium, severe) in the field and this characteristic can help reliably determine sex when coupled with morphometric measurements.

I present here an exploration of effective methods of sexing American Oystercatchers in the field without the permitting, cost of equipment and personnel, and laboratory knowledge required to molecularly sex the species. Although the origin of eye flecks remains unclear, I conclude that they can be used to assist in reliably sexing adult American Oystercatchers. Noting the presence and severity of eye flecks can also help correctly determine the sex of a captured bird in the event that it is a particularly large male or a particularly small female oystercatcher. Additionally, advances in optical technology, spotting scopes or high-resolution photography could potentially allow for eye flecks to function as a tool for sexing the birds at a distance.

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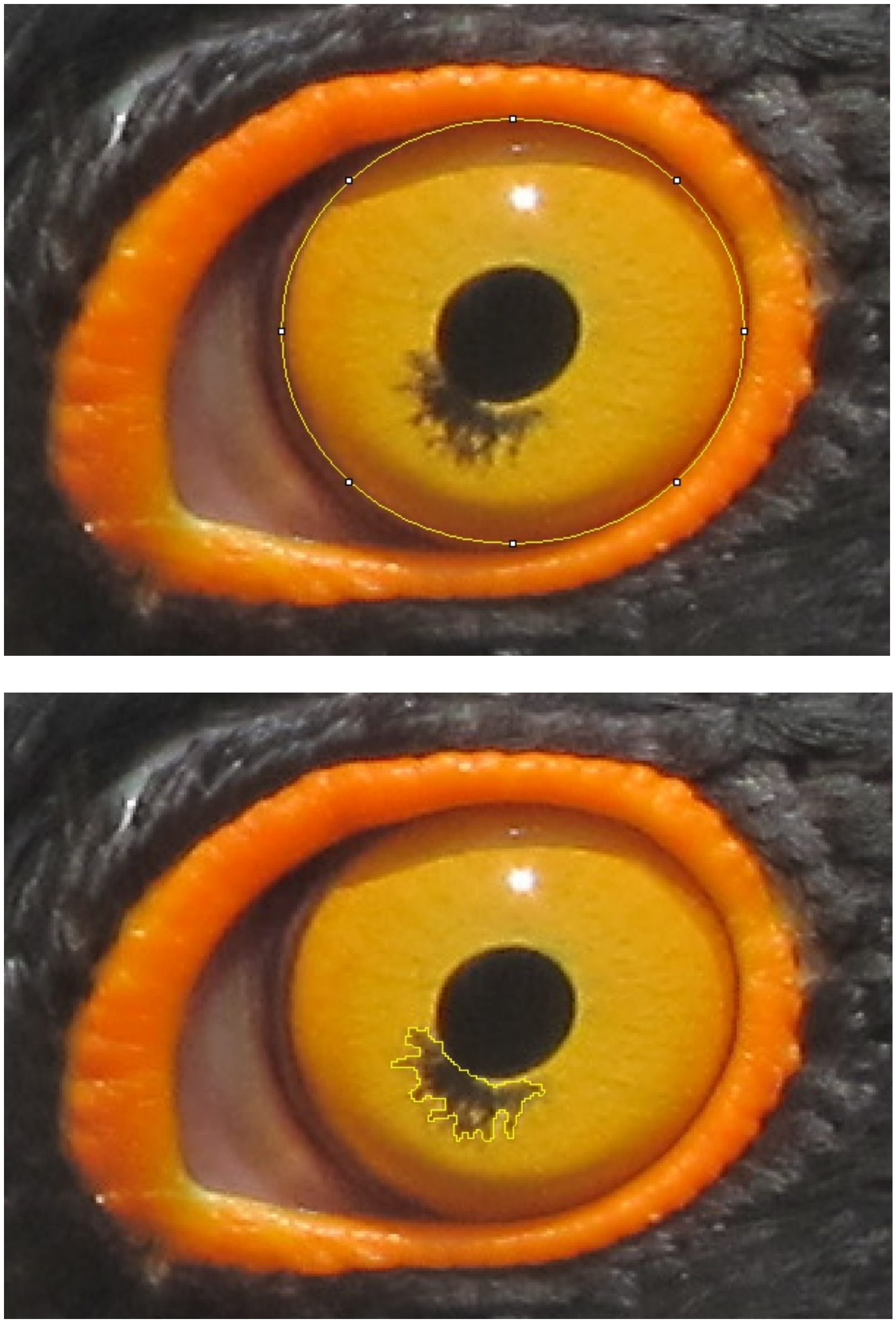

Figure 3.

Photographs depicting how eye fleck proportions were derived from ImageJ. Top photograph illustrates how the total number of pixels in the eye were obtained, while the bottom photograph illustrates how the number of flecked pixels were calculated.

Table 7.

Correlation coefficients (r) for morphometric variables and eye fleck proportions calculated from adult American oystercatchers (*Haematopus palliatus*) (n=27) captured on the upper Texas coast, 2012 and sexed molecularly. Of the 42 birds captured overall for this study, we only used 27 birds for which we had photographic documentation of the eye flecks as well. Covariates with |r|>0.60 were considered to be highly correlated.

Covariate	Wing	Culmen	Tarsus	Weight	Eye Flecks
Wing	1.00	0.42	0.2	0.17	0.16
Culmen		1.00	0.3	0.21	0.16
Tarsus			1.00	0.41	0.35
Weight				1.00	0.29
Eye flecks					1.00

Table 8.

Sample means ($\bar{x}$) and standard deviations (SD) for morphometric variables measured from American oystercatchers (*Haematopus palliatus*) (n=42) captured on the upper Texas coast, 2012 and sexed molecularly. An asterisk (*) indicates that data from females differed significantly from data from males (two sample *t*-tests, $P < 0.05$).

	Female		Male		P-value
	mean	±SD	mean	±SD	
Wing (mm)	264.94	10.22	256.63	6.06	0.003*
Culmen (mm)	93.29	3.25	86.5	4.27	<0.001*
Tarsus (mm)	64.64	2.36	62.62	2.3	0.004*
Weight (g)	693.89	60.01	622.08	43.41	<0.001*
Eye Flecks (%)**	3.5	2	1.4	1.4	0.005*

**N=27 as we only obtained high quality photos of eyes for 27 of the 42 birds captured.

APPENDIX 1.
NLCD 2001 Land Cover Class Definitions http://www.epa.gov/mrlc/definitions.html

Cover Type		Definition
Developed		Areas characterized by a high percentage (30% or greater) of constructed matierals (e.g. asphalt, concrete, buildings, etc).
	Open Space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed setting for recreation, erosion control, or aesthetic purposes.
	Low Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of the total cover. These areas most commonly include single-family housing units.
	Medium Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
	High Intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80-100 percent of the total cover.
Barren		Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little to no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present is more widely spaced and scrubby than in the "green" vegetated categories; lichen cover may be extensive.
	Barren Land (Rock/Sand/Clay)	Barren areas of bedrock, desert pavement, scarps, talus, slides volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
	Unconsolidated shore	Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms representing this class.

APPENDIX 2.
Data acquired in ArcMap and used in logistic regression

Nest	Oyster (m)	Intracoastal (m)	Beach (m)	Urban (m)	Shell (%)	Elevation (m)
UWGalB072	806.04	94.87	7208.95	725.51	0.45	1.53
UWGalB071	306.10	360.56	5545.13	1469.05	1.00	1.69
UWGalB070	208.09	891.85	5214.92	1622.30	0.33	1.37
UWGalB069	850.00	170.29	7870.77	1147.14	1.00	1.52
UWGalB068	134.54	1103.18	4962.12	1469.05	0.00	1.52
UWGalB064	894.71	241.87	8111.19	1297.84	0.88	1.45
UWGalB063	894.71	241.87	8111.19	1297.84	0.88	1.45
UWGalB060	92.20	680.29	5408.81	1791.88	0.60	1.53
UWGalB052	10.00	1480.71	3950.92	1147.14	0.22	1.52
UWGalB050	233.45	978.01	5142.19	1469.05	0.50	1.54
UWGalB048	292.06	363.59	5536.65	1469.05	1.00	1.67
UWGalB047	10.00	1161.08	4776.96	1147.14	0.27	1.52
UWGalB046	126.49	936.22	4893.11	1147.14	0.43	1.53
UWGalB041	1433.77	1843.61	8047.71	324.46	0.43	0.65
UWGalB040	0.00	1445.89	3963.09	1147.14	0.00	1.52
UWGalB039	120.42	1041.39	4805.05	1147.14	0.55	0.00
UWGalB037	395.60	250.00	7504.25	1539.04	0.63	0.00
UWGalB036	773.18	707.11	5738.08	513.01	0.28	1.03
UWGalB034	1084.62	457.06	5413.35	513.01	0.77	0.09
UWGalB033	900.06	608.28	5606.07	513.01	0.53	1.13
UWGalB030	235.37	705.20	5099.19	1337.78	0.00	1.52
UWGalB029	990.05	531.51	5510.08	513.01	0.47	1.28
UWGalB027	320.16	358.05	5553.64	1469.05	1.00	1.71
UWGalB025	886.40	222.04	8123.95	1297.84	0.90	1.53
UWGalB024	962.08	121.66	7543.92	648.92	1.00	0.64
UWGalB021	144.22	335.41	5500.91	1622.30	0.91	1.52
UWGalB019	300.00	368.92	5535.23	1469.05	1.00	1.69
UWGalB018	890.51	231.95	8117.57	1297.84	0.88	1.53
UWGalB017	1656.80	530.85	8912.24	1147.14	0.48	1.22
UWGalB016	922.66	202.24	7756.04	725.51	1.00	0.87
UWGalB015	200.00	319.06	5533.68	1622.30	1.00	1.53
UWGalB014	250.00	372.02	5511.34	1469.05	1.00	1.61
UWGalB013	308.06	374.43	5533.83	1469.05	1.00	1.71
UWGalB012	1504.16	1960.87	8196.20	324.46	0.74	1.42
UWGalB011	1096.36	190.00	7446.48	458.85	0.29	1.25

Nest	Oyster (m)	Intracoastal (m)	Beach (m)	Urban (m)	Shell (%)	Elevation (m)
UWGalB009	1310.34	618.14	8189.88	648.92	0.72	1.34
UWGalB008	872.35	225.61	8102.18	1297.84	0.72	1.52
UWGalB007	870.00	170.29	7780.23	827.21	1.00	2.28
UWGalB006	1010.20	158.11	7560.75	648.92	1.00	1.49
UWGalB004	1352.04	594.81	8301.36	725.51	0.38	1.31
UWGalB003	904.43	90.55	7544.22	827.21	0.99	1.40
UWGalB001	1665.08	540.09	8932.32	1147.14	0.39	1.19
USwanL015	281.78	1200.00	13060.42	1539.04	0.26	2.98
USwanL013	415.93	2101.17	12194.35	1337.78	0.75	0.87
USwanL011	264.76	1400.00	12868.77	1747.27	0.82	2.00
USwanL009	560.09	2660.00	11669.52	827.21	0.40	1.48
USwanL008	482.60	2124.62	12181.25	1337.78	0.52	0.00
USwanL007	407.92	2090.86	12203.36	1337.78	0.84	1.13
USwanL006	354.68	1580.00	12694.11	1849.70	0.89	1.43
USwanL005	257.10	1390.00	12878.08	1747.27	0.77	2.20
USwanL004	440.11	1810.44	12480.36	1539.04	0.00	1.32
USwanL003	415.93	2101.17	12194.35	1337.78	0.75	0.87
USwanL002	550.09	2660.00	11668.36	827.21	0.40	1.75
USwanL001	481.66	2134.60	12171.30	1337.78	0.51	0.00
UMosesL003	3444.78	7968.22	20254.39	1376.56	0.00	0.59
UMosesL001	1002.10	8022.45	19797.50	2471.01	0.00	1.11
UGalB002	472.97	3317.30	11007.04	688.28	0.76	0.00
UGalB001	106.30	2414.00	10130.07	1469.05	0.95	0.00
UDickB010	372.02	7572.42	19943.99	1747.27	0.53	1.44
UDickB008	187.88	7264.23	19613.59	1622.30	0.31	1.43
UDickB007	300.67	7049.69	18727.91	2534.11	0.00	1.30
UDickB006	297.32	7500.03	19893.55	1670.26	0.34	1.45
UDickB005	151.33	7142.81	19298.63	2064.84	0.54	1.13
UDickB004	165.53	7242.69	19601.40	1622.30	0.40	1.46
UDickB002	334.22	7531.30	19914.43	1670.26	0.54	1.44
UDickB001	388.33	7592.13	19961.29	1747.27	0.54	1.44
random	3487.76	28.28	1972.46	1622.30	0.00	0.70
random	4021.80	602.08	2493.87	2164.41	0.34	1.46
random	4671.84	3103.58	5071.59	4707.45	0.00	1.51
random	4047.94	2643.20	4755.72	4383.20	0.00	1.51
random	272.95	1049.95	2881.11	2115.21	0.00	1.48
random	1449.17	908.74	5207.35	4724.19	0.00	1.51
random	3808.73	3297.30	7012.65	3947.21	0.00	1.37
random	1875.23	53.85	5829.11	4645.55	0.00	0.19

Nest	Oyster (m)	Intracoastal (m)	Beach (m)	Urban (m)	Shell (%)	Elevation (m)
random	5455.76	4930.92	8770.55	2052.06	0.00	1.55
random	1361.25	429.42	5486.66	5231.74	0.00	1.44
random	4761.93	4058.60	8646.00	2675.56	0.00	1.47
random	2083.55	6167.86	1442.22	725.51	0.00	1.51
random	687.97	902.50	5213.11	5155.73	0.00	1.31
random	4985.14	4222.91	9640.13	2395.29	0.00	2.70
random	3070.98	6236.68	1392.16	1395.55	1.00	0.00
random	4491.61	7163.00	620.08	1973.61	0.66	1.52
random	4274.35	6816.51	898.44	2052.06	1.00	0.00
random	7400.68	6732.76	11307.06	0.00	0.00	1.51
random	5141.40	7269.35	490.92	2762.67	1.00	1.52
random	1816.62	1573.34	8105.22	5525.34	0.00	1.50
random	2416.61	2098.48	8844.31	5176.11	0.00	1.51
random	2475.88	2014.27	9131.59	5515.80	0.00	1.50
random	513.13	136.01	7465.67	6882.82	0.00	1.47
random	451.88	296.98	7225.95	6669.19	0.00	0.60
random	210.24	1011.19	6519.45	6262.14	0.23	1.55
random	4876.89	4402.56	12155.15	6173.25	0.00	3.41
random	2201.93	2043.55	9524.22	8111.48	0.00	1.52
random	2722.65	5793.96	511.96	0.00	0.00	1.92
random	1893.91	5367.33	1131.37	0.00	0.00	1.44
random	2002.62	1668.77	9271.95	7626.51	0.00	1.49
random	3389.99	5447.17	1053.09	324.46	0.00	1.42
random	2289.83	890.95	8577.53	7954.21	0.00	0.54
random	3306.27	7075.03	152.32	0.00	0.07	1.53
random	223.61	2480.91	9196.94	7388.13	0.00	1.53
random	547.08	961.67	11560.77	4230.43	0.00	1.36
random	910.05	563.21	15521.43	1026.03	0.00	1.46
random	1280.35	830.06	7196.14	2800.52	0.33	1.53
random	1179.92	622.41	7092.40	2675.56	0.00	1.51
random	3117.77	6548.19	1814.66	324.46	0.00	1.30
random	2867.14	447.21	17704.46	1297.84	0.00	1.44
random	2738.06	2363.26	8805.11	3284.90	0.00	1.49
random	2637.97	523.45	17855.46	1337.78	0.00	1.53
random	5166.43	4755.85	11542.20	5740.27	0.00	1.53
random	3350.94	1067.05	18397.04	513.01	0.27	2.84
random	3551.79	727.80	18667.15	827.21	0.90	2.72
random	1879.28	4239.59	2440.35	513.01	0.00	1.52
random	1358.31	702.92	8558.53	1147.14	0.35	1.53

Nest	Oyster (m)	Intracoastal (m)	Beach (m)	Urban (m)	Shell (%)	Elevation (m)
random	2191.28	1339.59	9362.38	725.51	0.00	1.52
random	2197.38	1337.95	9370.34	725.51	0.00	1.52
random	336.15	2412.34	3573.93	648.92	0.00	1.52
random	180.28	2182.89	3647.16	324.46	0.00	1.51
random	970.82	1497.77	3390.24	513.01	0.00	1.71
random	2073.86	1464.92	9798.38	725.51	0.00	1.27
random	5980.18	5395.23	12956.73	2615.87	0.00	1.75
random	3555.98	3471.31	6915.96	0.00	0.00	1.69
random	3473.51	3820.27	7697.08	0.00	0.00	4.29
random	6108.11	5477.59	13250.09	1026.03	0.00	1.36
random	8882.71	9474.72	17985.51	513.01	0.00	2.54
random	415.93	228.04	7489.10	1451.02	0.84	1.44
random	7990.76	7344.29	15029.60	1451.02	0.00	3.15
random	1056.22	2049.41	7610.95	0.00	0.00	1.52
random	8994.50	8968.86	19248.80	1169.85	0.00	3.62
random	701.14	1667.15	7643.68	229.43	0.00	1.52
random	463.25	825.65	6850.78	0.00	0.00	1.52
random	9351.92	6563.18	22947.51	1539.04	0.00	5.12

APPENDIX 3.
2011 Nest locations

Nest ID	Year	Bands	Bay	Latitude	Longitude	Island Type*
UWGalB001	2011	M3,M2	West Galveston	29.297473	-94.939346	sinc
UWGalB002	2011	UB,H9	West Galveston	29.28956	-94.933454	li
UWGalB003	2011	H7,UB	West Galveston	29.289858	-94.926971	li
UWGalB004	2011	UB,M1	West Galveston	29.294263	-94.933426	sinc
UWGalB005	2011	R3,R4	West Galveston	29.303277	-94.907638	sinc
UWGalB006	2011	UB	West Galveston	29.29074	-94.926063	li
UWGalB007	2011	UB	West Galveston	29.290088	-94.930914	li
UWGalB008	2011	UB,H8	West Galveston	29.289704	-94.936669	li
UWGalB009	2011	P3,P4	West Galveston	29.293972	-94.931888	sinc
UWGalB010	2011	UB,N8	West Galveston	29.292459	-94.937812	sinc
UWGalB011	2011	J6,J5	West Galveston	29.291297	-94.922883	sinc
UWGalB012	2011	UB	West Galveston	29.304645	-94.90819	sinc
UWGalB013	2011	T5,T6	West Galveston	29.283638	-94.891177	li
UWGalB014	2011	UB	West Galveston	29.283331	-94.891686	li
UWGalB015	2011	UB,E7	West Galveston	29.283353	-94.89246	li
UWGalB016	2011	H0,A2	West Galveston	29.290495	-94.929847	li
UWGalB017	2011	UB,P9	West Galveston	29.297416	-94.939138	sinc
UWGalB018	2011	N6,N7	West Galveston	29.289946	-94.936745	li
UWGalB019	2011	UB,E7	West Galveston	29.283638	-94.891305	li
UWGalB020	2011	UB	West Galveston	29.304638	-94.908138	sinc
UWGalB021	2011	T7,T8	West Galveston	29.283046	-94.892947	li
UWGalB022	2011	H8,UB	West Galveston	29.289914	-94.93696	li
UWGalB023	2011	UB	West Galveston	29.290299	-94.930407	li
UWGalB024	2011	UB	West Galveston	29.290319	-94.926368	li
UWGalB025	2011	N7,N6	West Galveston	29.289916	-94.936833	li
UWGalB026	2011	H0,A2	West Galveston	29.290472	-94.929611	li
UWGalB027	2011	T5,T6	West Galveston	29.283805	-94.891222	li
UGalB001	2011	T0,T9	Galveston	29.325331	-94.892023	sic
UGalB002	2011	N9,UB	Galveston	29.332722	-94.897499	sic
USwanL001	2011	N0,UB	Swan Lake	29.343288	-94.896883	sinc
USwanL002	2011	N5,N4	Swan Lake	29.338565	-94.898145	sinc
USwanL003	2011	P1,P0	Swan Lake	29.343633	-94.896208	sinc
USwanL004	2011	R8,R7	Swan Lake	29.346176	-94.8959	sinc
USwanL005	2011	T2,T1	Swan Lake	29.350082	-94.893181	sinc
USwanL006	2011	R5,R6	Swan Lake	29.348339	-94.893969	sinc
USwanL007	2011	P1,P0	Swan Lake	29.343694	-94.896138	sinc
UEGalB001	2011	UB	East Galveston	29.51176	-94.50294	sinc

Nest ID	Year	Bands	Bay	Latitude	Longitude	Island Type*
UDickB002	2011	N1,N2	Dickinson	29.457175	-94.93079	sinc
UDickB003	2011	UB	Dickinson	29.467888	-94.945361	sinc
UDickB004	2011	UB,M9	Dickinson	29.456444	-94.927527	sinc
UDickB005	2011	T3,T4	Dickinson	29.453583	-94.925722	sic
UDickB006	2011	UB,M0	Dickinson	29.457325	-94.930417	sinc
UDickB007	2011	UB,M0	Dickinson	29.447833	-94.922556	main
UDickB008	2011	UB,M9	Dickinson	29.456333	-94.927704	sinc
UMosesL001	2011	P8,P7	Moses Lake	29.44974	-94.933914	main
UMosesL002	2011	UB	Moses Lake	29.429747	94.948642	main
CEMatB001	2011	UB,P2	East Matagorda	28.740023	-95.796409	sinc
CEMatB002	2011	UB,M4	East Matagorda	28.738556	-95.799243	sinc
CEMatB003	2011	M8,M7	East Matagorda	28.737706	-95.810771	sinc
CEMatB004	2011	UB	East Matagorda	28.731361	-95.761638	li
CEMatB005	2011	UB	East Matagorda	28.691055	-95.800027	sinc
CEMatB006	2011	UB	East Matagorda	28.692304	-95.803681	sinc
CEMatB007	2011	UB	East Matagorda	28.711055	-95.883749	sinc
CEMatB008	2011	UB	East Matagorda	28.712026	-95.887713	sinc
CEMatB009	2011	UB	East Matagorda	28.735194	-95.826888	sinc
CEMatB010	2011	UB,P2	East Matagorda	28.739694	-95.797611	sinc
CEMatB011	2011	R2,R1	East Matagorda	28.747076	-95.781688	sinc
CEMatB012	2011	UB	East Matagorda	28.692093	-95.80462	sinc

*sinc = small islands/shell spits not connected to the mainland at low tide

sic = small islands/shell spits connected to the mainland at low tide

li = large islands

main = mainland

APPENDIX 4.
2012 Nest Locations

Nest ID	Year	Bands	Bay	Latitude	Longitude	Island Type*
UWGalB028	2012	J6,K5	West Galveston	29.29133588	-94.92288502	sinc
UWGalB029	2012	K6, UB	West Galveston	29.28386793	-94.87844844	li
UWGalB030	2012	UB	West Galveston	29.27374067	-94.90944397	li
UWGalB031	2012	R3,R4	West Galveston	29.30332996	-94.90774998	sinc
UWGalB032	2012	UB	West Galveston	29.30460837	-94.90817025	sinc
UWGalB033	2012	12,UB	West Galveston	29.28470286	-94.87772156	li
UWGalB034	2012	L8,L9	West Galveston	29.28304492	-94.87933424	li
UWGalB035	2012	T5,T6	West Galveston	29.28378453	-94.89115222	li
UWGalB036	2012	10,UB	West Galveston	29.28576292	-94.87653578	li
UWGalB037	2012	UB	West Galveston	29.28549989	-94.93276485	li
UWGalB038	2012	UB	West Galveston	29.3046315	-94.90810261	sinc
UWGalB039	2012	14,UB	West Galveston	29.27053769	-94.9094205	li
UWGalB040	2012	15,16	West Galveston	29.26888159	-94.89263875	main
UWGalB041	2012	R3,R4	West Galveston	29.30336994	-94.90773993	sinc
UWGalB042	2012	P9,19	West Galveston	29.29743907	-94.93923007	sinc
UWGalB043	2012	M2,M3	West Galveston	29.29752314	-94.93940399	sinc
UWGalB044	2012	H0,UB	West Galveston	29.29049274	-94.92989321	li
UWGalB045	2012	J6,K5	West Galveston	29.29133152	-94.92288644	sinc
UWGalB046	2012	13,UB	West Galveston	29.27149985	-94.90928287	li
UWGalB047	2012	UB	West Galveston	29.26915929	-94.91112932	li
UWGalB048	2012	UB	West Galveston	29.28361597	-94.89135305	li
UWGalB049	2012	10,UB	West Galveston	29.28575696	-94.87650837	li
UWGalB050	2012	L1,L2	West Galveston	29.27121042	-94.91443095	li
UWGalB051	2012	H0, UB	West Galveston	29.29048	-94.92955995	li
UWGalB052	2012	15,16	West Galveston	29.26866157	-94.89292139	main
UWGalB053	2012	K6,UB	West Galveston	29.28459129	-94.87790622	li
UWGalB054	2012	12,UB	West Galveston	29.2847995	-94.87766591	li
UWGalB055	2012	T5,T6	West Galveston	29.28377515	-94.89111333	li
UWGalB056	2012	E7,22	West Galveston	29.28322806	-94.89272224	li
UWGalB057	2012	L1,L2	West Galveston	29.27204995	-94.91439993	li
UWGalB058	2012	UB	West Galveston	29.2691996	-94.91113854	li
UWGalB059	2012	UB	West Galveston	29.2737224	-94.9093205	li
UWGalB060	2012	L3,L4	West Galveston	29.27408994	-94.91446992	li
UWGalB061	2012	J5,K6	West Galveston	29.2913606	-94.92271814	sinc
UWGalB062	2012	UB	West Galveston	29.290477	-94.926227	li
UWGalB063	2012	28,UB	West Galveston	29.28985999	-94.93659999	li
UWGalB064	2012	L6,L7	West Galveston	29.28985999	-94.93659999	sinc
UWGalB065	2012	M2,M3	West Galveston	29.29745969	-94.93928405	sinc
UWGalB066	2012	12,UB	West Galveston	29.28491	-94.87766	li

Nest ID	Year	Bands	Bay	Latitude	Longitude	Island Type*
UWGalB068	2012	L0,UB	West Galveston	29.26975189	-94.91326871	li
UWGalB069	2012	33,34	West Galveston	29.28976997	-94.93283995	li
UWGalB070	2012	UB	West Galveston	29.27196815	-94.91436917	li
UWGalB071	2012	L1,L2	West Galveston	29.28369996	-94.89125993	li
UWGalB072	2012	UB	West Galveston	29.28828	-94.923658	li
UWGalB073	2012	L3,L4	West Galveston	29.27437	-94.9137	li
UWGalB074	2012	T5,T6	West Galveston	29.2837	-94.89114	li
UGalB003	2012	20,21	Galveston	29.32547595	-94.89189042	sic
UGalB004	2012	20,21	Galveston	29.32531871	-94.89203182	sic
UGalB005	2012	UB	Galveston	29.33268	-94.89746	sic
USwanL008	2012	K7,UB	Swan Lake	29.34335053	-94.89687983	sinc
USwanL009	2012	N3,11	Swan Lake	29.33861584	-94.89817819	sinc
USwanL010	2012	K8,K9	Swan Lake	29.34651227	-94.8962532	sinc
USwanL011	2012	L5,UB	Swan Lake	29.34997114	-94.89326279	sinc
USwanL012	2012	R5,R6	Swan Lake	29.34840079	-94.89406108	sinc
USwanL013	2012	K7,UB	Swan Lake	29.34362956	-94.89620375	sinc
USwanL014	2012	N3,11	Swan Lake	29.33862045	-94.89817374	sinc
USwanL015	2012	L5,UB	Swan Lake	29.35181064	-94.89200969	main
USwanL016	2012	R5,R6	Swan Lake	29.34867631	-94.89385002	sinc
UDickB009	2012	M0,UB	Dickinson	29.45742999	-94.93046997	sinc
UDickB010	2012	UB	Dickinson	29.45714995	-94.93115997	sinc
UDickB011	2012	P5,P6	Dickinson	29.4571	-94.93147999	sinc
UDickB012	2012	N1,N2	Dickinson	29.45753996	-94.93064993	sinc
UDickB013	2012	T3,T4	Dickinson	29.45375998	-94.92582992	sic
UDickB014	2012	UB	Dickinson	29.46778994	-94.94542999	sinc
UDickB015	2012	UB,P7	Dickinson	29.45174103	-94.92481537	sic
UMosesL003	2012	31,26	Moses Lake	29.42960694	-94.94884889	main
CEMatB013	2012	M4,UB	East Matagorda	28.73858155	-95.79912909	sinc
CEMatB014	2012	17,UB	East Matagorda	28.71100995	-95.88346998	sinc
CEMatB015	2012	UB	East Matagorda	28.69114526	-95.80099775	sinc
CEMatB016	2012	24,26	East Matagorda	28.7120369	-95.88763453	sinc
CEMatB017	2012	R2,UB	East Matagorda	28.7470808	-95.78166163	sinc
CEMatB018	2012	24,25	East Matagorda	28.71113995	-95.88326999	sinc
CEMatB019	2012	UB,35	East Matagorda	28.69114207	-95.80099608	sinc
CEMatB020	2012	UB,36	East Matagorda	28.69215653	-95.80454255	sinc
CEMatB021	2012	R2,UB	East Matagorda	28.74001242	-95.78778813	sinc
CEMatB022	2012	UB	East Matagorda	28.74206993	-95.80469996	sinc
CEMatB023	2012	M4,UB	East Matagorda	28.73876997	-95.79910998	sinc
CEMatB024	2012	35,UB	East Matagorda	28.6911445	-95.80095903	sinc
CEMatB025	2012	36,UB	East Matagorda	28.69203726	-95.80466643	sinc
CEMatB026	2012	17,UB	East Matagorda	28.71103593	-95.88347979	sinc

Nest ID	Year	Bands	Bay	Latitude	Longitude	Island Type*
CEMatB027	2012	24,25	East Matagorda	28.71205995	-95.88749992	sinc
CEMatB028	2012	R2,UB	East Matagorda	28.74003782	-95.78776214	sinc

*UB = unbanded birds

**sinc = small islands/shell spits not connected to the mainland at low tide

sic = small islands/shell spits connected to the mainland at low tide

li = large islands

main = mainland

APPENDIX 5.

Morphometric variables and eye fleck proportions calculated from adult American oystercatchers (*Haematopus palliatus*) (n=27) captured on the upper Texas coast, 2012 and sexed molecularly.

Band #	% Flecked	Sex	Wing (mm)	Culmen (mm)	Tarsus (mm)	Weight (g)
10	0.60	M	259	88.37	63.4	675
12	2.80	M	257	88.7	66.74	670
13	0.80	M	252	92.32	61.7	600
14	0.50	M	265	86.52	64.89	610
15	2.00	F	262	94.75	59.33	670
16	4.50	F	256	91.7	63.22	630
19	4.60	M	258	82.4	61.03	650
20	4.00	M	259	84.19	65.19	650
21	4.80	F	253	85.26	64.88	740
22	1.30	M	250	84.64	56.75	630
23	0.20	F	251	96.21	63.01	630
26	6.70	F	260	99.6	65.56	650
27	5.00	F	264	92.02	65.06	590
28	0.90	M	261	78.57	61.44	650
29	0.00	M	261	89.96	62.75	650
30	1.00	M	251	83.95	58.8	550
31	0.00	M	259	89.08	62.01	570
32	0.60	M	247	82.17	62.51	590
34	2.10	M	249	82.67	60.19	600
35	1.90	F	268	91.42	63.8	720
36	2.70	F	258	94.63	61.57	770
37	2.90	F	292	96.92	61.59	630
38	0.00	M	258	95.64	65.11	610
L8	1.80	F	260	91.64	67.76	800
L9	2.40	M	262	90.12	61.12	675
N2	6.80	F	261	90.34	66.93	700
P9	2.60	F	268	93.87	66.19	690