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Arbour Guthrie April 9, 2019

Sedimentary and Ecological Interactions of Shoreline Management and Feral Horses on Cumberland Island, Georgia

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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By Arbour Guthrie

People have modified barrier islands in the eastern U.S. for centuries, whether through deforestation, agriculture, shoreline development, or introduction of non-native species. Cumberland Island (Georgia) is no exception in this respect. Before its current status as a U.S. National Seashore, a jetty was constructed in the late 1800s with the intent of stabilizing an inlet between Cumberland and Amelia Island (Florida). Moreover, non-native livestock were introduced repeatedly to the island, including horses released in the 1940s, which have been feral since. Despite the long-time presence of these human alterations, relatively little research has been done to investigate geological and ecological impacts of the jetty and feral horses on Cumberland, or whether they interact. For this research, I documented long-term changes in sedimentary processes caused by the jetty on the southeastern end of Cumberland Island, while also investigating effects of feral-horses (*Equus caballus*) in the same area. To document effects on dunes, salt marshes, and other near-coastal environments, I used aerial photos and GIS to map shoreline change related to the jetty and probable nearby feral-horse trails, which was supplemented by field work for baseline observations. My results showed a statistically significant difference in beach width north and south of the jetty, with the northern side wider. The southern shoreline stabilized about 30 years ago, whereas the northern shoreline continues to widen. More than 100 extensive and intersecting horse trails are also evident in dunes and salt marshes near the jetty. My primary conclusion is that the jetty and feral-horses had a combined and noticeable effect on sedimentological and ecological processes on the southeastern end of the island. The jetty interrupts longshore drift, resulting in less sand movement and deposition on the beach to its south. Moreover, long-term activities of the horses, such as browsing of vegetation (e.g., sea oats (*Uniola paniculata*) and trampling of coastal dunes, accelerated erosion in these environments. Both factors led to a thin, sand-deprived beach, radically altered salt marshes, and likely contributed to westward movement of windblown sand on the southern end of Cumberland Island.

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Introduction

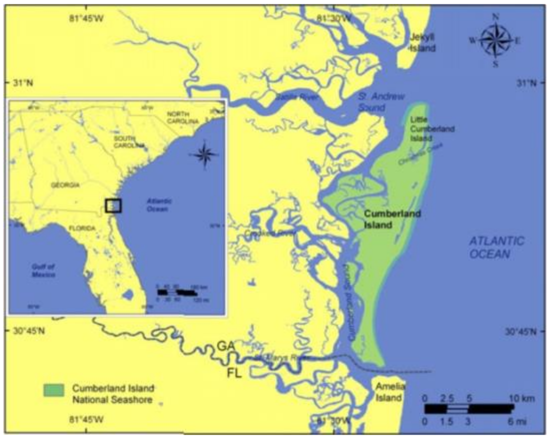

Figure 1. Location of Cumberland Island and Cumberland Island National Seashore. Image by USGS, "U.S. Geological Survey Open-File Report 2004-1196".

Cumberland Island is Georgia's southernmost barrier island, and most of it is designated as a U.S. National Seashore (Fig. 1). The island has an area of 147 km^2, which includes diverse environments, such as maritime forests, salt-water marshes, and extensive beaches and dunes (Ruckdeschel 2017). It is a composite barrier island with Pleistocene bedrock and Holocene sand beaches composed of fine to medium-grained silicate sand (Martin, 2013; Ruckdeschel 2017). Cumberland Island, along with the other Georgia barrier islands, has an average tidal range of 2-3 meters (mesotidal) and is located in a low to moderate wave-energy environment (Frey and Howard 1988; Pilkey 2003; Ruckdeschel 2017). Cumberland Island has a limited human population, and the few current residents have life leases on the Island (Ruckdeschel 2017).

Barrier islands can be found all over the world and are each unique in their formation, sedimentary processes, and environments (Pilkey 2003). Many barrier islands, though, are subject to human intervention, particularly those with beaches serving as popular vacationing locations (Pilkey 2003). Like many barrier islands, Cumberland Island has experienced human alterations as a part of its history over the past few centuries. For example, from 1881 to 1972 the Carnegie family owned most of Cumberland Island, and it was under their ownership when a jetty was constructed; horses were then introduced in the 1940s (Ruckdeschel 2017). Although horses had been introduced to the island by the Spanish as early as the late 1500s, the Carnegie horses led to the feral population there today. The earliest version of the boulder-mound jetty was constructed in the 1890s in an attempt to stabilize the inlet between Cumberland and Amelia Island (Florida) to its south (Bullard 2003; Ruckdeschel 2017).

Despite the long-time presence of the jetty and feral horses on Cumberland, relatively little research has been done on their large-scale impacts. I found a few previous studies focused on sedimentary impacts of a jetty on the southern end of the island, but none were done recently (Griffin 1982; Byrnes and Matteson 1995; Ruckdeschel 2017). For example, Byrnes and Matteson (1995) discovered that the sediment-transport patterns on Cumberland Island and Amelia Island were directly impacted by the installation of jetties to stabilize the inlet. Jetties act as barriers to longshore drift by trapping sand on the up-drift side. The dominant shoreline drift direction for Cumberland is north to south, hence sand accumulates north of the jetty and starves the sand south of the jetty (Griffin 1982; Gittman et al. 2015, Flor-Blanco et al. 2015). With the Cumberland jetty, it initially caused an additional 2 km^2 of sediment accumulation to its north, while also starving southern Cumberland and northern Amelia Island of sand (Griffin 1982). Research on other islands suggests that jetties have overall negative impacts, contrary to their intended benefits (Frihy et al. 1991; Bulleri and Chapman 2010; Mohanty et al. 2012; Oost et al. 2012; Pietrafesa 2012; Keshtpoor et al. 2013; Gittman et al. 2015). For example, in northwestern Spain, jetties led to abnormal sand movement along the shoreline, impacting the functionality of beach-dune systems (Flor-Blanco et al. 2015). Furthermore, Hall and Pilkey (1991) found New Jersey beaches with stabilization structures, such as jetties, were statistically narrower compared to “unstructured” beaches. After studying various jetties along the east coast of the U.S., Pietrafesa (2012) documented that hardened structures actually lead to erosion, counteracting their intended purpose for stabilizing inlets and eliminating erosion. Coastal engineers have tried for centuries to apply such coastal management methods for inlet migration, beach movement, and sea level rise (Pietrafesa 2012), but ultimately all efforts failed. Of all negative effects of human alterations to islands, jetties and groins are among the more impactful (Paris and Mitasova 2018, Oost et al. 2012).

Some research on the ecological impact of feral horses was conducted in the 1980s, but very little has been added since (Turner 1988). Feral horses damage dune structure and integrity through intensive grazing, which leads to destabilization of dunes and eventually erosion (Goodloe et al. 2000; Turner 1987; Turner 1988; Ruckdeschel 2017). In the Cumberland Island marshes, Turner (1987) also found that the feral-horse grazing, clipping, and trampling led to low production of above-ground vegetation. Turner (1988) further discussed grazing impacts on vegetation cover there, and suggested management of the horses to prevent damage to the salt marshes. Unfortunately, her recommendations never came to fruition, as horses still roam the island. Researchers have also examined horse-grazing impacts on other barrier islands, (Levin et al. 2002; Freedman et al. 2011), and some used remote sensing to look at the effects of horse grazing (De Stoppalaire et al. 2004). Assateague Island (Maryland-Virginia) is another island made popular because of its feral horses, and is a prominent location for studies on feral-horse impact on barrier islands. Seliskar (2003) found that feral horses there had a detrimental effect on vegetative cover and potentially made dunes vulnerable to erosion. Taggart (2008) likewise conducted research on four North Carolina barrier islands, Currituck Banks Reserve, Rachel Carson Reserve, Masonboro Island, and Zeke's Island Reserve, and their estuarine habitats. They discovered that feral horses on Currituck Banks and Rachel Carson Reserve adversely impact island ecosystems, and strongly recommended removing the feral horses, both for the health of island ecosystems and the horses.

Researchers have also shown that coastal erosion affects dune vegetation, which in turn destabilizes dunes and leads to more erosion (Feagin et al. 2005: Oost et al. 2012; Zuo et al. 2012; Ajedeba 2019). In a study of dune-beach systems and storm erosion, Silva and others (2016) found that vegetation helps reduce beach and coastal erosion, strengthens the resilience of coastal zones, and reduces shoreline retreat. The role of vegetation in beach-dune systems connects to the impact of feral horses on the island, as horse grazing on dune vegetation affects dune structure and stabilization.

Because both feral horses and the jetty on Cumberland are there because of humans, we need to ask questions regarding their overall and perhaps interactive environmental impact on the southern part of the island. Despite the long-time presence of the jetty and horses on Cumberland, relatively little research has been attempted on their large-scale impacts. Previous researchers have documented the effects of jetties on barrier islands, as well as those of feral horses, but not in combination. This study accordingly looks at the combined impact of the feral horses and the jetty on the ecological and sedimentological sustainability of Cumberland Island.

Methods

Study Site

Most of the research incorporated maps, aerial photography, and Geographic Information Systems (GIS) for data collection, but I also visited Cumberland for “ground-truthing” these remotely sensed observations. My study was conducted on the southern end of Cumberland Island north of Amelia Island inlet and south of the South End Trail, an official park trail but one used infrequently by people. This area along the shoreline is the location of the previously mentioned jetty, which was intended to maintain the inlet between Cumberland and Amelia Islands (Bullard 2003; Ruckdeschel 2017). This part of the island is also a common location for horses; their traces are on dunes and in marshes of this area and visible in areal imagery, including on Google Earth$^{\text{TM}}$. This visibility allows for digital-temporal comparisons between data collected in the field and trails shown in images. For site visits, I recorded field observations, took photographs, and recorded GPS coordinates. This area was also an apt location for examining combined effects of the jetty and feral-horse activities on the erosion and accretion of sediments on a barrier island.

Materials Used

For field research, I used a GarminMap 60CSx Handheld GPS Navigator to collect GPS data for the shoreline and horse-trail locations. I also used Garmin® BaseCamp$^{\text{TM}}$, an open-access application, to download and convert GPS data to ESRI's ArcGIS. I measured beach width with a MDL LaserAce 1000 Laser rangefinder, and horse-trail width with a tape measure. Photos were taken with a Sony Alpha DSLR-SLT-A55 Digital Camera.

Measuring Beach Width

For the jetty and shoreline, I walked the shoreline of the beach around the jetty and took GPS measurements to get a baseline position of the shoreline during the time of my thesis research. For each GPS location, I measured the distance between the water and the dunes at 10 m intervals. To measure distance, I used the laser range finder, with a field assistant standing at the foot of the dunes with a large white board; this allowed the laser to find a uniform surface for registering the distance. I took distance measurements 70 m north and south of the jetty. I also took photographs of the beach around the jetty, as well as the dune and back-dune areas west of it. While on the beach, I collected data comparing the sediments north and south of the jetty, such as mineral composition and sand textures. A review of the literature revealed that no previous researchers had collected data in this way on Cumberland, as most only used aerial imagery. However, these data were only meant to augment geospatial data, while using a practiced and tried field methodology.

Horse-Trail Mapping

To map some of the horse trails, I walked along the most prominent horse trails and set the GPS to track my location as a route. I also took waypoints along trails at locations with confirmed horse presence, whether through traces or sightings. Through notes, photographs, and GPS waypoints, I marked relevant field observations, such as vegetative ground cover around the trail, types of vegetation, and signs of horse presence on and adjacent to the trails. All GPS measurements were downloaded to ArcGIS to make a new feature class to compare and add to the trail-feature class created through aerial maps, a process subsequently discussed in the next section. From this, I approximated feral-horse movements and impacts while also showing their qualitative effects on the ground.

Various telltale signs indicate whether a trail was primarily made by a horse, rather than a feral hog or raccoon. For example, broader trail widths, horse hoof prints, and browse lines of Spanish moss in wooded areas are all signs of horse presence. Furthermore, the horse browsing line is much higher than that of deer. Hence, if present, I would have measured the browse line of the Spanish moss, but there was no Spanish moss on trails I walked. Additional evidence of horse influence includes feces and urination traces (Fig. 2). These feral-horse activities have a negative impact on vegetation and may be inferred by declining vegetative cover or type of vegetation around these trails. As mentioned previously, horses impact the island in various ways, including compacting soil, erosion, nutrient cycling, water pollution, quality and quantity of vegetation, and dune stability, as well as fauna and flora of the high marsh, ground-nesting birds, and interspecies competition (Ruckdeschel 2017). These impacts would take years to document thoroughly, so I only focused on those directly related to my research.

Figure 2. Horse feces on trail in salt marsh on southern end of Cumberland Island, Georgia. (Photo by Arbour Guthrie, November 4th, 2018.)

Geographic Information Systems: Computer Processes

Most of this research required the use of maps, aerial photography, and GIS. Through the collection of aerial photographs from Google Earth™ and other sources, including U.S. Geological Survey (USGS) maps, I analyzed how the island has changed over the past 50 years in sediment deposition and island shape. Many other researchers have used remote sensing to analyze coastal changes (e.g., Klemas 2001; De Stoppalaire G.H. et al., 2004) and GIS (Mumby et al. 1995; Klemas 2001); however, the focus of the maps I created was to document changes near the jetty and horse trails in the south end of the island using techniques similar to those of previous studies.

Aerial Images for Shorelines

Google Earth™, other aerial imagery, and USGS topographic maps helped test how much the jetty has affected longshore drift; on Cumberland, this sand-transport direction normally follows a north-south orientation. A growing number of archived remote-sensing datasets have been used to study coastal temporal changes of topology and vegetative cover in the coastal regions of the USA, which then have been used in barrier island and coastal research (Klemas 2001; De Stoppalaire et al. 2004). These researchers used ArcGIS and ERDAS IMAGINE– a program similar to ArcGIS – to analyze the remote-sensing datasets and their collected data. GIS with ArcMap was used for all data analysis and map creations in this study; other researchers have shown the effectiveness of GIS when conducting research on coastlines (Mumby et al. 1995; Klemas 2001).

For information on historical shorelines, I used topographic maps from the USGS historical Topographic Map Explorer for 1919, 1944, 1948, 1957, 1958, 1960, 1981, 1988, and 1994. Maps were saved as TIFF files and imported into ArcMap, and output coordinates were changed to WGS 1984 spatial reference. Aerial imagery was collected from online sources Google Earth® (1994, 1999, 2003, 2005, 2006, 2007, 2009, 2011, 2013, 2014, 2016, and 2017). I also used aerial imagery from the 1970s and 1980s in the University of Georgia Maps and Government Information Library and digitally scanned these images. These aerial photos were taken by the Georgia Department of Transportation (1976) and USGS (1974, 1988). Images that were not converted to TIFF files were brought in as JPEG files and georeferenced using known coordinates on the images.

Measuring Shoreline Distance and Beach Area

Using ArcGIS, I created vector-line feature classes by drawing over old shorelines from historical maps and aerial imagery, with all assigned individual years in the feature class attribute table. Using the symbology tab in Properties, then “unique features” for categorical data, each year was given a unique color to distinguish on the map. The ESRI “World Imagery” Basemap provided by ArcMap was used for the current shoreline imagery. GPS measurements of the current (2018) shoreline taken on Cumberland were downloaded and converted to ArcGIS as an additional comparison. I compared the 2018 shoreline, based on the Basemap and GPS measurements, to historical shorelines, based on the shoreline-feature classes created from historical maps and aerial imagery. The distances between the historical shorelines and 2018 shoreline were measured using the measurement tool in ArcMap for every 50 m starting 250 m north and south of the jetty, and an average of those points were divided into two sections around the jetty: North above Jetty and South below Jetty. From this, I have a representative collection of maps displaying shoreline change on the southern end of the island. This allowed me to make historical comparisons related to the jetty and to map shoreline change over the 50 years.

In addition, I measured the beach area north and south of the jetty. For each year I created polygons north and south of the jetty based on that year’s shoreline and dune location. Then by using the “Calculate Geometry” function in the attribute table, I calculated the area for each polygon. These data made it so I could compare total beach area between the years as well as the difference between the beach area north and south of the jetty, and see if that difference changed over time.

Layers for Horse Trail

Using ArcGIS, I mapped horse trails visible in the southern end of the island. I used aerial imagery from Google Earth™ from 1999, 2003, 2006, 2011, 2014 and 2017 and the "Construct Feature" tool on ArcMap to make a vector-line feature class of the horse trails for each year. I traced the visible and prominent horse trails from the images with the tool to create the horse trail polylines. Each drawn trail was assigned a year in the attribute table and given a distinct color based on each year, using the symbology tab in Properties, then "unique features" for categorical data. I then measured their individual distances in a given year by using the "Calculate Geometry" function in the table. To calculate their collective distances per year, I selected the trails for a given year using the "Select by Attribute" tool and the "Summarized Statistics" tool for finding the sum distance of the trails for each year. Drawing these lines helped to identify overall patterns of horse movement and high-use areas in this part of the island.

These maps show what parts of the southern end of the island were affected by feral-horse movements, while also quantifying the effects of horses there. Maps of trails over the years also define patterns of change, and help test whether the feral-horse movements correspond with any changes in sediment distributions near the jetty.

Vegetation Cover on Dunes

Vegetative cover from 1994, 1999, 2006, 2011 and 2017 was used to compare vegetation distribution on Cumberland. The vegetative data were derived from aerial images from Google Earth™, which I imported into ArcMap and then georeferenced using known coordinates. Once these were in ArcMap, I converted JPEG images in raster format into vector format, which required multiple steps. First, I used the stretch function to give each cell a specific number between 0-255 relating to its color intensity, with white sand around 240 and dark forest at about

100. I then used block statistics, which averages the color of the surrounding pixels into one larger pixel, to create an image with slightly larger averaged pixels amenable to converting to polygons. After using block statistics, I reclassified the image with only three categories of color, with dense vegetation the range of 0-150 as 1, light vegetation 151-220 as 2, and no cover (sand) 221-255 as 3, with variations depending on the brightness of each image. These numbers – 1, 2, and 3 – were used as grid codes, and once the reclassification was done, I could convert the image to vector format. Given these grid codes, I used the “Raster to Polygon” tool in the Conversion Toolbox of ArcGIS to create polygons. Once the polygons were created, I deleted all areas except those of interest in the dunes, and calculated the area for each polygon using the “Calculate Geometry” function in the table. I then used the “Select by Attribute” tool to select the features based on their grid code, “Summarized Statistics” tool to find the sum area of the polygons for each grid code, and thus calculated the sum areas for each type of vegetative cover (dense, light, and none).

Results

Shoreline

Based on my analysis, the jetty increased the difference between the shoreline north and south of it. For example, the shoreline within 250 m south of the jetty reaches the approximate location (within 30 m) of the current shoreline in 1988, 15 years before the northern end in 2003, thus indicating the jetty halted shoreline progression there since 1988 (Fig. 3). Moreover, the 1982 southern shoreline was within 10 m of its current location, and all remaining years stayed within 30 m of the 2018 shoreline. In contrast, the shoreline north of the jetty had a relatively steady migration seaward to its current position.

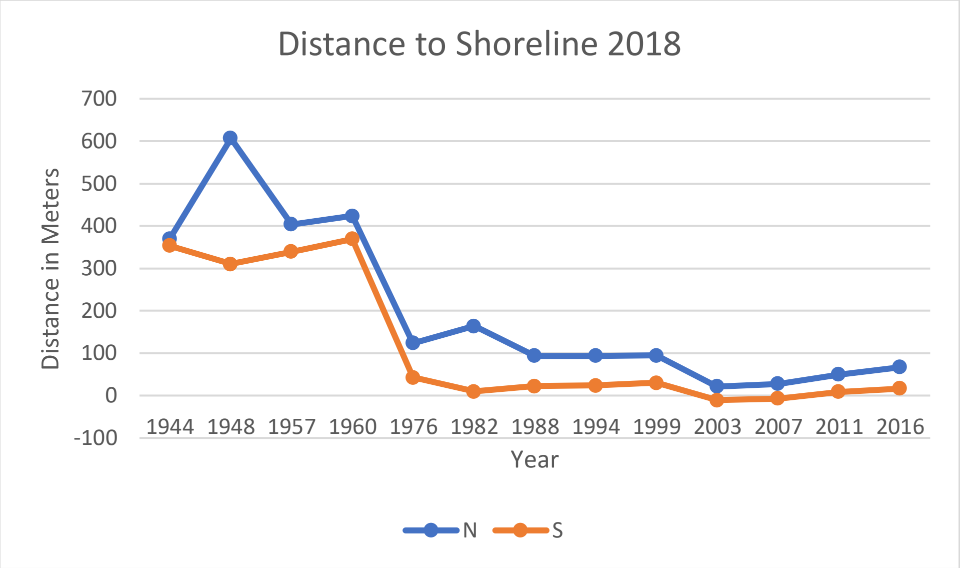

Figure 3. Graph depicting data summarized in Table 1, showing how the southern part of the shoreline reached the approximate location of current shoreline 15 years before the northern end. These data indicate that the jetty halted shoreline progression since at least 1988, with each point an average of distances within 250 m north and south of the jetty.

Table 1. Distance from years 1944 to 2018 from 2018 shoreline. Measurements taken within 250 m north and south of the jetty every 50 m. (Graph of table shown in Figure 3.)

	North Jetty	**South Jetty**
1944	370 m	353.4 m
1948	607 m	309.8 m
1957	404 m	339 m
1960	424 m	369 m
1976	124 m	42.4 m
1982	164 m	9.6 m
1988	94 m	21.8 m
1994	93 m	24 m
1999	94 m	30.4 m
2003	21 m	-10.6 m
2007	27 m	-6.6 m
2011	50 m	8.8 m
2016	67 m	16.4 m

Historical topographic maps combined with aerial photos show the degrees of changing shorelines of Cumberland overall during the past 70 years (Fig. 4, Table 2). At the northern end of Cumberland Island, the average change in shoreline distance between 1944 and 2018 is +214 m, indicating net accretion. In contrast, for the central shoreline of Cumberland Island, the average distance between 1944 and 2018 is –140 m, or net erosion. The highest accretion rate is immediately north of the jetty, with an average distance change between 1948 and 2018 of 551 m, whereas the area immediately south of the jetty ("end point") is 309 m. A two-sample t-test of the section south of the jetty shows it is indeed significantly smaller than the section north of the jetty (N end < S end: P-Value = 0.0357). The historical shorelines north of the jetty (Fig. 5) follow a steady progression east towards the position of the current shoreline, whereas the shoreline south of the jetty became static and shows no clear progression.

Figure 4. Shoreline accretion or erosion of different sections of Cumberland Island between 1948 and 2018.

Table 2. Average shoreline distance between 1948 and 2018 in various sections of the island (Figure 4).

	North	Central	South	Curve	End Point
Cumberland (1948-2018)	214 m	-140 m	270 m	551 m	309 m

Cumberland Southern Shoreline
1919-2018

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5. Shoreline changes discerned from topographic maps of southern end of Cumberland Island. The shoreline accreted at a normal rate north of the jetty, but halted south of the jetty.

Remnants of the old jetty were in the high marshes (Fig. 6). Large rocks there were in a straight line, and when tracing the line of these rocks to the current jetty, it follows the pattern of the jetty pictured back in 1919 (Fig. 7). This is evidence showing how much the shoreline has migrated and progressively covered the jetty, with the middle section currently buried under the dunes.

Figure 6. Image of the old jetty in the high marsh. Image taken approximately 1km from current shoreline. (Photo by Arbour Guthrie, November 4, 2018.)

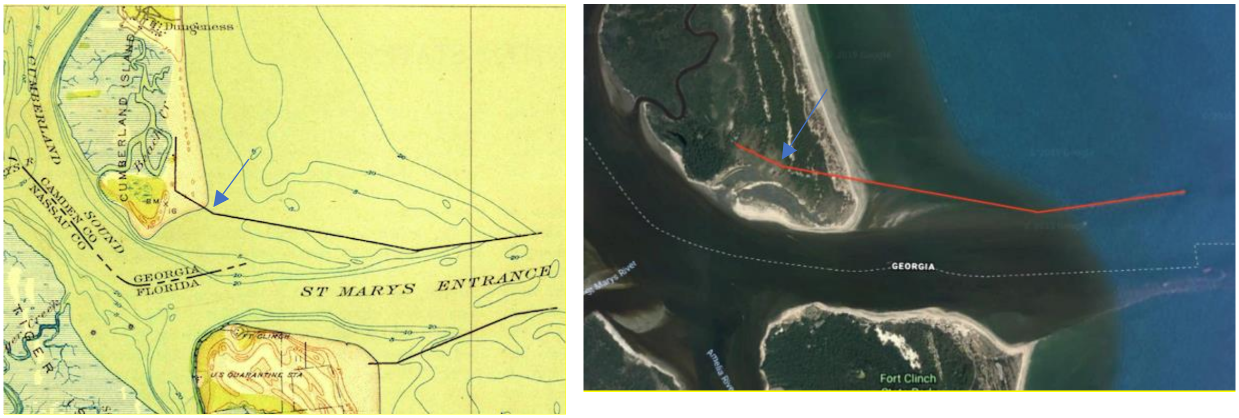

Figure 7. Maps comparing 1919 and 2017 A) USGS topographic map from 1919 B) Approximate outline of old and current jetty 2017. Bend in the jetty noted by blue arrow.

Direct comparison of beach width between years shows the southern beach is consistently narrower than the northern beach (Fig. 8) and that difference between the two increased over time (Fig. 9). The average difference between the northern and southern beach within 50 m of the jetty was 70 m.

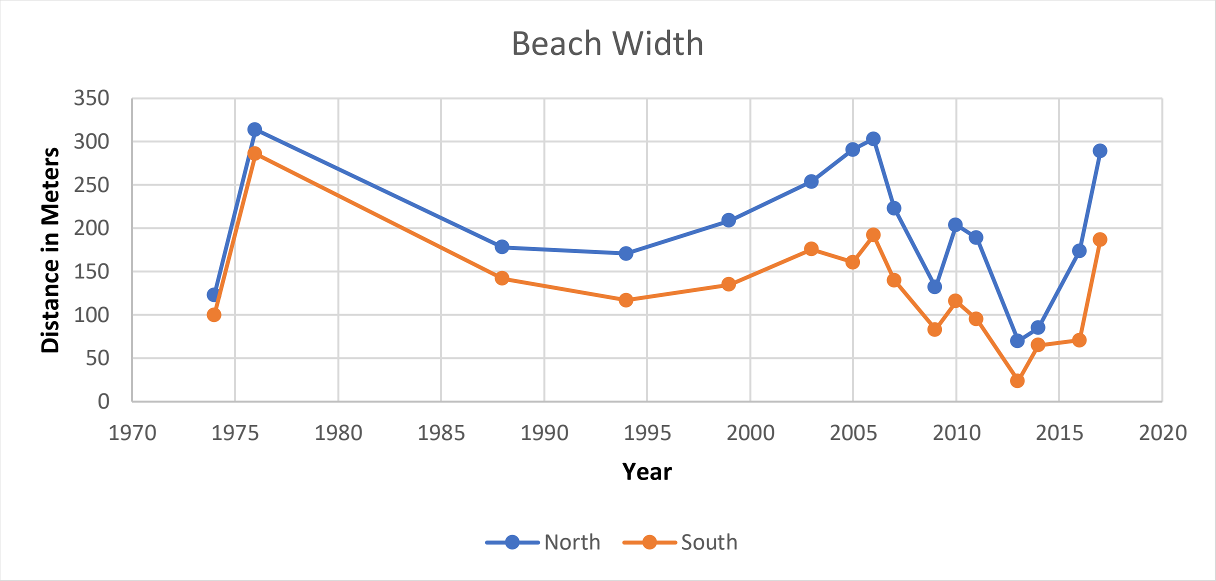

Figure 8. Shoreline distance to dunes (beach width) between 1974 and 2017, with each measurement taken 10 m north and south of jetty.

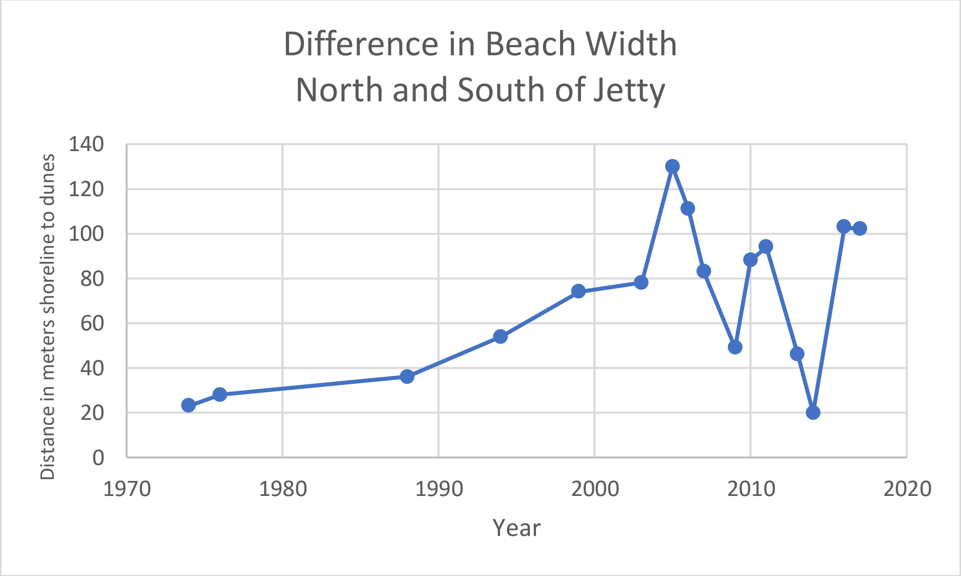

Figure 9. Differences between shoreline distance from dunes north and south of jetty from 1974 to 2017, with measurements taken within 10 m of the jetty.

Between 1974 and 2003, the average difference for the southern shoreline was 48 m, whereas between 2005 and 2017 the average difference for the northern shoreline was 95 m, or nearly double (Fig. 10). Assuming equal variance, these shorelines are significantly different, as supported by a two-sample t-test (2017-2005 difference ≠ 2003-1974 difference: P-Value = 0.0032; 2017-2005 difference > 2003-1974 difference: P-Value = 0.9984).

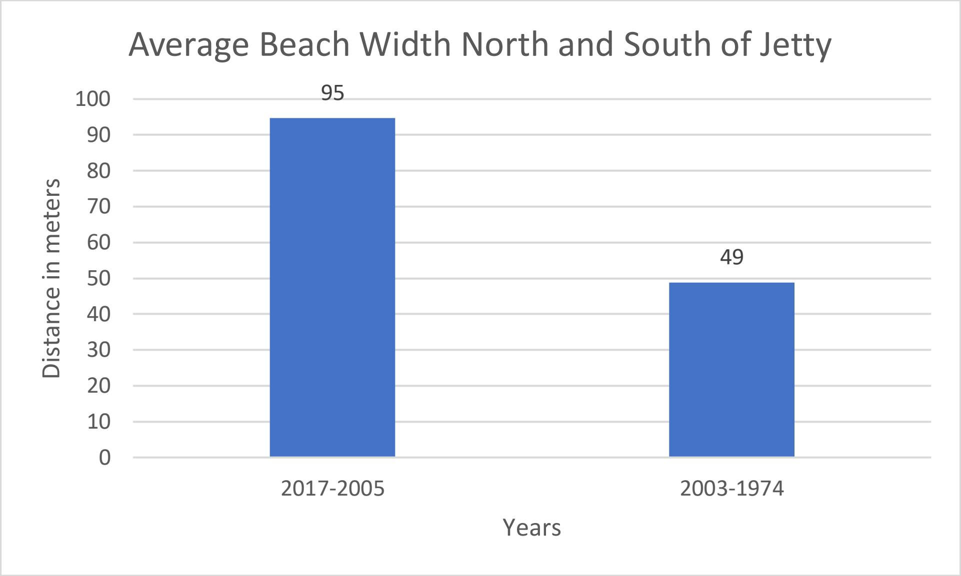

Figure 10. Averaged difference of shoreline distance between north and south of the jetty.

This difference in shoreline is also visible on site, as the beach is notably wider north of jetty and accompanied by normal wave action, whereas the beach south of the jetty is narrower and quieter (Fig. 11). These observable differences tell of both long-term and immediate impacts of the jetty.

Figure 11. Jetty on southeastern corner of Cumberland Island facing east, hence northern shoreline is left and the southern shoreline is right. (Photo by Arbour Guthrie, November 3, 2018.)

The beach area over the years has fluctuated, but the beach area south of the jetty decreased by an average of 42 m^2 compared to 22 m^2 north of the jetty (Figs. 12, 13). Beach area south of the jetty has had a more rapid decline in area. Beach area was calculated by measuring the area between the shoreline and dunes with previously depicted data (Fig. 8).

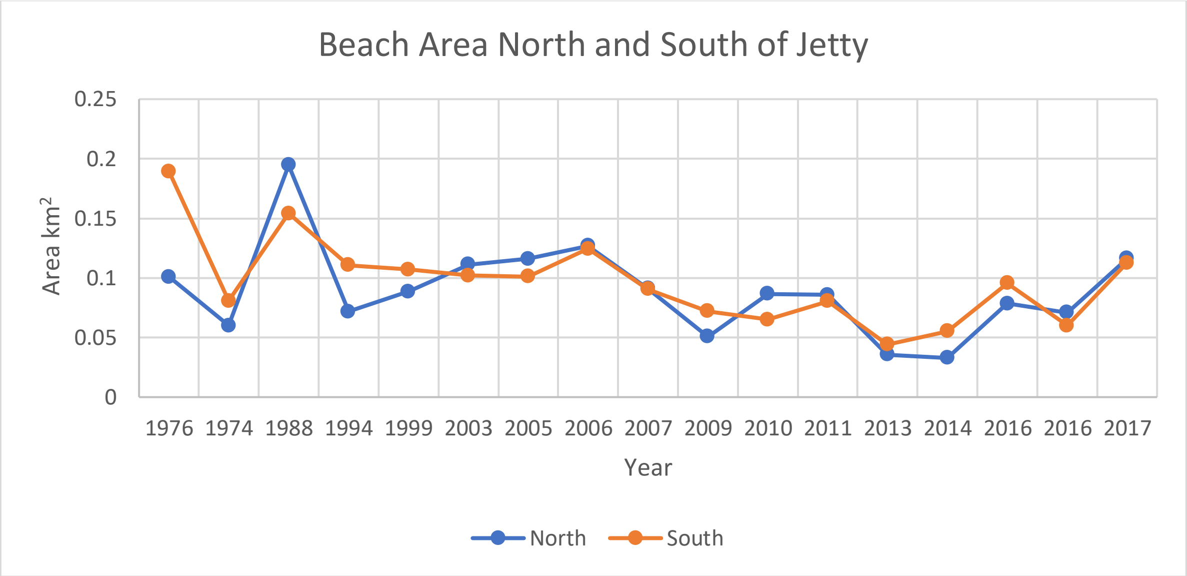

Figure 12. Beach area (kilometers squared) between the shoreline and dunes for each year in 800 m zone north and south of the jetty.

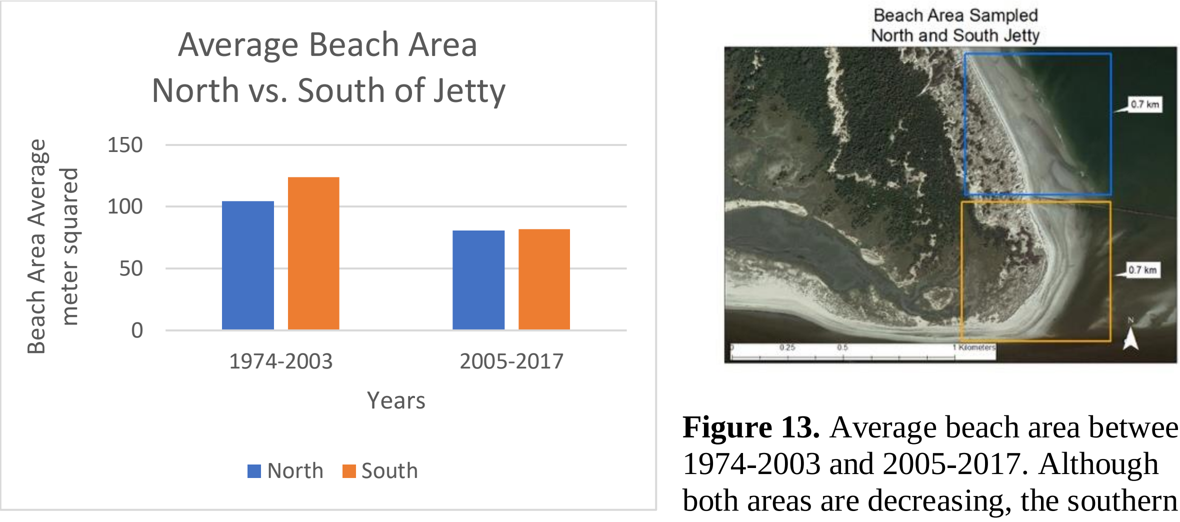

Figure 13. Average beach area between 1974-2003 and 2005-2017. Although both areas are decreasing, the southern beach area is decreasing at a faster rate.

Horse Trails

Aerial imagery revealed an overall steady increase in number and lengths of horse trails on the southern end of Cumberland Island. For instance, between 1999 and 2017 showed an increase of 21,659 m of trails, with an average increase of approximately 800-1,000 m/year (Fig. 14). Beginning with aerial images from 1999, trails expanded in both number and area (Fig. 15). About 2,000 m of trail used in 1999 are still in use today (Fig. 16).

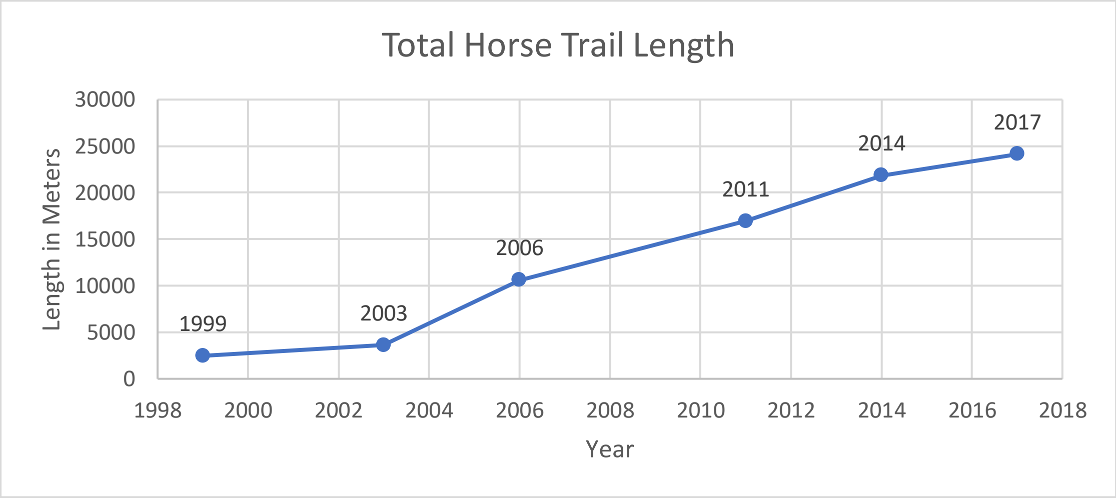

Figure 14. Total horse trail length for each year sampled; measurements drawn with ARCMap and cumulative trail length measured for each year, showing a steady increase of visible trails over the past 20 years.

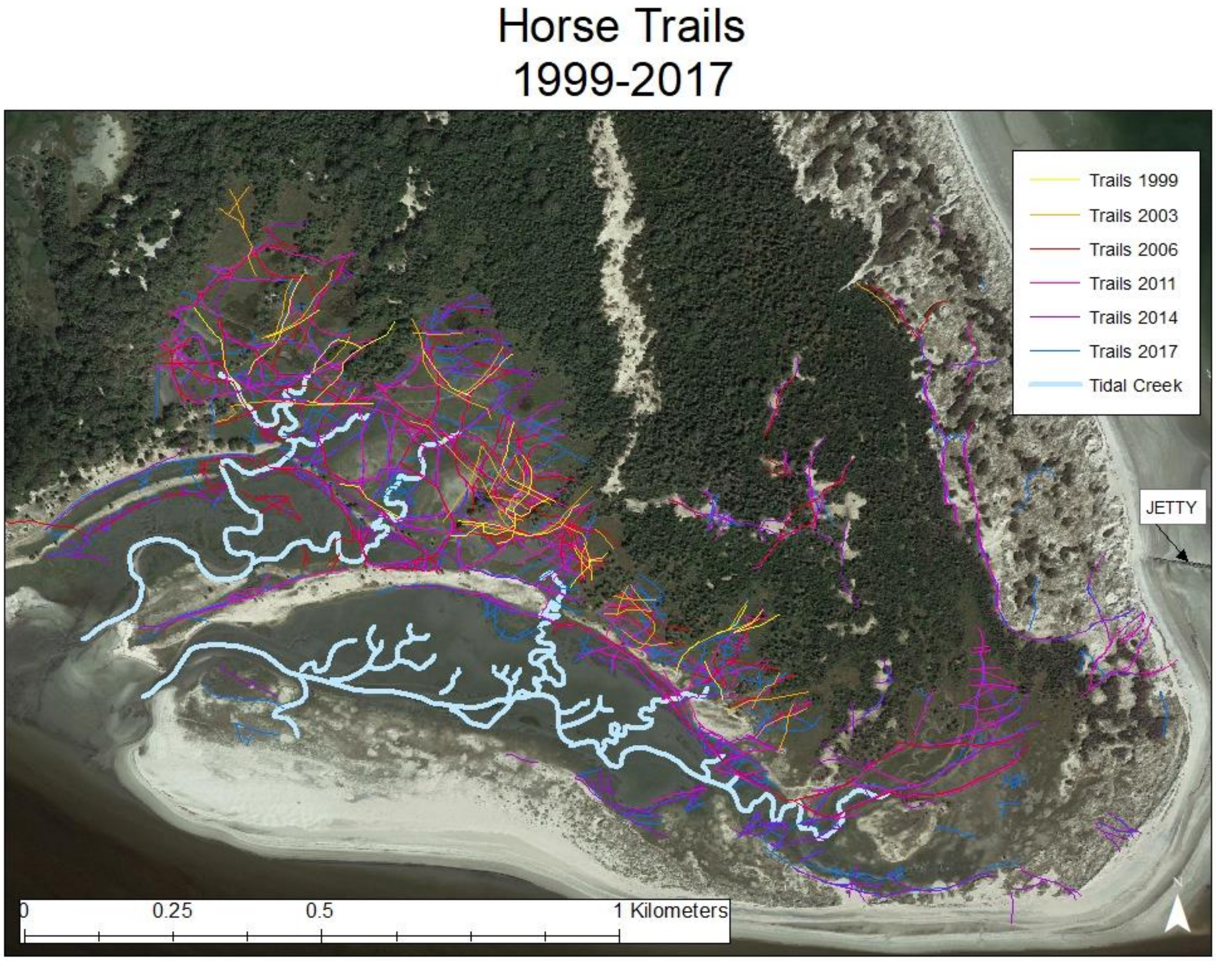

Figure 15. Trails from the 1999 to 2018, with depiction of main trail area used since 1999.

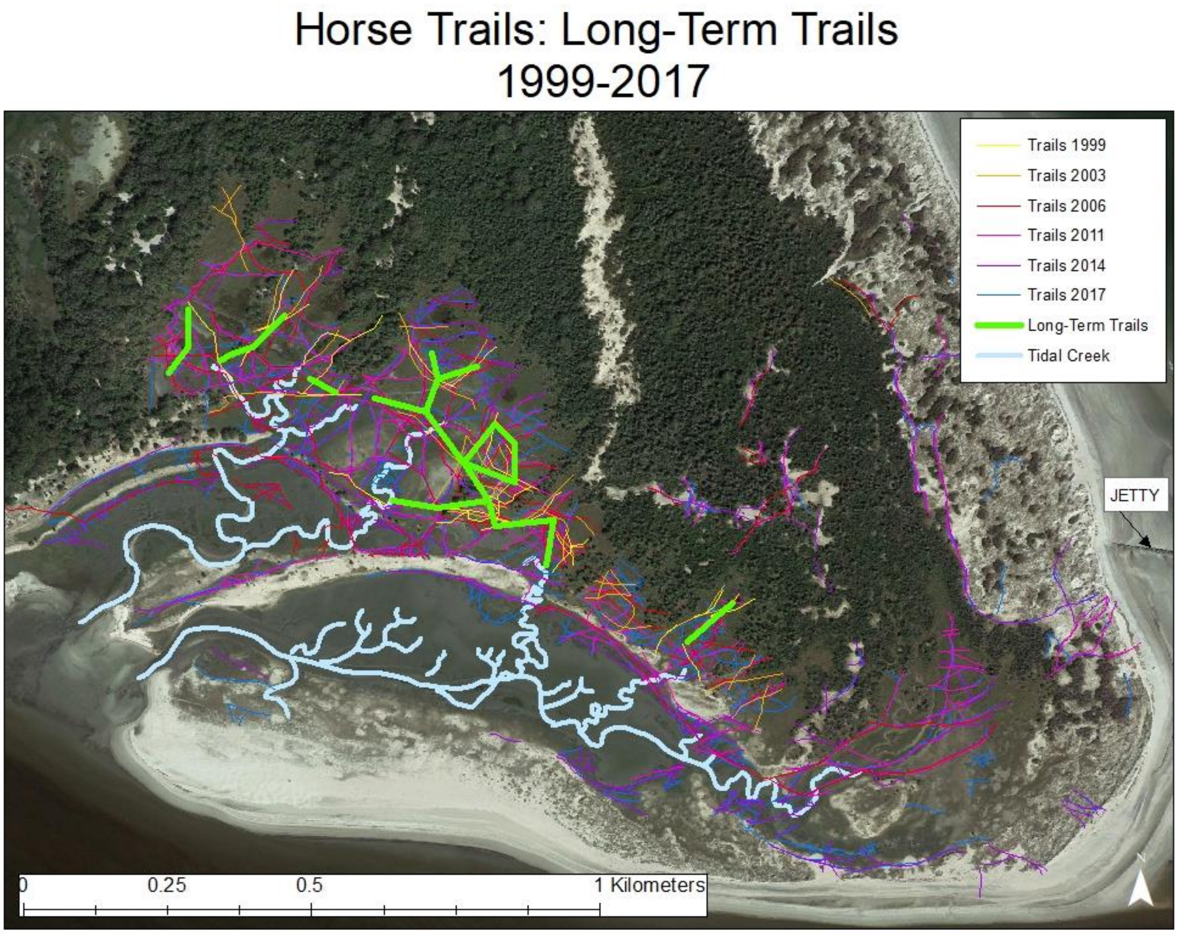

Figure 16. Trails from the 1999 to 2018, with trails that in use since 1999 indicated as Long-Term trails.

Some trails were in the dunes, but given the erodibility and low compressibility of sand versus less erodible and easily compacted clay-rich marsh soils, trails in marshes are more visible in the landscape, and hence more readily show habitual feral-horse movements across the landscape. Furthermore, trails in marshes are also likely used by horses to access dunes for grazing. Although horses compacted sediments and left their tracks and feces in marshes, the vegetation surrounding the trail – mostly consisting of the succulent glasswort (*Salicornia virginica*) – seemed otherwise unharmed (Fig. 17D). However, areas surrounding the trails in dunes, which consist of more grasses, were noticeably grazed (Figure 17A-D).

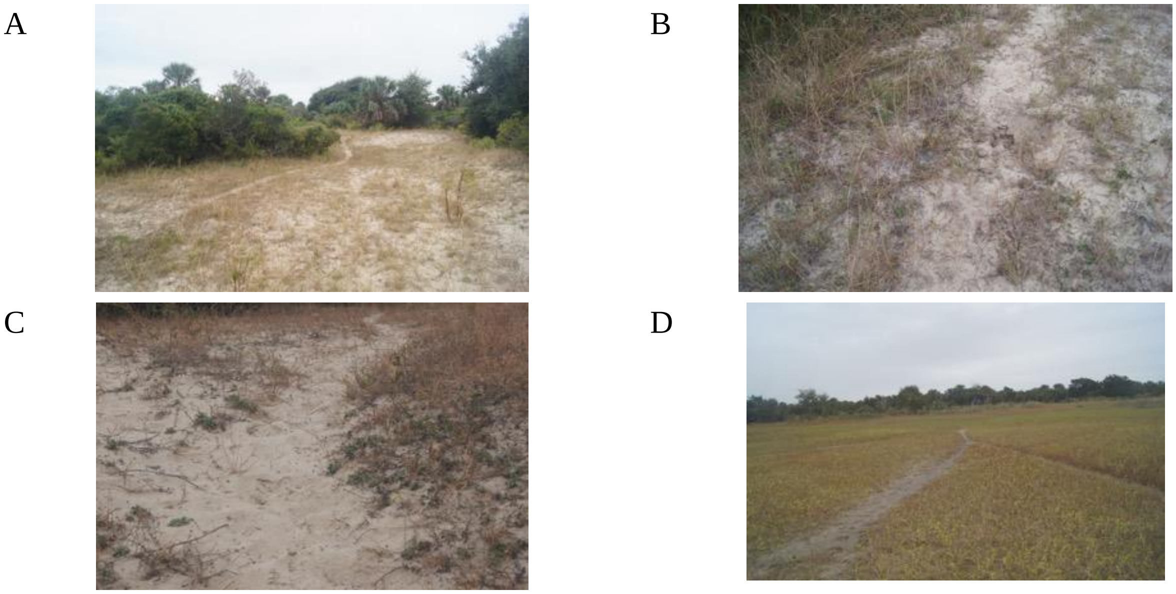

Figure 17. Feral-horse trails on Cumberland Island. A) Horse trail in dunes. B) Horse feces on trail in dunes. C) Horse tracks in trail in dunes. D) Horse trail in high marsh. (Photos by Arbour Guthrie, November 4, 2018.)

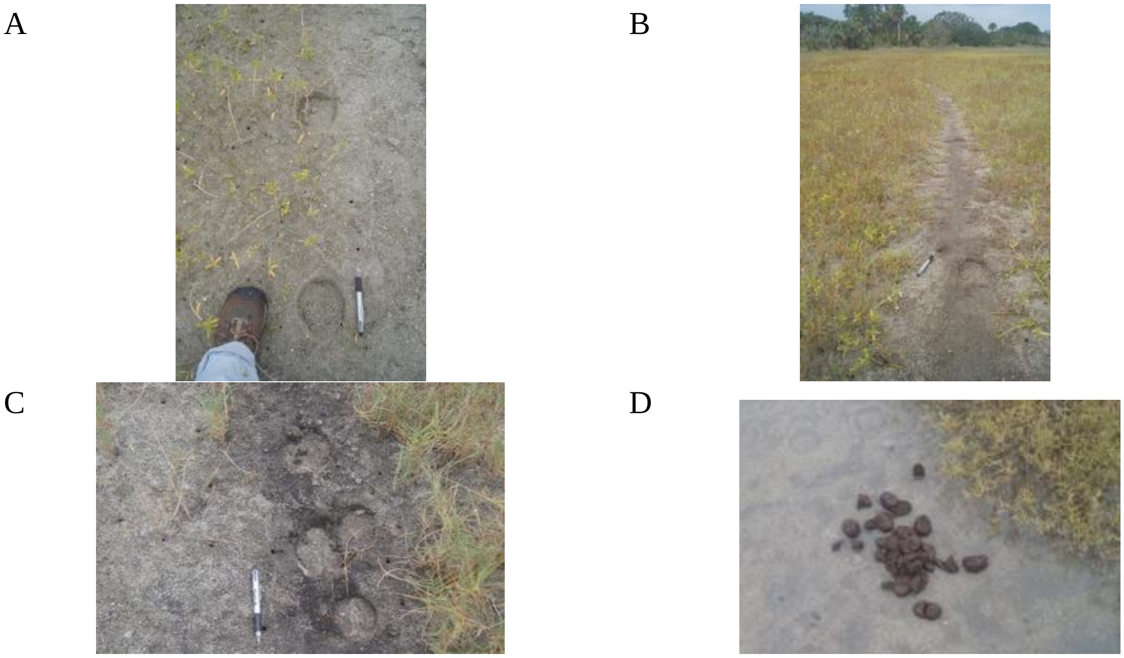

Figure 18. A) Image of horse print, pen for scale (13 cm/5 in). B) Horse tracks on trails in marshes, pen for scale. C) Image of horse prints in horse feces on trail, pen for scale. D) Image of horse feces and horse prints in low-lying area of marshes, marsh grasses are visible on the right. (Photos by Arbour Guthrie November 4th, 2018.)

Vegetation in high marshes on the southern portion of Cumberland was dominated by glasswort (*Salicornia virginica*) saltmeadow cordgrass (*Spartina patens*), and smooth cordgrass (*Spartina alterniflora*) in the low marshes (Figure 19). In some places, vegetation grows tall in the middle of muddy places with uncertain footing where horses tend to avoid, contrasting with grazed vegetation on drier, easily reachable land (Fig. 19C). Horses apparently consume what they can from the marshes, but leave behind *Salicornia virginica*, which may be too salty. Nevertheless, horses graze vegetation that is readily available, as can be seen with the tall vegetation in the middle of the ponded areas and grazed vegetation on pond edges (Fig. 19D). *Spartina alterniflora* is normally the dominant vegetation for low marshes on the Georgia coast, but also is a tasty treat to feral horses known to graze it (Turner 1987). Evidence for this dietary preference is visible where grazed grasses are short when compared to non-grazed *Salicornia virginica* patches in the high marsh (Fig. 19C).

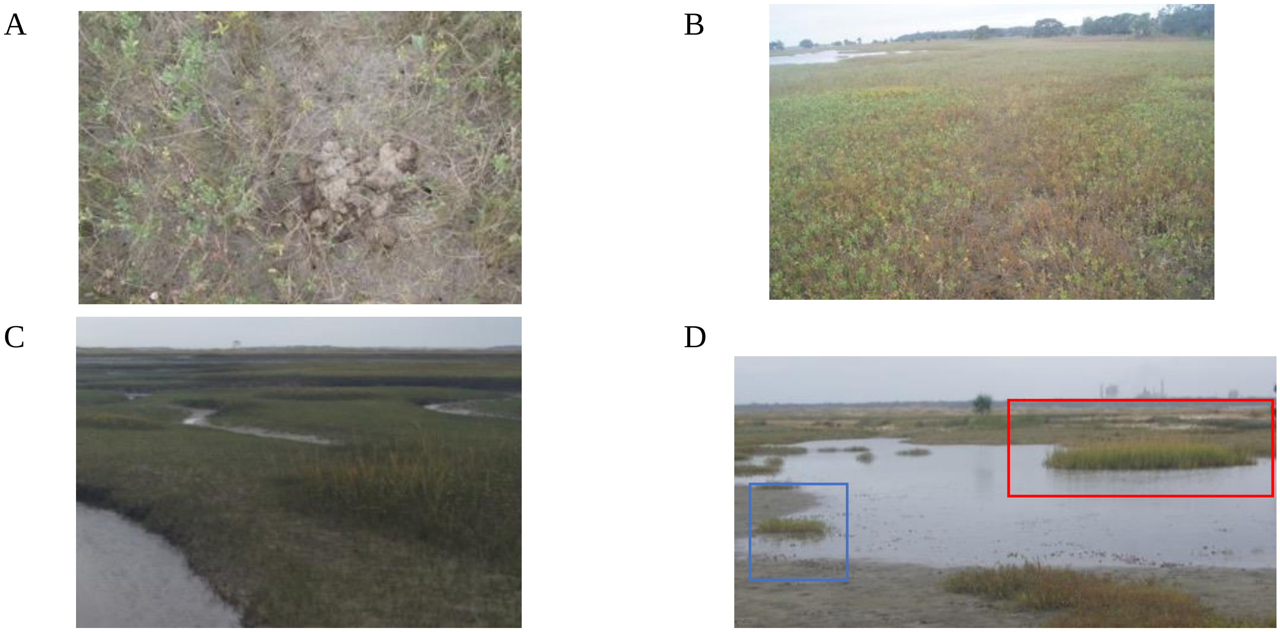

Figure 19. Images depicting vegetation found in the marshes A) Image of glasswort (*Salicornia virginica*) and dead saltmeadow cordgrass (*Spartina patens*) next to horse feces. B) A field full of *Salicornia virginica* with the beginnings of a trail in the center of the image. C) Grazed grasses, possibly *Spartina alterniflora* adjacent to tidal creek. D) Tall patch of vegetation in the red box and a grazed patch in the blue box. Photos taken by Arbour Guthrie November 4th, 2018.

Bedding traces also indicated horse habitats were in nearby maritime forests (Fig. 20A - B), providing further evidence that trails in high marshes were not for grazing, but a consequence of horses habitually passing through to low marshes and dunes. In the low marsh, the horses graze the *Spartina alterniflora*. In the dunes, horses are most likely to consume sea oats (*Uniola paniculata*), which leads to a decrease in dune vegetation (Fig. 21).

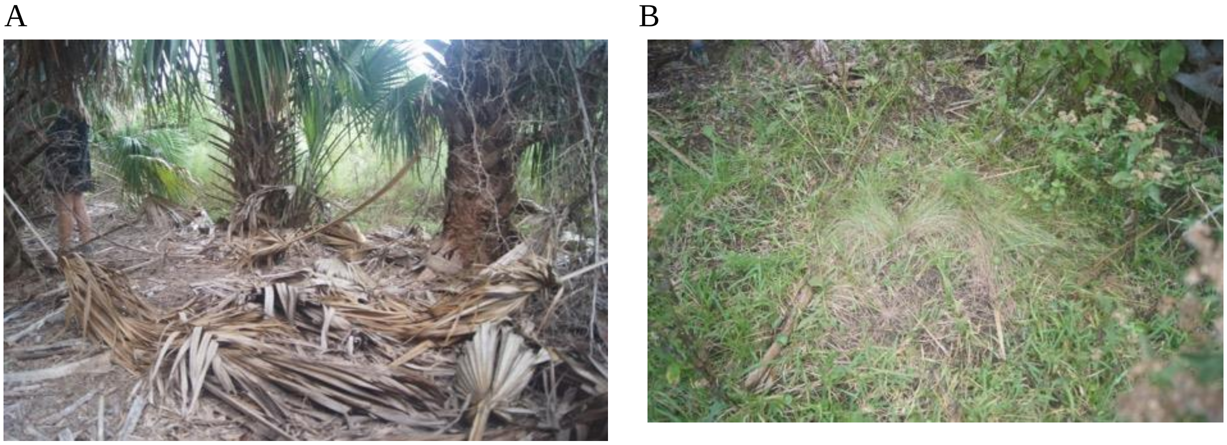

Figure 20. A) Traces of horse bedding in maritime forest. B) Matted-down grass in the maritime forest closer to marshes, also likely from horses bedding. Photos taken by Arbour Guthrie November 4th, 2018.

Dune Vegetation:

Between the years 1994 and 2017, dune vegetation decreased in area both north and south of the jetty (Fig. 21A). Currently the area south of the jetty has less vegetation than north of the jetty, as well as a decrease in proportional area of vegetation on dunes over time (Fig. 21B). The increased unvegetated dune area follows the same trend as sand area in the southern dunes, but vegetation does not follow any particular trend (Fig. 22). Sand area increased almost threefold since 1999, from 10,000 to 28,000 m^2. As total vegetated area remained within a range of 50,000-120,000 m^2 over the past 30 years (with some fluctuation), the proportional amount of vegetated areas on the southern dunes decreased. Since 1994, 38,066 m^2 of dune area was added to the southwestern portion of the dune fields south of the jetty (Fig. 23, Table 3), with an average of 1,655 m^2 every year. These trends imply that another factor – namely, the feral horses – affected the formerly vegetated area. Given this unexpected westward sand movement, there is a strong possibility that this sand is coming from eroded dune sands. In this scenario, the horses graze and trample the dunes, leading to decreased vegetation and dune destabilization, which then leads to wind transporting and depositing the sediment west.

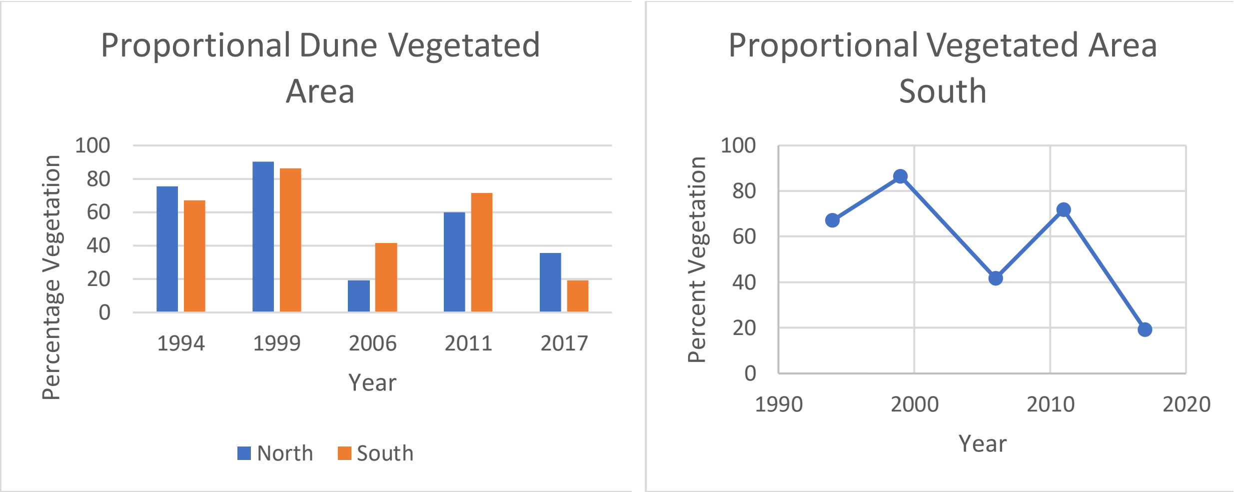

Figure 21A and B. A) Percent area of dune area on the southern end of Cumberland Island covered with vegetation for the area north and south of the jetty. B) Percent area of the dunes south of the jetty covered in vegetation. Measurements taken 800m north and south of the jetty.

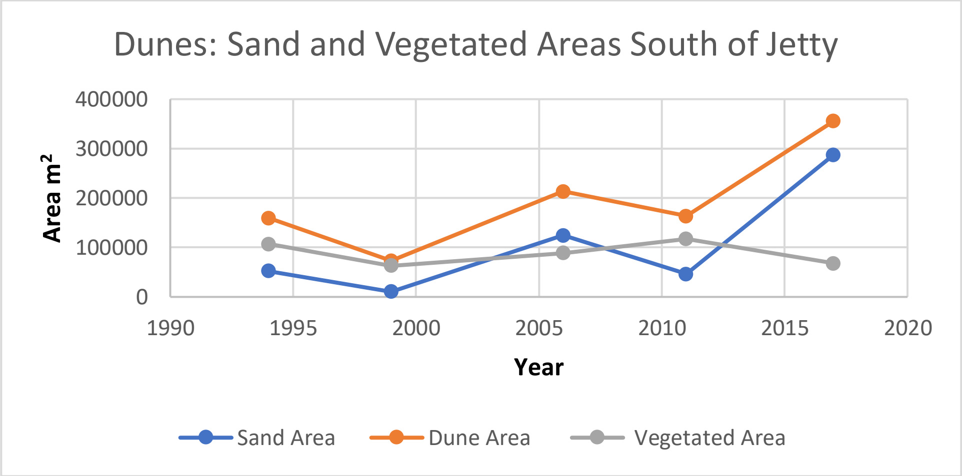

Figure 22. Comparison of total dune area with sand area and vegetation area south of the jetty. The sand area follows the curve of the total dune area, and within the last 10 years the vegetated area follows an inverse pattern to the sand and dune area curve.

Table 3. Area in meters squared of dunes added to the southern part of the island. Over the past 20 years 38,066 m^2 of dune area was added, depicted in Figure 21.

	1999	2006	2011	2017	Total	Average	Annual Average
Area Added	3,205	7,582	15,576	11,703	38,066	9,516.5	1,655

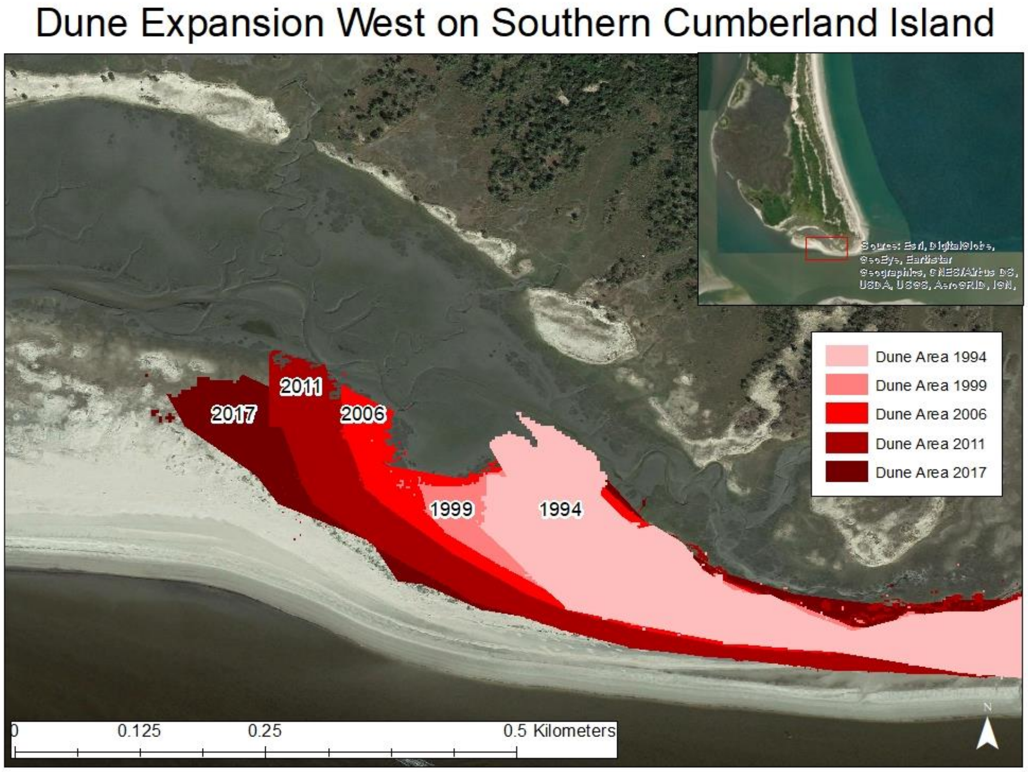

Figure 23. Area on southern end of Cumberland island where the dune field is expanding westward, from 1994 through 2017.

Discussion

The main goal of my study was to examine whether or not the jetty and feral horses on Cumberland Island affected its southeastern shoreline and dune vegetation during the past half-century, using field work, aerial imagery, and GIS analysis. My initial hypothesis stated that the jetty and feral-horse population on the island had a significant impact on the shoreline and dunes, changing their baseline dynamics. Overall my results support the initial hypothesis that the jetty and the feral horses affect this part of the island, as proportional dune vegetation has decreased noticeable over the past 20 years, along with shoreline destabilization.

In a sense, though, the jetty stabilizes part of the shoreline, with my results showing a halting of shoreline progression south of the jetty as early as 1982. The southern part of the shoreline has been subject to erosion since jetty installation (Griffin, 1982), and if it is a typical jetty-shoreline system, erosion will continue (Frihy et al., 1991; Byrnes and Matteson, 1995; Bulleri and Chapman, 2010; Pietrafesa, 2012; Mohanty et al. 2012; Oost et al. 2012; Keshtpoor et al. 2013; Gittman et al. 2015). Remnants of the jetty were found in the high marsh, providing further evidence of major shoreline progression north of the jetty (Fig. 6 and 7). However, coastal erosion directly degrades dune vegetation and stability, which in turn destabilizes dunes and can lead to more erosion (Feagin et al. 2005: Oost et al. 2012; Zuo et al. 2012; Ajedeba 2019); vegetation tends to reduce beach and coastal erosion (Silva et al. 2016).

Lack of shoreline progression typically means stabilization in specific locations along the shoreline (Jarmalavičius et al. 2012), which is happening on Cumberland’s southern shoreline as well as other jetty-impacted shorelines. In most instances, this would lead to temporarily stable dunes and increases in vegetation. This did not occur on Cumberland, though, because of the horses. Despite the western growth of the dune area on the southern shoreline from the stabilizing jetty, horse grazing led to an overall decrease in dune vegetation. Evidence of horses grazing in the dunes includes their trails, which increasingly encroached on dune systems over time (Fig. 17). Further trace evidence during visits to the island indicate that horses were crossing marshes to reach dunes from maritime forests. As mentioned previously, feral horse grazing, clipping, and trampling can have a detrimental effect on vegetative cover and potentially increase dune vulnerability to erosion (Tuner 1987; Turner 1988; Seliskar 2003; Silva et al. 2016). Horse grazing also likely led to accelerated erosion of dune and beach sand, as suggested by the decrease of dune vegetation areas both north and south of the jetty. Furthermore, sediment was lost at a faster rate in the south where the jetty is starving the shoreline of sand, while horses simultaneously contributed to increased erosion.

Nevertheless, the long-term steady decline in dune vegetation over the past 30 years is cyclical in the short-term, and perhaps embedded in the decline (Fig. 21). This decrease is at least partly a result of grazing by feral horses. As horses steadily eat and pull vegetation from the dunes, sand is more prone to erosion (Seliskar, 2003). Hence when a strong storm hits a sandy shoreline, larger amounts of sand are eroded (Feagin et al., 2010; Silva et al., 2016). Once that sand is eroded, the proportion of vegetated dune areas slightly increases, but only because the overall area has decreased in years with high proportional dune vegetation. In 1999 and 2011, the dunes decreased in overall area with a slight increase in vegetation. Because the vegetation trend does not vary as much as the dune area trend, the data support my hypothesis that another factor, such as the feral horses, are controlling the vegetation and consequently making changes in dune area more drastic. As horses continue to graze on the vegetation, they further decrease vegetative cover and destabilize sand until another event erodes the sand, resulting in an overall trend of decreased vegetated areas. This cyclical trend is important to recognize, because if research is conducted on a smaller temporal scale of just five years, the data may show an increase of vegetated area, which happened between 2006 and 2011 (Fig. 21). This, however, would be an inaccurate picture, as a large temporal scale is needed to understand the change in vegetation over time.

Based on my results, the horses and the jetty combined are affecting the geology of the southeastern portion of the island and changing its sedimentary regimes. The jetty is changing the natural shoreline migration by “starving” the southern end of sediment, while the horses are decreasing the dune vegetation, which exposes more sand to erosion. The lack of new sediment south of the jetty and exposure of dune sediment to erosion from the horses has contributed to a steady westward transport of sand south of the jetty, creating new eolian deposits (Fig. 23). The horses are also increasing compaction through numerous and intersecting trails in the salt marsh, altering sediment structure and impacting organisms in the sediment, such as fiddler crabs, an example of how the horses are affecting marsh fauna as well as flora (Fig. 18A and C). The overall cumulative effects of the jetty and feral horses are the decreased vegetative cover, destabilized dunes, eroding southern beaches, and the western dune field expansion.

Although my findings and those of many other studies document how feral horses on barrier islands cause damage to the ecosystems there, little is being done to manage the feral-horse population on Cumberland Island. Previous researchers likewise found that the feral horses have an adverse impact on the island (Turner, 1987; Levin et al., 2002; De Stoppelaire et al., 2004; Freedman et al., 2011), and some people strongly recommended removing the horses for the health of island ecosystems and the horses (Taggart, 2008). The U.S. National Park Service also recognizes the damage done by the horses. In their public pamphlet on feral horses, they state that horses consume between 200 to 400 tons of vegetation each year, “…removing up to 98% of it in areas they frequent. This impact can cause damage to island resources by destabilizing dunes and streambanks, selectively removing native grasses and forbs, and threatening the biodiversity of native plants and wildlife” (U.S. National Park Service, 2018a). The U.S. National Park Service also conducts annual horse population surveys to keep track of growth or decline. The counts range from 120 to 148 horses a year, but most likely the total count is 150-190 (U.S. National Park Service, 2018b). U.S. National Park Service policies state that if an exotic species competes with native species or damages natural ecosystems, then these species must be controlled or eradicated, but they make an exception for feral horses (Ruckdeschel 2017). Realistically, given the public's positive views about horses, and the economic benefits that tourism brings to the county, local businesses, and the National Park Service, the horses are most likely staying for now.

The U.S. National Park Service does not mention the jetty in any recent pamphlets or literature, and seemingly has no intention of removing the jetty. Because barrier islands are naturally extremely dynamic, and normally experience rapid and drastic geomorphic and hydrologic changes (Feagin et al., 2010), it ultimately might be beneficial to conduct research in the long-term and short-term positive and negative consequences of jetty removal. Although the ecological, economic, and political consequences of removing the jetty must be considered first, my data suggests negative long-term ecological consequences of keeping the jetty there, especially with the continued presence of feral horses.

Similar methods for examining shoreline response were used in Brynes and Hiland's (1994) study on Cumberland and Amelia Island, with similar data collection through measuring differences in shorelines compared to the then-current year, while displaying differences with similar graphics. Accordingly, the methods I used are common, well-practiced, and comparable (Hapke et al., 2013; Flor-Blanco et al., 2015). Because of the limited availability of aerial images taken during the first half of the 20th century, my data rely heavily on images from the past 50 years. Another limitation of my study was that available images were not taken at the same times of the year, which do not account for daily (tidal) or seasonal differences and thus may cause issues comparing year to year. This limiting factor is why I compared within a given year for northern and southern sections, which hopefully improved accuracy. In addition, LiDAR images for multiple years were not available until 2005 for Cumberland; more such data would have produced more accurate dune vegetation polygons. However, the methods I used produced accurate results through in-depth comparison between images and polygons. The last limitation of my study was that photos were only available after jetty was installed. Hence, I was unable to look at immediate effects, but could examine long-term effects, which was my main subject of interest anyway. Cumberland Island, particularly the southern portion, apparently was not important to agencies taking aerial images prior to 1950; the USDA and subsequent state departments took such images mostly for agricultural purposes.

For future research, I suggest comparing Cumberland to other Georgia barrier islands for shoreline and beach changes, and perhaps actually tag and track horses to see places they graze most frequently. Then this information could be combined with my results to provide potential management solutions for the horses. I would also collect feces samples to see what the horses are consuming, and if it varies over the island. Future research could also compare vegetative cover to storm events, testing the hypothesis that large storms impact the proportional vegetative cover on the dunes. If aerial images were available, I would have liked to minimize seasonal and tidal variables of images and analyze aerial images taken in the same month at the same time of day. With greater resource availability and time, such a study is possible, evidenced by studies of other jetties (Frihy et al. 1991; Hall and Pilkey 1991; McBride and Brynes 1997; Jarmalavičius et al. 2012; Mohanty et al. 2012; Flor-Blanco et al. 2015). Additionally, future research could include measurements of dune heights with dune vegetative-cover analyses to consider other impacts of horses and the jetty on dune structure and stability.

In general, my research contributes more to understanding long-term anthropogenic effects on barrier islands, and how two seemingly unrelated components can combine to create positive-feedback changes of island environments. Over the long-term, the feral horses and jetty on Cumberland Island likely have a larger combined impact on the dune system and shoreline than they would individually. The interwoven aspects of coastal geology and invasive-species behavioral ecology are perhaps unique to this study, as most other studies of barrier islands mostly focus on one aspect of shoreline degradation or vegetation degradation.

Conclusions

The negative effects of human inhabitance and interference on Cumberland Island are evident and will continue to affect the sedimentary regimes and ecology of the island. Although more than 40 years have elapsed since the island became a protected U.S. National Seashore, the effects of human development and feral livestock pre-dating their management still prevail. The jetty and feral horses are causing a positive-feedback loop of erosion and deposition on the southern end of the island, with their combined presence affecting the island more so than they would individually.

The jetty starved the southern end of Cumberland Island of sand, and the feral horses are destabilizing dunes, leading to erosion. These two forces together led to a shrinking southern shoreline and weakened dune system on this part of the island. Horses do not belong on the island, as they are not meant to be restricted to its woodland, salt-marsh, or dune environments. The quality of life for the horses on Cumberland island is low, and many have suffered and died from being trapped in the low salt marsh, stuck between trees, bitten by venomous snakes, and starved of proper nutrition, along with other tragic endings (Ruckdeschel 2017). Although the tourists may love seeing the horses, management should take into consideration the well-being of the horses and island ecosystems. The jetty is also not natural to the island, and this human-made structure is affecting sediment erosion and accretion.

The past and present human alterations, the feral horses and jetty, will continue to have an environmental impact in the future. The U.S. National Park Service needs to consider the long-term health of island ecosystems and its inhabitants when discussing management of the horses and jetty. Cumberland Island is unique for this study because of its limited development and U.S. National Park management, which allows a more focused look on the effects of a jetty without other development. Further management and regulations regarding development and implementation of shoreline structures and wildlife management should consider the negative effects that the jetty and feral horses have on the natural sedimentary processes on the island. As managers of the island, we need to prioritize ecological and sedimentological sustainability so that we can continue to learn about and thrive with the diverse, delicate, and dazzling Cumberland Island.

References

Ajedegba, Johnson O., Jong-Won Choi, and Kim D. Jones. 2019. “Analytical Modeling of Coastal Dune Erosion at South Padre Island: A Consideration of the Effects of Vegetation Roots and Shear Strength.” *Ecological Engineering* 127 (February): 187–94. https://doi.org/10.1016/j.ecoleng.2018.11.020.

Bulleri, Fabio, and Maura G. Chapman. 2010. “The Introduction of Coastal Infrastructure as a Driver of Change in Marine Environments.” *Journal of Applied Ecology* 47 (1): 26–35. https://doi.org/10.1111/j.1365-2664.2009.01751.x.

Byrnes, Mark R., and Matteson W. Hiland. 1995. “Large-Scale Sediment Transport Patterns on the Continental Shelf and Influence on Shoreline Response: St. Andrew Sound, Georgia to Nassau Sound, Florida, USA.” *Marine Geology* 126 (1–4): 19–43. https://doi.org/10.1016/0025-3227(95)00064-6.

De Stoppelaire, Georgia H., Thomas W. Gillespie, John C. Brock, and Graham A. Tobin. 2004. “Use of Remote Sensing Techniques to Determine the Effects of Grazing on Vegetation Cover and Dune Elevation at Assateague Island National Seashore: Impact of Horses.” *Environmental Management* 34 (5): 642–49. https://doi.org/10.1007/s00267-004-0009-x.

Feagin, Rusty A., Douglas J. Sherman, and William E. Grant. 2005. “Coastal Erosion, Global Sea-Level Rise, and the Loss of Sand Dune Plant Habitats.” *Frontiers in Ecology and the Environment* 3 (7): 359–64. https://doi.org/10.2307/3868584.

Feagin, Rusty A., William K. Smith, Norbert P. Psuty, Donald R. Young, M. Luisa Martínez, Gregory A. Carter, Kelly L. Lucas, James C. Gibeaut, Jane N. Gemma, and Richard E. Koske. 2010. “Barrier Islands: Coupling Anthropogenic Stability with Ecological Sustainability.” *Journal of Coastal Research* 26 (November): 987–92. https://doi.org/10.2112/09-1185.1.

Freedman, Bill, Paul M. Catling, and Zoe Lucas. 2011. “Effects of Feral Horses on Vegetation of Sable Island, Nova Scotia.” *The Canadian Field-Naturalist* 125 (3): 200. https://doi.org/10.22621/cfn.v125i3.1222.

Frey, R. W., and J. D. Howard. 1988. “Beaches and Beach-Related Facies, Holocene Barrier Islands of Georgia*.” *Geological Magazine* 125 (6): 621–40. https://doi.org/10.1017/S0016756800023438.

Frihy, Omran E., Alfy M. Fanos, Ahmed A. Khafagy, and Paul D. Komar. 1991. “Patterns of Nearshore Sediment Transport along the Nile Delta, Egypt.” *Coastal Engineering* 15 (5–6): 409–29. https://doi.org/10.1016/0378-3839(91)90021-8.

Gittman, Rachel K, F Joel Fodrie, Alyssa M Popowich, Danielle A Keller, John F Bruno, Carolyn A Currin, Charles H Peterson, and Michael F Piehler. 2015. “Engineering Away Our Natural Defenses: An Analysis of Shoreline Hardening in the US.” *Frontiers in Ecology and the Environment* 13 (6): 301–7.

Griffin, Martha M. 1982. *Geologic Guide to Cumberland Island National Seashore*. Vol. Geologic Guide 6. Atlanta: Department of Natural Resources Environmental Protection Division Georgia Geologic Survey.

Hall, Mary Jo, and Orrin H. Pilkey. 1991. “Effects of Hard Stabilization on Dry Beach Width for New Jersey.” *Journal of Coastal Research* 7 (3): 771–85.

Hapke, Cheryl J., Meredith G. Kratzmann, and Emily A. Himmelstoss. 2013. “Geomorphic and Human Influence on Large-Scale Coastal Change.” *Geomorphology* 199 (October): 160–70. https://doi.org/10.1016/j.geomorph.2012.11.025.

Jarmalavičius, Darius, Gintautas Žilinskas, and Donatas Pupienis. 2012. “Impact of Klaipėda Port Jetties Reconstruction on Adjacent Sea Coast Dynamics.” *Journal of Environmental Engineering and Landscape Management* 20 (3): 240–47. https://doi.org/10.3846/16486897.2012.660884.

Keshtpoor, Mohammad, Jack A. Puleo, Jeffrey Gebert, and Nathaniel G. Plant. 2013. “Beach Response to a Fixed Sand Bypassing System.” *Coastal Engineering* 73 (March): 28–42. https://doi.org/10.1016/j.coastaleng.2012.09.006.

Klemas, Victor V. 2001. “Remote Sensing of Landscape-Level Coastal Environmental Indicators.” *Environmental Management* 27 (1): 47–57. https://doi.org/10.1007/s002670010133.

Levin, Phillip S., Julie Ellis, Rachel Petrik, and Mark E. Hay. 2002. “Indirect Effects of Feral Horses on Estuarine Communities.” *Conservation Biology* 16 (5): 1364–71. https://doi.org/10.1046/j.1523-1739.2002.01167.x.

National Park Service “Feral Horses - Cumberland Island National Seashore (U.S. National Park Service).” Accessed February 27, 2019. https://www.nps.gov/cuis/learn/nature/feral-horses.htm.

Martin, Anthony J. 2013. *Life Traces of the Georgia Coast.* Indiana University Press.

McBride, Randolph A., and Mark R. Byrnes. 1997. “Regional Variations in Shore Response along Barrier Island Systems of the Mississippi River Delta Plain: Historical Change and Future Prediction.” *Journal of Coastal Research* 13 (3): 628–55.

Mohanty, Pratap Kumar, Sisir Kumar Patra, Satyanarayan Bramha, Budhadev Seth, Umakanta Pradhan, Balaji Behera, Pravakar Mishra, and Uma Sankar Panda. 2012. “Impact of Groins on Beach Morphology: A Case Study near Gopalpur Port, East Coast of India.” *Journal of Coastal Research* 279 (January): 132–42. https://doi.org/10.2112/JCOASTRES-D-10-00045.1.

Mumby, Peter J., Peter S. Raines, David A. Gray, and Janet P. Gibson. 1995. "Geographic Information Systems: A Tool for Integrated Coastal Zone Management in Belize." *Coastal Management* 23 (2): 111–21. https://doi.org/10.1080/08920759509362260.

Oost, A. P., P. Hoekstra, A. Wiersma, B. Flemming, E. J. Lammerts, M. Pejrup, J. Hofstede, et al. 2012. "Barrier Island Management: Lessons from the Past and Directions for the Future." *Ocean & Coastal Management*, Special Issue on the Wadden Sea Region, 68 (November): 18–38. https://doi.org/10.1016/j.ocecoaman.2012.07.010.

Paris, Paul J., and Helena Mitasova. 2018. "Geospatial Contrasts between Natural and Human-Altered Barrier Island Systems: Core Banks and Ocracoke Island, North Carolina, U.S.A." *Journal of Coastal Conservation* 22 (4): 679–94. https://doi.org/10.1007/s11852-018-0601-5.

Pietrafesa, L.J. 2012. "On the Continued Cost of Upkeep Related to Groins and Jetties." *Journal of Coastal Research* 284 (September): iii–ix. https://doi.org/10.2112/JCOASTRES-D-12A-00004.1.

Pilkey, Orrin H. 2003. *A Celebration of the World's Barrier Islands*. Columbia University Press.

Ruckdeschel, Carol. 2017. *A Natural History of Cumberland Island*. Mercer University Press.

Seliskar, D. M. 2003. "The Response of *Ammophila breviligulata* and *Spartina patens* (Poaceae) to Grazing by Feral Horses on a Dynamic Mid-Atlantic Barrier Island." *American Journal of Botany* 90 (7): 1038–44. https://doi.org/10.3732/ajb.90.7.1038.

Silva, R., M. L. Martínez, I. Odériz, E. Mendoza, and R. A. Feagin. 2016. "Response of Vegetated Dune–Beach Systems to Storm Conditions." *Coastal Engineering* 109 (March): 53–62. https://doi.org/10.1016/j.coastaleng.2015.12.007.

Taggart, John B. 2008. “Management of Feral Horses at the North Carolina National Estuarine Research Reserve.” *Natural Areas Journal* 28 (2): 187–95. https://doi.org/10.3375/0885-8608(2008)28[187:MOFHAT]2.0.CO;2.

Turner, Monica Goigel. 1987. “Effects of Grazing by Feral Horses, Clipping, Trampling, and Burning on a Georgia Salt Marsh.” *Estuaries* 10 (1): 54–60. https://doi.org/10.2307/1352025.

———. 1988. “Simulation and Management Implications of Feral Horse Grazing on Cumberland Island, Georgia.” *Journal of Range Management* 41 (5): 441. https://doi.org/10.2307/3899586.

Zuo, Xiaoan, Xueyong Zhao, Shaokun Wang, Yuqiang Li, Jie Lian, and Xin Zhou. 2012. “Influence of Dune Stabilization on Relationship between Plant Diversity and Productivity in Horqin Sand Land, Northern China.” *Environmental Earth Sciences; Heidelberg* 67 (5): 1547–56. http://dx.doi.org.proxy.library.emory.edu/10.1007/s12665-012-1950-2.

Maps:

Esri. "World Imagery" [basemap]. Scale Not Given. "World Imagery". December 3, 2018. http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9. (Dec 5, 2018).

Esri. "World Topographic Map" [basemap]. Scale Not Given. "World Imagery". November 29, 2018.https://www.arcgis.com/home/item.html?id=30e5fe3149c34df1ba922e6f5bbf808f. (Dec 5, 2018).

“U.S. Geological Survey Open-File Report 2004-1196, COASTAL VULNERABILITY ASSESSMENT OF CUMBERLAND ISLAND NATIONAL SEASHORE (CUIS) TO SEA-LEVEL RISE, Figure 1.” n.d. Accessed March 2, 2019. https://pubs.usgs.gov/of/2004/1196/html/fig1.html.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. January 1994. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. March 1999. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. November 2003. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. November 2005. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. January 2006. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. November 2007. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. September 2009. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. December 2010. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. May 2011. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. March 2013. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. December 2014. January 28, 2019.

“Southern Cumberland Island” 30°43’15.06” N and 81°27’30.60” W. Google Earth. October 2016. January 28, 2019.

"Southern Cumberland Island" 30°43'15.06" N and 81°27'30.60" W. Google Earth. October 2017. January 28, 2019.

U.S. Geological Survey, 1994, USGS 1:24000-scale Quadrangle for Fernandina Beach, FL 1994: U.S. Geological Survey.

U.S. Geological Survey, 1988, USGS 1:250000-scale Quadrangle for Jacksonville, FL 1988: U.S. Geological Survey.

U.S. Geological Survey, 1981, USGS 1:100000-scale Quadrangle for Fernandina Beach, FL 1981: U.S. Geological Survey.

U.S. Geological Survey, 1981, USGS 1:24000-scale Quadrangle for Fernandina Beach, FL 1981: U.S. Geological Survey.

U.S. Geological Survey, 1960, USGS 1:250000-scale Quadrangle for Jacksonville, FL 1960: U.S. Geological Survey.

U.S. Geological Survey, 1958, USGS 1:24000-scale Quadrangle for Fernandina Beach, FL 1958: U.S. Geological Survey.

U.S. Geological Survey, 1957, USGS 1:250000-scale Quadrangle for Jacksonville, FL 1957: U.S. Geological Survey.

U.S. Geological Survey, 1948, USGS 1:250000-scale Quadrangle for Jacksonville, FL 1948: U.S. Geological Survey.

U.S. Geological Survey, 1944, USGS 1:62500-scale Quadrangle for Fernandina, FL 1944: U.S. Geological Survey.

U.S. Geological Survey, 1919, USGS 1:62500-scale Quadrangle for Fernandina, FL 1919: U.S. Geological Survey.

U.S. Geological Survey, 1993, USGS 1:24000-scale Quadrangle for Jekyll Island, GA 1993: U.S. Geological Survey.

U.S. Geological Survey, 1981, USGS 1:100000-scale Quadrangle for Brunswick, GA 1981: U.S. Geological Survey.

U.S. Geological Survey, 1979, USGS 1:24000-scale Quadrangle for Jekyll Island, GA 1979: U.S. Geological Survey.

U.S. Geological Survey, 1978, USGS 1:250000-scale Quadrangle for Brunswick, GA 1978: U.S. Geological Survey.

U.S. Geological Survey, 1978, USGS 1:250000-scale Quadrangle for Brunswick, GA 1978: U.S. Geological Survey

U.S. Geological Survey, 1961, USGS 1:250000-scale Quadrangle for Brunswick, GA 1961: U.S. Geological Survey.

U.S. Geological Survey, 1957, USGS 1:24000-scale Quadrangle for Jekyll Island, GA 1957: U.S. Geological Survey.

U.S. Geological Survey, 1956, USGS 1:250000-scale Quadrangle for Brunswick, GA 1956: U.S. Geological Survey.

U.S. Geological Survey, 1948, USGS 1:250000-scale Quadrangle for Brunswick, GA 1948: U.S. Geological Survey.

U.S. Geological Survey, 1946, USGS 1:250000-scale Quadrangle for Brunswick, GA 1946: U.S. Geological Survey.

U.S. Geological Survey, 1945, USGS 1:62500-scale Quadrangle for Brunswick, GA 1945: U.S. Geological Survey.