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# Long-term Population and Colony Dynamics of Brown Pelicans (*Pelecanus occidentalis)* in Rapidly Changing Coastal Louisiana, USA

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**Abstract.—**Coastal Louisiana has suffered from dramatic coastal land loss. Following translocations to Louisiana in the late 1960s, Brown Pelican (*Pelecanus occidentalis*) colonies were annually surveyed between 1971 and 2010 using aerial methods. The goals of this study were to describe long-term Brown Pelican colony dynamics, investigate physical changes to nesting islands via satellite imagery, and relate colony dynamics to physical island changes. Thirty Brown Pelican colonies were found, with a mean colony persistence of 5.5 years. Following exponential growth up to 2000, nesting plateaued, declined sharply in 2006 primarily due to land losses following the intense 2005 hurricane season, and stabilized at lower levels until 2010. From 1998 to 2010, island size decreased by a mean of 68.7%, with 10 of the islands vanishing entirely. Colony size was positively correlated to island size. Colonies did not shift between State regions, but appeared to shift within regions. To persist in Louisiana, Brown Pelicans will need to continue adjusting to a changing coastline, as well as planned coastal restoration projects. Future monitoring of Brown Pelicans in Louisiana may provide insight into their adaptive responses to changing availability and suitability of nesting island habitat. *Received 18 July 2015, accepted 5 October 2015.*

**Key words.—**Brown Pelican, coastal erosion, coastal restoration, colony, distribution, hurricane, long-term data, Louisiana, *Pelecanus occidentalis*, waterbird.

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Many coastal waterbird species are of conservation concern in the United States due to rapidly changing coastal habitats, primarily due to habitat loss or fragmentation due to human development (Bildstein *et al.* 1991; Brown *et al.* 2001). Human development may also precipitate indirect impacts, such as human disturbance (Foster *et al.* 2009) and an increase in subsidized predators (Marzluff 2001), that may lead to declining populations. However, coastal habitats in some regions of the United States are relatively undeveloped and non-urbanized by humans. One such example is the Louisiana coastline where human settlement and urbanization is minimal in coastal waterbird habitats. Accordingly, coastal Louisiana supports large breeding populations of coastal waterbirds (Visser and Peterson 1994), including large proportions of the Gulf Coast and United States' breeding populations for some species (Spendelow and Patton 1988; Fontenot *et al.* 2012).

The Louisiana coastline is very dynamic in both long and short time scales due to the periodic delta switching of the Mississippi River outlet (~1,000-1,500 years; McBride *et al.* 2007) and periodic hurricanes that reshape and destroy coastal habitats (catastrophic hurricane frequency every ~130-450 years; Liu and Fearn 2000). There have been seven active deltas of the Mississippi River during the Holocene Epoch (McBride *et al.* 2007) with relict deltas reworked and shaped into barrier islands (Davis 1997). Many coastal waterbird species, including the Brown Pelican (*Pelecanus occidentalis*), use these barrier islands as nesting habitat (Visser *et al.* 2005; Fontenot *et al.* 2012). Brown Pelicans were considered an abundant and permanent resident along coastal Louisiana in the early 1900s (Kopman 1907; Bailey 1918; Lowery 1960). However, populations began declining precipitously in Louisiana during the late 1950s (Newman 1968; Schreiber and Risebrough 1972). Prior to reintroductions, the last nesting in the State was on North Island in May 1961 (van Tets 1965; Fig. 1), shortly followed by their extirpation from the State in 1963 (King *et al.* 1977). De-

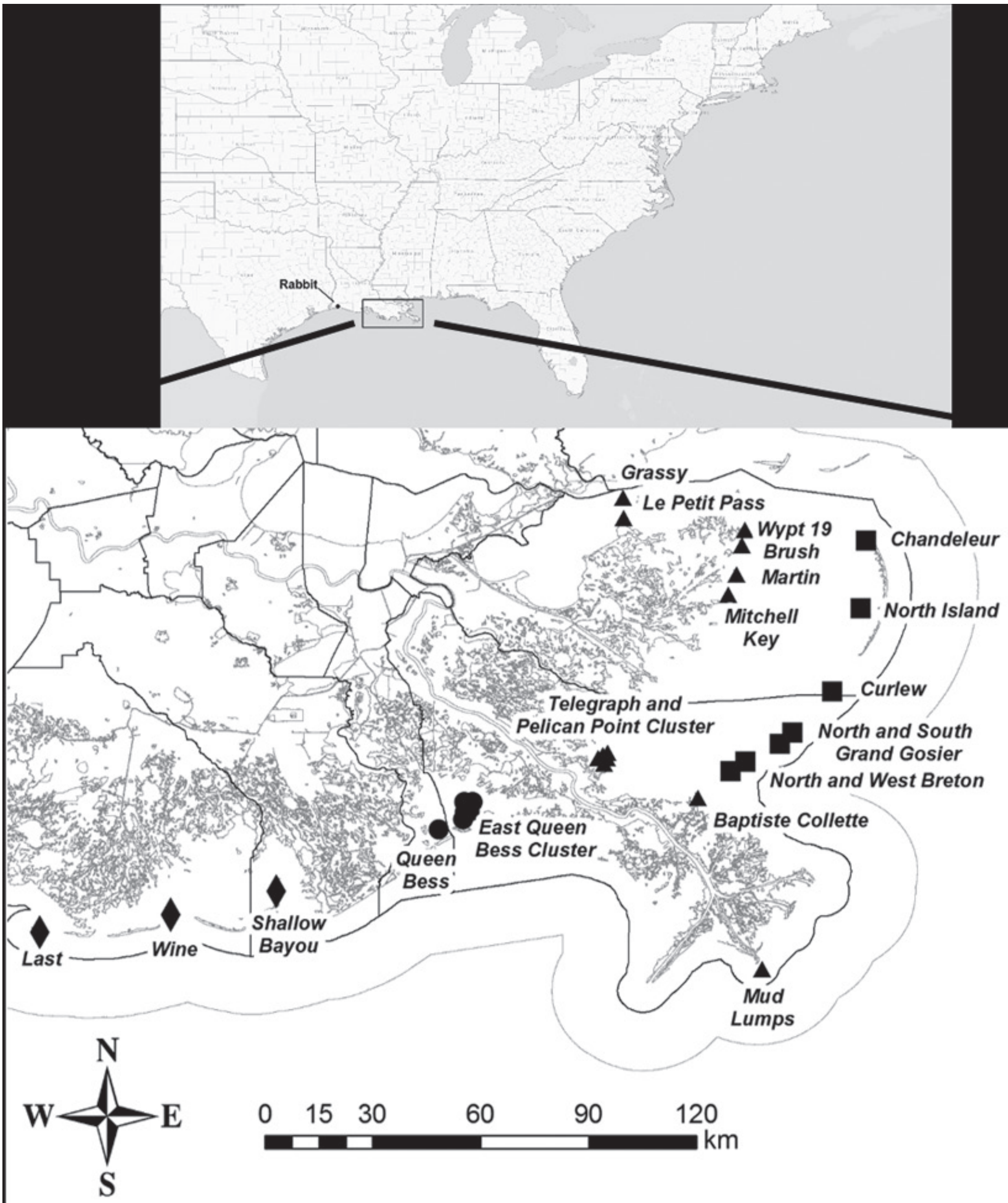


**Figure 1. Location of Brown Pelican nesting colonies in coastal Louisiana, with the inset showing the location of the recently established colony at Rabbit Island. Different symbols represent different regional groupings as defined in text (diamond: Terrebonne; circle: Barataria; triangle: Nearshore East; square: Chandeleur).**

clines were also noted in Texas (King *et al.* 1977), with declines in the region attributed to endrin toxicity and reproductive impairment due to pesticide contaminants (Blus *et al.* 1975, 1979; Wilkinson *et al.* 1994). As a result of the observed population declines and the threat of further declines from contaminated food resources, the Brown Pelican was federally listed as endangered throughout its United States' range on October 13, 1970 (U.S. Fish and Wildlife Service 1970).

Following the observed population declines, the Louisiana Department of Wildlife and Fisheries was tasked with reintroducing

Brown Pelicans into Louisiana. Over the course of 22 years (1968-1980), pre-fledged Brown Pelican chicks were translocated from Florida to historical nesting islands in Louisiana (McNease *et al.* 1992). McNease *et al.* (1984, 1992) documented the successful early stages of the reintroduction and colony dynamics in Louisiana (1968-1991), while Holm *et al.* (2003) documented the exponential increase of Brown Pelicans in Louisiana. The ultimate goal of the reintroduction was to restore Brown Pelican populations to the point where they could be removed from the United States' list of endangered and threatened wildlife. Brown Pelicans were removed from the list in 2009 due in part to the dramatic population recovery observed in the Gulf Coast portions of its range (U.S. Fish and Wildlife Service 2009).

Even though coastal Louisiana lacks high levels of human urbanization, coastal wetland and barrier island habitat changed dramatically between when the Brown Pelican was listed in 1970 and delisted in 2009 (Couvillion *et al.* 2011). From 1973 to 2010, it was estimated that Louisiana lost 3,073 km$^2$ of coastal wetlands and barrier islands (Couvillion *et al.* 2011). There were many factors contributing to these losses including: 1) the loss of the natural Mississippi River delta via channelization, isolation by levees, and impoundment of the Mississippi River (Boesch *et al.* 1994; Day *et al.* 2000); 2) remnant drainage, navigation, or oil/gas field canals that bisect coastal marshes (Turner *et al.* 1982; Day *et al.* 2005); 3) relative sea level rise (Dingler *et al.* 1992; Day *et al.* 2005); and 4) tropical systems (recent major storms in Louisiana include Hurricanes Katrina, Rita, Gustav, and Ike; Couvillion *et al.* 2011).

However, few data are available to accurately assess the long-term status of both Brown Pelican colonies and the low lying Gulf Coast islands used by Brown Pelicans and other waterbirds. Therefore, the goals of this study were to synthesize the Louisiana Department of Wildlife and Fisheries' 40-year Brown Pelican colony survey dataset to describe long-term Brown Pelican colony dynamics, investigate physical changes to nesting islands via satellite imagery, and relate observed colony dynamics to the physical changes to nesting islands.

## Methods

### Study Area

We conducted the study throughout coastal Louisiana, USA, with 30 colonies occurring in southeastern Louisiana and one colony in southwestern Louisiana (Rabbit Island; Fig. 1). The southeastern coastal region of Louisiana provides important habitats, including foraging, loafing, and nesting sites, for numerous waterbird species. The region is tidally influenced, with wind direction also factoring into regional and local water levels (i.e., wind-driven tides). The Mississippi River bisects the southeastern survey region, and in seasons with high river flows, surrounding Gulf of Mexico waters experience increased turbidity and decreased salinities. Compared to southeastern Louisiana, southwestern Louisiana has fewer coastal waterbird nesting sites (Fontenot *et al.* 2012), with Rabbit Island serving as the most important nesting island in the region (W. Selman, unpubl. data).

### Survey Methods

We surveyed Brown Pelican nesting colonies in southeastern Louisiana from 1971 to 2010, with the exception of 1991. We also surveyed Rabbit Island, the lone colony in southwestern Louisiana, from 2003 to 2010, with the exception of 2009. Because the Louisiana coastline is vast, we could not survey all potential breeding habitat every year due to logistical and monetary constraints. Thus, we found new colonies primarily along the established colony survey route (between existing colonies), to and from inland refueling stations, and through communication with other coastal researchers, coastal Louisiana Department of Wildlife and Fisheries staff, or the public. We collected data prior to 1993 from a combination of fixed-wing aerial surveys, photographic counts, and ground surveys as described by McNease *et al.* (1992). For later surveys from 1993 to 2010, one or two observers visually estimated the number of nests at colonies during the breeding season via rotary or fixed wing aircraft (observation height: 45-150 m). When two observers were counting, we made independent visual colony estimates and these estimates were compared for accuracy. For smaller colonies, we typically made single passes over the island, while multiple passes were needed for larger colonies to obtain consensus with our counts. We typically made multiple counts throughout each breeding season ($\bar{x}$ = 4, Range = 1-8), with annual nest totals for each colony from the survey with the maximum nest count. Because of the prolonged nesting season, it is possible that we did not account for all renesting attempts, thus making our method a conservative estimate for annual nests per colony. Once a colony was discovered, we surveyed it annually and only ceased surveys when the island vanished due to erosion.

Along with nesting data, we collected descriptive habitat-related information for Brown Pelican nesting islands during aerial surveys. Qualitative data collected were mainly of islands exhibiting dramatic changes between survey periods or years (e.g., island lost, no vegetation remaining), while also noting the impacts of storm events (e.g., colony failed due to island overwash; vegetation damaged). We used this qualitative information to discuss the trends in Brown Pelican colony size and the relationship between Brown Pelican colonies and coastal island change.

### Colony Data Analysis

To evaluate how coastwide annual nest counts from all colonies (dependent variable) varied from 1971 to 2010, we used a generalized linear model (McCullagh and Nelder 1989) with a Poisson distribution, a logarithmic link function, and year and year$^2$ as the independent variables. Next, to determine if regional shifts occurred in Louisiana from 1992 to 2010, we classified only southeastern Louisiana colonies into one of four regions based on their location and/or geomorphological similarities (Terrebonne, Barataria, Chandeleur, and Nearshore East). Terrebonne and Barataria regions are distinct bay systems separated by marsh and mainland features. The Chandeleur region (~75 km long) is composed of a chain of similar, offshore, sand dominated barrier islands. The Nearshore East region consisted of nearshore, smaller islands east of the active Mississippi River delta; even though this region was long (~135 km), these marsh islands were more similar to each other than the nearby Chandeleur islands that were taller and sand dominated. Once colonies were categorized into regions, we used a two-factor ANOVA to determine if the mean colony nest counts within a region (dependent variable) were similar across regions (independent variable), 5-year intervals (factor; 1992-1995, 1996-2000, 2001-2005, 2006-2010), and with a region by 5-year interval interaction. If effects test results were significant, we used a Tukey-Kramer post hoc test to delineate differences.

### Quantifying Island Size Change

We used Google Earth Pro (Google, Inc.) to measure the area of islands (ha) from 1998 imagery (2004 imagery was used for Wine Island) and then from imagery in late 2009 or early 2010 near the end of the study period. The polygon tool was used to trace the island perimeter as visible from Google Earth Pro imagery for both time periods. Even though all islands were not occupied by Brown Pelican colonies in 1998 and the entire area of islands were not used by Brown Pelicans for nesting, using these islands provided a proxy for coastal island loss. We did not measure two islands that hosted Brown Pelican colonies due to a lack of imagery (Mud Lumps colony) or due to a difficulty in measuring the exact size of the island (Chandeleur colony). Because island sizes had a non-normal distribution, we used a nonparametric Wilcoxon Ranked sum test to determine if island area (ha) was equal between the first imagery date (1998, or 2004 for Wine Island) and for imagery at the end of the study (2009 or 2010).

To directly compare island area and colony counts, we traced island perimeters when Google Earth Pro imagery was available for a specific Brown Pelican colony across multiple years. For example, archived imagery was available for Brush Island in 1998, 2004, 2006, and 2009, with colony nest counts also made in those years. We repeatedly measured a total of 18 islands from 1998 to 2010 and associated colony data with island areas for those years (Table 1). To determine if island area was correlated with colony size, we used a linear regression with colony size as the dependent variable, island size as the independent variable, and colony as a random factor (to account for repeated, non-independent measures for islands). We excluded 12 islands because two (Mud Lumps and Chandeleur) were not measurable, seven (LePetit, Grassy, Chandeleur, Telegraph Point, Pelican Point 2, Pelican Point 3, Wypt 19) were only active for a single year, two (Queen Bess and Last) were not subject to natural erosion processes due to restoration, and one (Rabbit) due to its geographic separation. We used JMP 9 for all statistical analyses (SAS Institute, Inc. 2010), with statistical significance at $P < 0.05$.

## RESULTS

### Louisiana Nesting Colony Summary

We estimated 216,841 nests from 1992 to 2010 (19 years) at 30 different colonies (Table 2; Fig. 1). In 1992, Brown Pelicans were observed at four colonies, peaked at 15 colonies in 2006, and 10 colonies were observed at the end of the study in 2010 ($\bar{x}$ = 8.7 colonies per year, SD = 3.49). These colonies produced a low of 2,380 nests in 1992, peaked at 17,215 nests in 2005, and at the end of the study in 2010, produced 10,664 nests ($\bar{x}$ = 11,412, SD = 4,162; Table 2; Fig. 2). Colony sizes were highly variable across years, with nine large colonies averaging > 900 nests per year (Range = 930-4,495), 12 medium colonies averaging 100-900 nests per year (Range = 100-850), and nine small colonies averaging < 100 nests per year (Range = 5-95; Table 2). Of the 30 colonies, 19 were east of the Mississippi River, 10 were west of the Mississippi River (Fig. 1), and Rabbit Island was the lone colony in southwestern Louisiana. The generalized linear model indicated a significant nonlinear relationship between total annual Brown Pelican nests observed over time (Fig. 2). The generalized linear model Beta estimate for the intercept was -479.9 ($\chi^2_2$ = 273,850.4, SE = 1.92, $P < 0.0001$), 0.25 for year ($\chi^2_1$ = 273,328, SE = 0.001, $P <$

**Table 1. Island size dynamics related to Brown Pelican colonies in coastal Louisiana between 1998 and 2010 (Wine Island from 2004-2010) sorted by order of colonization. The number of years active also includes data pre-1991 as summarized by McNease *et al.* (1992) and excludes 1992 when surveys were not completed. Coordinates indicate the center location of the island in 1998. Islands in bold were included in comparisons of island size vs. colony size. Region abbreviations: B = Barataria, C = Chandeleurs, NE = Nearshore East, SW = Southwest, and T = Terrebonne.**

| Island Name | Region | Date Established | Number of Years Active | Coordinates | Island Area in 1998 (ha) | Island Area in 2010 (ha) | Size Change (ha) | Percent Change |
|---|---|---|---|---|---|---|---|---|
| Queen Bess | B | 1971 | 39 | 29° 18' 15.48" N, 89° 57' 33.94" W | 15.0 | 14.3 | 0.7 | -4.7 |
| **North** | C | 1979 | 30 | 29° 52' 37.75" N, 88° 52' 35.51" W | 57.8 | 15.9 | 41.9 | -62.5 |
| Last | T | 1987 | 23 | 29° 03' 02.06" N, 90° 55' 32.40" W | 66.9 | 32.5 | 34.4 | -51.4 |
| Mud Lumps | NE | 1990 | 4 | 29° 59' 33.18" N, 89° 08' 14.53" W | | | | n/a |
| **North Grand Gosier** | C | 1990 | 8 | 29° 33' 27.10" N, 89° 03' 12.81" W | 27.1 | 0 | 27.1 | -100.0 |
| **South Grand Gosier** | C | 1996 | 8 | 29° 31' 57.75" N, 89° 04' 58.68" W | 49.0 | 0 | 49.0 | -100.0 |
| LePetit Pass | NE | 1997 | 1 | 30° 05' 17.60" N, 89° 28' 27.12" W | 1.7 | 0 | 1.7 | -100.0 |
| **Wine** | T | 1997 | 11 | 29° 05' 40.67" N, 90° 36' 38.13" W | 10.5 | 0 | 10.5 | -100.0 |
| **Martin** | NE | 1998 | 8 | 29° 57' 32.05" N, 89° 11' 53.54" W | 18.4 | 7.1 | 11.3 | -61.4 |
| **Brush** | NE | 1998 | 5 | 30° 02' 16.90" N, 89° 10' 52.54" W | 30.9 | 9.6 | 21.3 | -69.0 |
| **Mitchell** | NE | 1998 | 4 | 29° 53' 46.69" N, 89° 12' 30.50" W | 6.5 | 0 | 6.5 | -100.0 |
| Grassy | NE | 1998 | 1 | 30° 09' 15.07" N, 89° 28' 28.61" W | 2.3 | 0 | 2.3 | -100.0 |
| **Curlew** | C | 1999 | 4 | 29° 38' 39.16" N, 88° 58' 15.48" W | 172.0 | 0 | 172.0 | -100.0 |
| Chandeleur | C | 1999 | 1 | 29° 02' 49.24" N, 88° 52' 15.18" W | | | | n/a |
| **Baptiste Collette** | NE | 2000 | 5 | 29° 23' 01.25" N, 89° 17' 55.52" W | 10.3 | 8.9 | 1.4 | -14.0 |
| Telegraph Point | NE | 2000 | 1 | 29° 30' 59.63" N, 89° 31' 53.95" W | 0.6 | 0 | 0.6 | -100.0 |
| **Pelican Point** | NE | 2000 | 8 | 29° 30' 06.69" N, 89° 32' 05.87" W | 16.3 | 6.0 | 10.3 | -63.2 |
| **West Breton** | C | 2002 | 4 | 29° 29' 39.17" N, 89° 10' 26.51" W | 37.9 | 0 | 37.9 | -100.0 |
| Rabbit | SW | 2003 | 6 | 29° 50' 57.24" N, 93° 23' 00.83" W | 88.4 | 82.9 | 5.5 | -6.2 |
| **Shallow Bayou** | T | 2004 | 7 | 29° 08' 37.59" N, 90° 20' 51.45" W | 6.2 | 1.0 | 5.2 | -83.9 |
| **East Queen Bess** | B | 2006 | 4 | 29° 20' 02.73" N, 89° 52' 17.82" W | 5.9 | 2.0 | 3.9 | -66.0 |
| **Pelican Point 1** | NE | 2006 | 2 | 29° 31' 42.43" N, 89° 32' 44.14" W | 4.5 | 1.3 | 3.2 | -71.5 |
| Pelican Point 2 | NE | 2006 | 1 | 29° 32' 21.54" N, 89° 32' 03.85" W | 7.0 | 1.6 | 5.4 | -77.3 |
| Pelican Point 3 | NE | 2006 | 1 | 29° 31' 51.71" N, 89° 33' 10.26" W | 11.7 | 3.8 | 7.9 | -67.9 |
| **North Breton** | C | 2006 | 5 | 29° 27' 47.31" N, 89° 12' 16.57" W | 37.9 | 10.4 | 27.5 | -72.6 |
| **East Queen Bess 1** | B | 2007 | 4 | 29° 20' 50.26" N, 89° 52' 01.64" W | 4.9 | 1.1 | 3.7 | -76.5 |
| **East Queen Bess 2** | B | 2007 | 3 | 29° 21' 01.22" N, 89° 51' 50.14" W | 1.6 | 0.1 | 1.5 | -93.9 |
| **East Queen Bess 3** | B | 2008 | 3 | 29° 21' 56.84" N, 89° 51' 53.30" W | 4.9 | 0.9 | 4.0 | -81.7 |
| **East Queen Bess 4** | B | 2008 | 2 | 29° 21' 46.25" N, 89° 51' 12.60" W | 7.1 | 1.6 | 5.6 | -78.2 |
| Wypt 19 | NE | 2010 | 1 | 30° 03' 40.46" N, 89° 10' 58.21" W | 49.2 | 19.2 | 30.0 | -61.0 |

**Table 2. Brown Pelican colonies and summary data from 1992 to 2010. The mean nests/year includes only data from years where the colony was active. X indicates the year that the island vanished due to erosion.**

| Colony Name | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | Total Nests | Mean Nests/Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Queen Bess | 80 | 435 | 375 | 800 | 900 | 1,200 | 1,400 | 2,150 | 850 | 2,250 | 2,200 | 2,300 | 3,000 | 2,800 | 1,625 | 1,500 | 1,300 | 1,200 | 2,000 | 28,365 | 1,493 |
| North | 0 | 111 | 100 | 500 | 700 | 700 | 875 | 1615 | 600 | 810 | 1,150 | 1,485 | 1,400 | 1,180 | 26 | 65 | 125 | 200 | 519 | 12,161 | 676 |
| Last | 750 | 1,040 | 1,500 | 2,500 | 2,000 | 3,000 | 3,700 | 4,930 | 1,550 | 4,300 | 4,500 | 3,900 | 5,400 | 6,200 | 3,075 | 3,850 | 5,500 | 2,000 | 3,400 | 63,095 | 3,321 |
| Mud Lumps | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 10 | 0 | **X** | | | | | | 80 | 27 |
| North Grand Gosier | 1,500 | 3,600 | 5,000 | 7,000 | 3,100 | 4,100 | 4,500 | 0 | 0 | 0 | 0 | 0 | **X** | | | | | | | 28,800 | 4,114 |
| South Grand Gosier | | | | | 1,900 | 2,500 | 3,725 | 1,700 | 75 | 350 | 1,700 | 250 | **X** | 0 | | | | | | 12,200 | 1,525 |
| LePetit Pass | | | | | | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **X** | | | | | | 5 | 5 |
| Wine | | | | | | | 130 | 220 | 75 | 75 | 200 | 0 | 16 | 110 | 225 | 425 | 525 | 165 | **X** | 2,166 | 197 |
| Martin | | | | | | | 36 | 20 | 0 | 0 | 225 | 0 | 380 | 525 | 137 | 90 | 40 | 0 | 0 | 1,453 | 182 |
| Brush | | | | | | | 20 | 0 | 0 | 0 | 0 | 0 | 260 | 325 | 45 | 0 | 0 | 125 | 0 | 775 | 155 |
| Mitchell | | | | | | | 2 | 30 | 71 | 0 | 35 | 0 | 0 | **X** | | | | | | 138 | 35 |
| Grassy | | | | | | | 6 | 0 | 0 | 0 | 0 | 0 | 0 | **X** | | | | | | 6 | 6 |
| Curlew | | | | | | | | 5,200 | 250 | 120 | 725 | 0 | **X** | | | | | | | 6,295 | 1,574 |
| Chandeleur | | | | | | | | 125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 125 | 125 |
| Baptiste Collette | | | | | | | | | 10,000 | 8,500 | 0 | 0 | 0 | 2,000 | 1,400 | 575 | 0 | 0 | 0 | 22,475 | 4,495 |
| Telegraph Point | | | | | | | | | 100 | 0 | **X** | | | | | | | | | 100 | 100 |
| Pelican Point | | | | | | | | | 175 | 0 | 300 | 470 | 170 | 700 | 160 | 300 | 150 | 0 | 0 | 2,425 | 303 |
| West Breton | | | | | | | | | | | 4,200 | 4,625 | 4,900 | 2,000 | **X** | | | | | 15,725 | 3,931 |
| Rabbit | | | | | | | | | | | | 4 | 0 | 75 | 8 | 100 | 175 | n/s | 550 | 912 | 152 |
| Shallow Bayou | | | | | | | | | | | | | 850 | 1,300 | 750 | 900 | 750 | 750 | 400 | 5,700 | 814 |
| East Queen Bess | | | | | | | | | | | | | | | 35 | 125 | 75 | 25 | 0 | 260 | 65 |
| Pelican Point 1 | | | | | | | | | | | | | | | 40 | 0 | 0 | 0 | 150 | 190 | 95 |
| Pelican Point 2 | | | | | | | | | | | | | | | 35 | 0 | 0 | 0 | 0 | 35 | 35 |
| Pelican Point 3 | | | | | | | | | | | | | | | 75 | 0 | 0 | 0 | 0 | 75 | 75 |
| North Breton | | | | | | | | | | | | | | | 400 | 3,200 | 2,250 | 2,000 | 2,500 | 10,350 | 2,070 |
| East Queen Bess 1 | | | | | | | | | | | | | | | | 275 | 75 | 800 | 800 | 1,950 | 488 |
| East Queen Bess 2 | | | | | | | | | | | | | | | | 100 | 150 | 50 | 0 | 300 | 100 |
| East Queen Bess 3 | | | | | | | | | | | | | | | | | 125 | 125 | 225 | 475 | 158 |
| East Queen Bess 4 | | | | | | | | | | | | | | | | | 75 | 10 | 0 | 85 | 43 |
| Wypt 19 | | | | | | | | | | | | | | | | | | | 120 | 120 | 120 |
| **Total Nests for Year** | 2,380 | 5,186 | 6,975 | 10,800 | 8,600 | 11,505 | 14,394 | 15,990 | 13,766 | 16,405 | 15,235 | 13,044 | 16,376 | 17,215 | 8,036 | 11,505 | 11,315 | 7,450 | 10,664 | 226,765 | 873 |
| **Total Colonies for Year** | 4 | 4 | 4 | 4 | 5 | 6 | 10 | 9 | 11 | 7 | 10 | 9 | 9 | 11 | 15 | 13 | 14 | 11 | 10 | | |

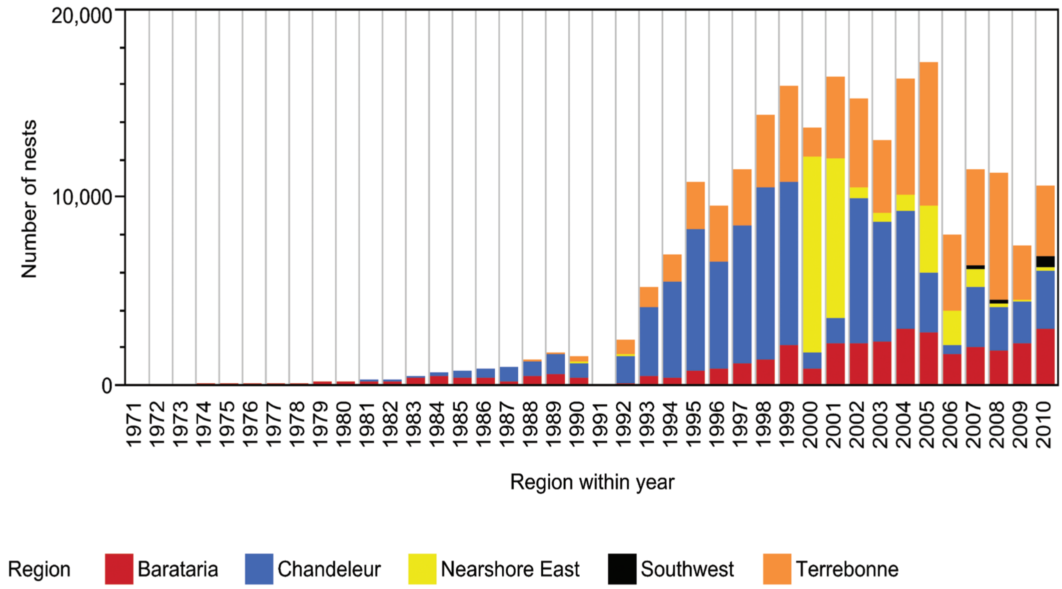


**Figure 2. Total number of Brown Pelican colony nests estimated by region in coastal Louisiana (excluding Rabbit Island in southwestern Louisiana).**

0.0001), and -0.01 for year$^2$ ($\chi^2_1$ = 71,595, SE < 0.0001, $P$ < 0.0001). Interpretation of the nonlinear fit indicates that populations increased from 1971 to 2000, peaked between 2001 and 2005 (Range = 13,044-17,215), dropped significantly in 2006 (8,036 nests), and stabilized at lower levels from 2006 to 2010 (Range = 7,450-11,505).

## Colony Persistence, Expansion, and Shifts

Of the five original colonies described by McNease *et al.* (1992), Queen Bess and North Island colonies were active the longest, for 39 and 30 years, respectively; it is likely that these colonies were also active in 1992 when surveys were not completed. Both of these colonies were initiated by the first translocation attempts of Brown Pelicans originating from Florida. In the early 1980s, a colony created from an intrastate translocation attempt at Last Island (aka Raccoon Island; Walter *et al.* 2013) was active during every year from 1987 to 2010. Following these three successful translocations, the other 27 colonies formed via natural expansion. Two periods of widespread expansion occurred from 1998-2000 and from 2006-2008, with 10 colonies forming during the first period and nine in the second period (Table 2). Of the 30 colonies observed from 1971 to 2010, they were active for a mean of 5.5 years (SD = 5.16; Range = 1-39 years). Seven colonies (23%) were active for only a single year, with subsequent annual surveys not detecting nesting at these colonies (Table 2).

There was a difference of mean number of nests across regions ($F_{3,206}$ = 8.11, $P$ < 0.001) and in mean nests by 5-year interval ($F_{3,206}$ = 3.56, $P$ < 0.02), but there was no region by 5-year interval interaction ($F_{9,206}$ = 0.72, $P$ = 0.68) indicating that regional shifts did not occur across any 5-year intervals (Fig. 2). For regional comparisons, Terrebonne and Chandeleur had significantly more nests than Nearshore East, but were not greater than Barataria; Barataria did not have significantly more nests than Nearshore East. For 5-year intervals, the mean number of nests in 2001-2005 was significantly greater than 2006-2010, but not greater than 1990-1995 or 1996-2000; the latter two also were not significantly greater than 2006-2010.

## Island Size Change, Disappearance, and Size Relative to Colony Size

Between 1998 and 2010, all 28 islands measured via Google Earth Pro imagery decreased in size, with complete island loss observed for 10 of the 30 islands (33%) due to coastal erosion and/or hurricane impacts between 2002 and 2010 (Table 1; Fig. 3). The total number of nests at eroded islands accounted for 29% of the overall nests counted since 1971 (65,515 nests), with four of these islands annually hosting large colonies (> 1,000 nests per year). Between 1998 and 2010, island area declined significantly ($\chi^2_1$ = 12.99, $P$ = 0.0003). In 1998, mean island area was 28.9 ha (median = 11.1; SD = 39.6; Range = 0.6-172.0; cumulative island area = 808.0 ha), while 2010 mean island area was 9.1 ha (median = 1.5; SD = 18.3; Range = 0-82.9; cumulative = 253.8 ha). On average, island area decreased by 68.6% ($n$ = 28, Range = 4.7-100.0%). Of the 30 islands, only three, including Queen Bess (4.7%), Rabbit (6.2%), and Baptiste Collette (14.0%), did not decline > 50% over the study period. Even though the Mud Lumps and Chandeleur Islands were not measured, the former disappeared completely in 2005, while the latter were heavily degraded (> 90% land lost) over the measured time period (Sallenger *et al.* 2009).

Using the 18 islands with multiple size measurements between 1998 and 2010, we found that colony size was positively correlated with island area ($r^2$ = 0.72, $F_{1,55}$ = 33.6, $P$ < 0.001). Brown Pelicans used islands as small as 0.5 ha (East Queen Bess 2) and as large as 172 ha (Curlew), but islands < 5 ha typically had < 500 nests, while those islands that annually hosted > 1,000 nests were larger (Range = 9-172 ha).

## DISCUSSION

As previously reported (McNease *et al.* 1984, 1992; Holm *et al.* 2003), Brown Pelicans have made a dramatic comeback since their extirpation from Louisiana in 1963. From 1992 to 2010, annual counts ranged from 2,380-17,215 nests in 4-15 colonies across coastal Louisiana. Beyond the five original islands reported by McNease *et al.* (1992), 25 additional islands were colonized from 1992 to 2010. These gains are partly responsible for the Brown Pelican being removed from the United States' list of endangered and threatened wildlife in 2009 (U.S.

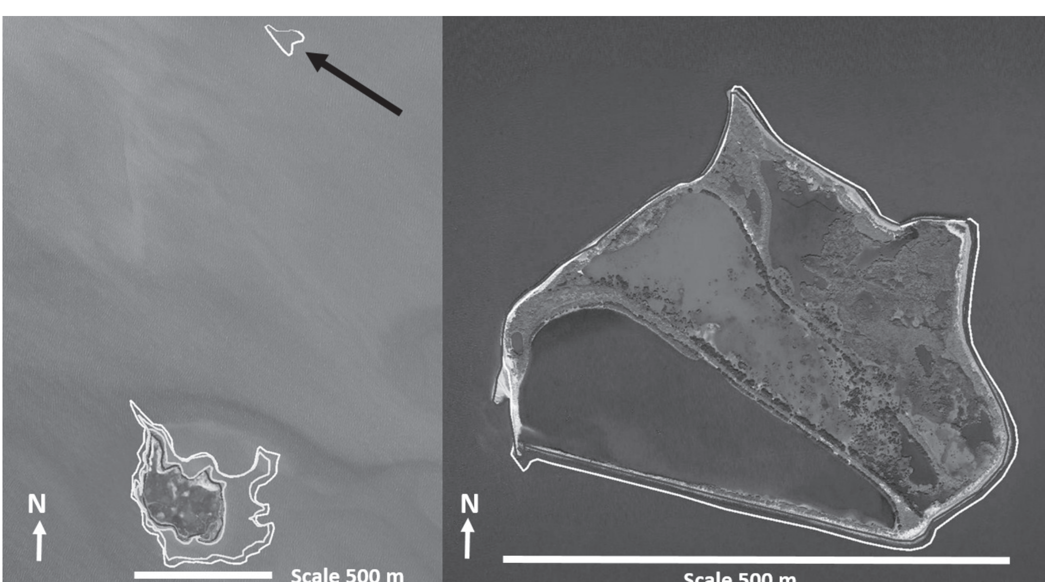


**Figure 3. Examples of island size change over time including the complete loss of Telegraph Point (A; upper island with arrow) and erosion of Pelican Point (left panel; lower island). Queen Bess (right panel) shows little size change due to rock stabilization and restoration. Outer white lines are island perimeters in 1998, black lines are 2010 perimeters, and other interior perimeters were calculated between those time periods.**

Fish and Wildlife Service 2009). However, our results indicate that these gains were followed in 2006 by significant declines in the nesting population, apparently due to nesting habitat loss attributable to tropical storms and coastal wave-driven erosion.

Because we conducted colony counts and not line transects, it is unknown how many colonies went unsurveyed, how long “new” colonies may have been present without prior detection, and how long the time period was between “true colonization” and our observations. It is likely that large and persistent colonies did not go undetected, but smaller or less persistent colonies may have been unsurveyed during the study or missed during some counts. For example, the Shallow Bayou colony was detected in 2004 with an estimated 850 nests. It is possible that Shallow Bayou was a smaller colony some years prior until it was detected as a large colony in 2004. However, Brown Pelicans in Florida were found to be the most visible nesting waterbird due to their larger size and the placement of their nests on top of vegetation (Rogers *et al.* 2005). Also, it is possible that there were differences in the dataset that may have been due to the different methods used pre-1991 (using photographic nest counts) and post-1991 (using visual estimation). We suspect that visual counts from 1992 to 2010 were likely conservative estimates as previously described by Rogers *et al.* (2005). Therefore, with continuous surveys of the same region over the study period, we are confident that our results depict conservative estimates, yet accurately portray long-term trends of Brown Pelican colony dynamics in Louisiana.

The barrier islands used by Brown Pelicans lacked high levels of human development, and this provided a unique opportunity to investigate the effects of natural coastal processes on colony dynamics. From 1992 to 2010, there were at least seven nesting seasons where tropical events directly impacted colonies (1998, 2001, 2003-2005, and 2008) or indirectly impacted island habitat following the nesting season (2002). McNease *et al.* (1992) also observed the detrimental effects of tidal flooding associated with storms on Brown Pelican productivity in Louisiana. In many cases, Brown Pelicans renested and successful reproduction was observed (J. Linscombe, pers. obs.). However, as in 2004 and 2005 when six tropical systems affected the Louisiana coastline, the impacts to Brown Pelicans were primarily manifested via considerable changes to nesting habitat and not by direct mortality. For example, in 2004, Hurricane Ivan (September 2004) produced significant island overwash and erosion, with Curlew, South Grand Gosier, and North Grand Gosier Islands completely lost (all from the Chandeleur region). These islands hosted some of the largest colonies observed during the study (Table 2). In July 2005, Hurricanes Cindy and Dennis directly impacted colonies east of the Mississippi River, while Hurricane Emily flooded most southeastern colonies. Later in 2005, Hurricane Katrina (August) and Rita (September) completely destroyed late-nesting attempts at Pelican Point Island, and more importantly, they significantly impacted the entire coast of Louisiana through coastal erosion, elevation loss, and vegetation degradation (Sallenger *et al.* 2009). Sharp declines in nesting numbers were noted the following year (2006) with the lowest coastwide nesting count observed since 1994 (8,036 nests); this pattern is apparent in nesting counts at several of the major colonies (Fig. 4). Our comparison of colony size vs. island size also supports the conclusion that as islands decreased in size they supported smaller colonies, likely because they had a lower carrying capacity and became less suitable for Brown Pelican colonies (Visser and Peterson 1994; Erwin *et al.* 2011). Thus, the significant declines in total Brown Pelican nest counts observed in this study are primarily associated with the long-term impacts to island habitats following the 2004 and 2005 hurricane seasons. Jodice *et al.* (2007) documented similar declines of Brown Pelicans in South Carolina between the mid-1980s until 2005, but these declines were attributable to emigration to neighboring States rather than habitat loss due to erosion.

We also documented 3 years (2000, 2002, 2003) where nesting attempts failed due to

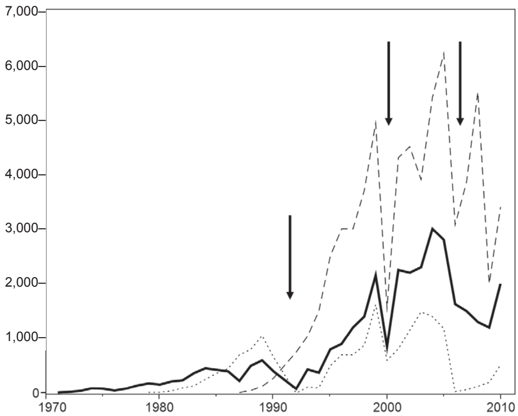


**Figure 4. Yearly nest counts for select Brown Pelican colonies observed throughout the study period (Queen Bess - solid line, Last - dashed line, North - stippled line). The left arrow indicates when Queen Bess Island was restored, the middle arrow relates to declines observed due to persistent high tides in 2000, and the right arrow indicates declines following the intense hurricane season of 2005.**

high tides driven by persistent strong southerly winds not associated with tropical systems. Nest counts in 2000 for the three reintroduction islands (Queen Bess, North, and Last Islands) declined by 61, 63, and 69%, respectively, due to wind-driven tides (Fig. 4). However, a higher-elevation, man-made dredge spoil island, Baptiste Collette, was initiated in 2000 with an estimated 10,000 nests documented (73% of the total nest count that year). Presumably, the greater elevation of the dredge spoil island provided better nesting habitat than was available on lower-lying natural islands.

Brown Pelican colonies typically persisted on an island as long as the island remained present. The three original reintroduction islands maintained Brown Pelican colonies the longest, but both Queen Bess and Last Islands would have been lost without significant coastal restoration projects for their continued persistence. Restoration projects included rock barriers and dredge spoil for Queen Bess Island and rock breakwaters for Last Island. North Island was impacted following the hurricanes of 2004-2005 and was predicted by Hess (2006) to provide limited future habitat for nesting Brown Pelicans. Indeed, the latter was confirmed in subsequent years with North Island colony estimates declining between 50-98% compared to pre-2004-2005 levels. Along with North Island, as islands began to shrink, so did the number of nests observed in the colony. Erwin *et al.* (2011) also observed Chesapeake Bay islands that diminished greatly in size from the mid-1990s until the mid-2000s. Similar to our study, Erwin *et al.* (2011) also observed declines of nesting seabirds and wading birds on local and regional scales.

Along with island area and elevation, island vegetation and structure is also an important determinant of colony success. Even though not directly quantified in this study, Walter *et al.* (2013) documented that suitable nesting platforms in the form of woody vegetation (black mangrove [*Avicennia germinans*] and marsh elder [*Iva frutescens*]) on Last and Wine Islands in Louisiana declined significantly following the hurricanes in 2008, while less suitable bare ground habitat increased on both islands. On Last Island, Walter *et al.* (2013) found that the number of Brown Pelican chicks per nest was greater in higher elevation nests and within woody vegetation (black mangrove and marsh elder). Therefore, following severe tropical storms, Brown Pelicans may be left to nest in suboptimal habitats at lower elevations due to decreased island elevations and damaged remaining woody vegetation.

Following nesting island losses due to erosion or hurricanes, we expected significant regional shifts in the population. We did not find evidence of regional shifts, but there appeared to be significant yearly shifts within regions. For example, the southern Chandeleur chain had a large number of Brown Pelican nests observed between 1992 and 1998 on North and South Grand Gosier Islands (estimated 5,000-8,000 nests) until both islands were severely diminished. In 1999, a similarly large group of Brown Pelicans nested for a single year on Curlew Island (5,200 nests; 14.5 km northeast of North Grand Gosier Island). Tropical Storm Allison in 1999 impacted Curlew Island's height and vegetation, and in 2000 and 2001, Baptiste Collette became the largest colony observed to date (8,500-10,000 nests; 43 km southeast of Curlew Island).

Then between 2002 and 2005, West Breton Island was colonized by a large number of Brown Pelicans (2,000-4,000 nests; 12.5 km northeast of Baptiste Collette), but was lost in late 2005 due to Hurricanes Katrina and Rita. Again in 2005 and 2006, 1,400 to 2,000 nests were estimated on Baptiste Collette Island and then in 2007, Brown Pelicans began nesting on North Breton Island until the end of the study (2,000-3,200 nests; 17.4 km northeast of Baptiste Collette). It is unknown how many individuals shifted islands, but our data for this region suggest that Brown Pelicans readily nested on new islands after prior islands were diminished, degraded, or destroyed.

One of the most important colony expansions occurred in 2003 when four Brown Pelican nests were observed on Rabbit Island in southwestern Louisiana, the first and only colony in this region. Rabbit Island is one of the most stable islands (6.2% island area lost from 1998-2010) relative to the rapidly diminishing islands in southeastern Louisiana ($\bar{x}$ = 63.7% island area lost). Because Rabbit Island is protected from the Gulf wave-driven forces and being a relatively large nesting island (89 ha), it may become the largest and most important colony for Brown Pelicans in coastal Louisiana within the next 25 years. This island was also used recently as a donor site for oil-spill rehabilitated Brown Pelicans from southeastern Louisiana (Selman *et al.* 2012) and is slated for restoration efforts (Selman and Davis 2015).

The continued persistence of Brown Pelicans in coastal Louisiana will be linked to their ability to respond to rapidly changing coastal conditions. They will have to adjust to the loss of larger barrier islands that have supported large colonies over the last 30 years. Some estimates predict that Louisiana barrier islands will disappear in < 100 years (U.S. Geological Survey 2015) without some form of barrier island restoration. Similar restoration projects have already proven successful on both Last and Queen Bess Islands (Visser and Peterson 1994; Walter *et al.* 2013). If large barrier islands are not restored, they will diminish and support smaller colonies until they vanish, with Brown Pelicans thereafter moving to nearshore islands as we observed between 2006 and 2010. However, nearshore islands are primarily small, low-lying, coastal marsh islands. These islands may not provide optimal nesting conditions (Visser and Peterson 1994; Visser *et al.* 2005), are not likely to persist as long as sand-dominated barrier islands, and will likely host smaller-sized colonies (Visser *et al.* 2005). Thus, large Brown Pelican colonies in Louisiana are not likely to continue into the future except for those on restored barrier islands or those on islands that are sheltered from the Gulf of Mexico, such as Rabbit Island. Man-made dredge spoil islands may provide suitable surrogate habitat similar to what we observed at Baptiste Collette Island.

Currently, the Coastal Protection and Restoration Authority of Louisiana (2012) has barrier island restoration projects planned in the Barataria and Terrebonne regions. These projects will extend barrier island life for coastal protection benefits, while also likely extending their use by nesting Brown Pelicans. We suspect that associated human activities and disturbance will likely have localized, short-term impacts on nesting. However, these projects should provide long-term positive benefits for Brown Pelicans similar to those we observed at Queen Bess Island following restoration in the early 1990s (Louisiana Department of Natural Resources 2001). Future research projects should monitor the short- and long-term impacts or benefits of island restoration projects to Brown Pelicans. Such data will be critical in assessing the value of the restoration and the suitability for Brown Pelican nesting. Future research and monitoring of Brown Pelicans and their colonies across coastal Louisiana will provide scientists with a greater understanding of their adaptive responses to changing availability and suitability of island nesting habitat.

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