Historical Visualization Evidence on Forest-Salt Marsh Transition in Winyah Bay, South Carolina: A Retrospective Study in Sea Level Rise

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Abstract

Rising sea level is expected to impact low-lying ecosystems along the Southeastern and Gulf coasts in North America, converting freshwater-forested wetlands into salt marsh. In this study, we examined the transition from cypress-tupelo wetland, dominated with swamp tupelo, water tupelo, and bald cypress, to salt marsh in a middle section of Winyah Bay estuary in northeastern South Carolina, where relative sea level rise has averaged 3-4 mm/y since 1920. Using historical aerial photographs and geographic information system analysis, the rate of landscape change from forested wetland to tidal marsh was measured from 1949 – 2009 through three observable steps: death of tupelos, invasion of grasses, and death of cypress. Over the 60-year period, length of time explained 95% of the variation in marsh area. The marsh area in the studied site has increased from 1.72 to 6.74 ha (~ 300% increase) while the forested wetland has been decreased from 17.3 to 12.3 ha (29% loss). This paper demonstrates an application of historical aerial photographs as a retrospective method to examine the impacts of sea level rise in coastal wetland ecosystems.

Key Words
Coastal Wetlands, Cypress, Forested Wetlands, Swamp

Introduction

Sea level rise is an expected consequence of global warming. Eustatic sea level is expected to rise 0.48 m with a range between 0.11 and 0.77 m by 2100 (Church et al. 2001), although that estimation may be conservative and the range can be as large as from 0.5 to 1.4 m (Rahmstorf 2007). In either case, sea level rise under a changing climate is of a great concern to low-lying states in the southeastern United States with large coastal wetlands, including North and South Carolina (SC), Louisiana, Florida, and Texas. Low topographic gradients along river corridors and shallow groundwater tables lead to the formation of extensive bottomland hardwood forests and tidal freshwater forests along the South Atlantic coast (Conner et al. 2007). Sea level rise increases water levels and salinity in estuaries and encroaches upon these freshwater-forested wetlands. It has been estimated that approximately 58,000 km^2 of land along the Atlantic and Gulf coasts lies below the 1.5 m contour (Titus and Richman 2001). Predicting the rate of landscape change associated with rising sea level is valuable information to each of these states for identifying high-risk areas and implementing coastal protection plans.

In this paper we examine the impact of historic sea level rise on an interface of salt marsh and cypress-tupelo wetland adjacent to the Winyah Bay estuary in northeastern SC. Winyah Bay, a moderate sized estuary along the Atlantic coastline, has experienced significant impacts by geologically controlled long-term sea level rise. The boundary between the low-lying coastal forest and high marsh has moved up slope through time. Sandy forested spodosols are subjected to tidal inundation and salinization, and forest vegetation (e.g., *Pinus*, *Quercus*, and *Vaccinium*) is replaced by coastal salt marshes (e.g., *Juncus* and *Spartina*) (Gardner et al., 1992). The main goal of this examination is to determine how well simple topographic analysis identifies the observed landscape changes during this 60-year period with roughly 24 cm of relative sea level rise.

Materials and Methods

<u>Study Site</u>

Winyah Bay is a 65 km^2 estuary situated on the SC coast, 97 km northeast of Charleston (Lat 33d 19 m 13s N, Long 79d 15m11s W). It is roughly 22 km long and varies from 1.2 km wide at the entrance, to 7.2 km wide in mid bay, and 2 km wide at the confluence of Waccamaw and Pee Dee rivers (Patchineelam and Kjerfve 2004). The estuary receives flow from four rivers (Pee Dee = 88%, Waccamaw = 7%, Black = 5%, and Sampit <1%) at an average rate of 557 m^3/s and has an annual sediment load of 4.3 x 10^5 ton/

yr (Patchineelan et al. 1999; Goni et al. 2005). Relative sea level rise has been estimated at Charleston, SC, to be 3.15 ± 0.25 mm/yr for the period 1921-2006, and at Springmaid Pier, SC (about 30 km northeast of Winyah bay), at 4.09 ± 0.76 mm/yr for the period 1957-2006 (NOAA 2011). The estuary is separated from the Atlantic Ocean by the Waccamaw Neck Peninsula, an upland area of ancient beach deposits from 2-10 m in elevation. Strawberry swamp is the local name for small creek that enters the eastern side of Winyah Bay, 18 km upstream from the estuary mouth.

Aerial Photo Interpretation

The Baruch Institute retrieved prints from the US Department Agriculture archives for 1949, 1952, and 1963 and maintained these as an onsite archive. These 1:15840 scale prints were scanned at 400 dots per inch and converted to tagged image file (TIF) format digital files. These digital photographs had a pixel size of approximately 1m (3.3 feet). From 1965 until 1992 Clemson University departments of Forestry and Agricultural Engineering operated a Cessna 150 with a pod containing a World War II era, Zeiss 9x9 inch format aerial camera. A variety of films were used including: infra-red enhanced panchromatic (1970); panchromatic (1965, 1973, and 1978); false color infra-red (1975, 1980, 1989-1992); and true color (1982, 1983, 1984, 1985, and 1987). This plane flew at 1,829 m (6,000 ft) and produced prints of approximately 1:12000 scale. For this paper images from 1970, 1980, and 1990 were also scanned at 400 dots per inch (dpi) and converted to TIF format digital files. These digital photographs had a pixel size of approximately 0.76 m (2.5 feet). National Arial Photography Project (NAPP) digital ortho-photographs were available from the South Carolina Department of Natural Resources (SCDNR) server for 1994, 1999, and 2006 for this area (SCDNR, 2011). These digital photos were geo-referenced to the 1983 North American Datum (NAD83) with the Universal Transverse Mercator (UTM) Zone 17 projection. Finally, Georgetown County contracted for high resolution, pixel size of 0.15m (6 inches), ortho-rectified aerial photographs (NAD83, State Plane FIPS_3900) in February 2009. A digital copy of the area of interest was obtained from this photography (Georgetown County 2011).

For this comparison photographs were chosen to span time steps of approximately one decade (1949, 1963, 1970, 1980, 1990, 1999, and 2009). The 2006 NAPP ortho-photograph was chosen as the cartographic base and all others were rectified (or projected for 2009) to this base. Since much of the forest was over 100 years old, uniquely positioned tree crowns (e.g., in openings, at road intersections) were used as ground control points. Twenty such trees were identified on the 2006 ortho-photo to serve as ground control points. For each photograph 1 - 4 trees were chosen near the edges of Strawberry Swamp, along with others near the periphery of the photographs as ground control points. Since the appearance of each photograph varied (film type, sun angle, crab and tilt of airplane) a subset of 5 - 8 control points were chosen for each photograph that produced the smallest rectification errors. First order polynomial, nearest neighbor, and transformations were used to re-sample each photograph and root mean square (RMS) errors of up to 5 pixels were accepted for final rectifications.

Marsh and Tree Mortality Identification

Strawberry swamp presently consists of two vegetation types. The forested portion is a cypress-tupelo type with the major species swamp tupelo (*Nyssa sylvatica* var. *biflora*), water tupelo (*Nyssa aquatica*), and bald cypress (*Taxodium distictum*). The marsh section is dominated by cordgrass (*Spartina cynosuroides*), bulrush (*Scirpus robustus*), and cattails (*Typha angustifolia*, *Typha latifolia*). Three steps can be identified in the progression from cypress-tupelo forest to marsh grass: 1) death of swamp tupelos, 2) invasion of grasses, and 3) death of cypress. These steps can be identified in each of the photographic types. Marsh grasses appear as fine-grained light gray on panchromatic (e.g., 1948), light green or slightly brown on true color (e.g., 2009), and light blue on false color infra-red (e.g., 1980). Living deciduous trees, both cypress and tupelo, are light gray with a much coarse grain on panchromatic, blue-green on true color and blue on false color infra-red. In addition to coarser texture caused by crown and shadow, individual crowns can be distinguished even on winter photographs. The appearance of individual crowns and shadows of cypress and tupelo become smaller with the loss of fine branches within 12-18 months of mortality. Pines and evergreen hardwoods found on the uplands have similar coarse grain of crowns and shadows. They are darker gray on panchromatic, light to dark green on true color, and red on false color infra-red. Using these visual clues the progression appears as four zones: unchanged forest (appears as over 70% crowns); forest with high mortality and invading grass (appears as areas with 30-70% tree crown) (step 1 – death of tupelo); marsh of all grass and occasional tree survivors (less than 30% of the tree crowns remaining) (step 2 – invasion of grasses); and marsh of all grass (step 3 – death of cypress).

Polygons were digitized on each photograph (using ARC-GIS 9.3) to mark the extent of marsh, and area of high forest mortality. The westward edge of each polygon was marked by a small rice field dike and ditch on the 1949 photograph. The dike is still recognizable as a color change in the marsh in the 2009 photo and serves a straight-line boundary that was extended to the present mash edge. This straight edge was used to create a closed polygon of the boundary of marsh grass. The area of high mortality was digitized as an appended polygon to the marsh polygon by digitizing the boundary between recognizable mortality and the normally appearing forest.

Land Elevation

Land elevation data for the area, where aerial photographs were interpreted, were derived from Light Detection and Ranging (LIDAR) data flown by Airbourne 1 in 2003 at 1,372 m (4500 feet) altitude with a point spacing of 1.4 m, horizontal accuracy of 0.5 m and 95% of vertical points of 0.37 m. The data consisted of an ARC-VIEW point shape file of all last return points. These data were relative to the 1983 North American (horizontal) Datum (UTM zone 17N projection) allowing them to be directly compared to the aerial photographs. Elevation data were relative to the North American Vertical Datum of 1988. A single tile of LIDAR data encompassed the entire region of the aerial photographs. This file was intersected with each marsh polygon, digitized from the aerial photography series, to produce a point shape file of elevations. These individual files contained from 15800-27800 points depending on marsh size. Mean elevation and standard errors were calculated for the each set of LIDAR points corresponding to the marsh polygons.

Results and Discussions

<u>Visual Evidences of Forested Wetland and Salt Marsh Transitions</u>
Figure 1 a-g shows the progression of forest to marsh at Strawberry swamp at roughly one-decade intervals from 1949 to 2009. Freshwater forested wetlands with water salinity of 0.5 ppt or less are dominated by bald cypress, water tupelo, and swamp tupelo (Fig. 2a). The area can be found in point A in the 2009 aerial photo (Fig. 1g). Degraded sites have experienced moderate saltwater intrusion with salinity of 0.5 – 5 ppt (oligohaline). Some species progressively fall out of the vegetation assemblage as the canopy opens, leaving only bald cypress and a scattering of swamp tupelo (Fig. 2b). This area can be found in point B in Figure 1g. Salt marsh site is defined as having originally been freshwater wetlands that now receive saline water inputs with salinity of 18 ppt or less (mesohaline). All the hardwood species had died and been replaced with salt marsh vegetation (e.g. *Juncus* and *Spartina*) (Gardner et al. 1992). Stumps are still visible but are progressively covered by sediment accretion (Fig. 2c). This area can be found in point C in Figure 1g.

In 1949, areas of salt marsh and forested wetland were estimated at 1.72 and 17.3 ha, respectively, whereas the areas were expanded and encroached to 6.74 and 12.3 ha in 2009. Our calculation shows that there are 300% increase in salt marsh and 29% loss in forested wetland in the studied site in the last 60 years. Although the rate of marsh expansion is not uniform, a couple of trends are apparent. The marsh tended to expand into the area that was identified to have had enhanced mortality the decade before. Although a few trees held on for several decades, most notably the group of trees near the center of the 1949 marsh, survivors tended to disappear within two decades after mortality was first observed.

Table 1 presents the results of GIS analysis performed on the polygons digitized in Figure 1. The area of marsh steadily increased with the smallest increase from 1970 - 80 (i.e. 0.01 ha) and the largest from 1999-2009 (i.e. 2.36 ha). Between 1949 and 1980 (Figures 1a - d) marsh expansion was primarily within

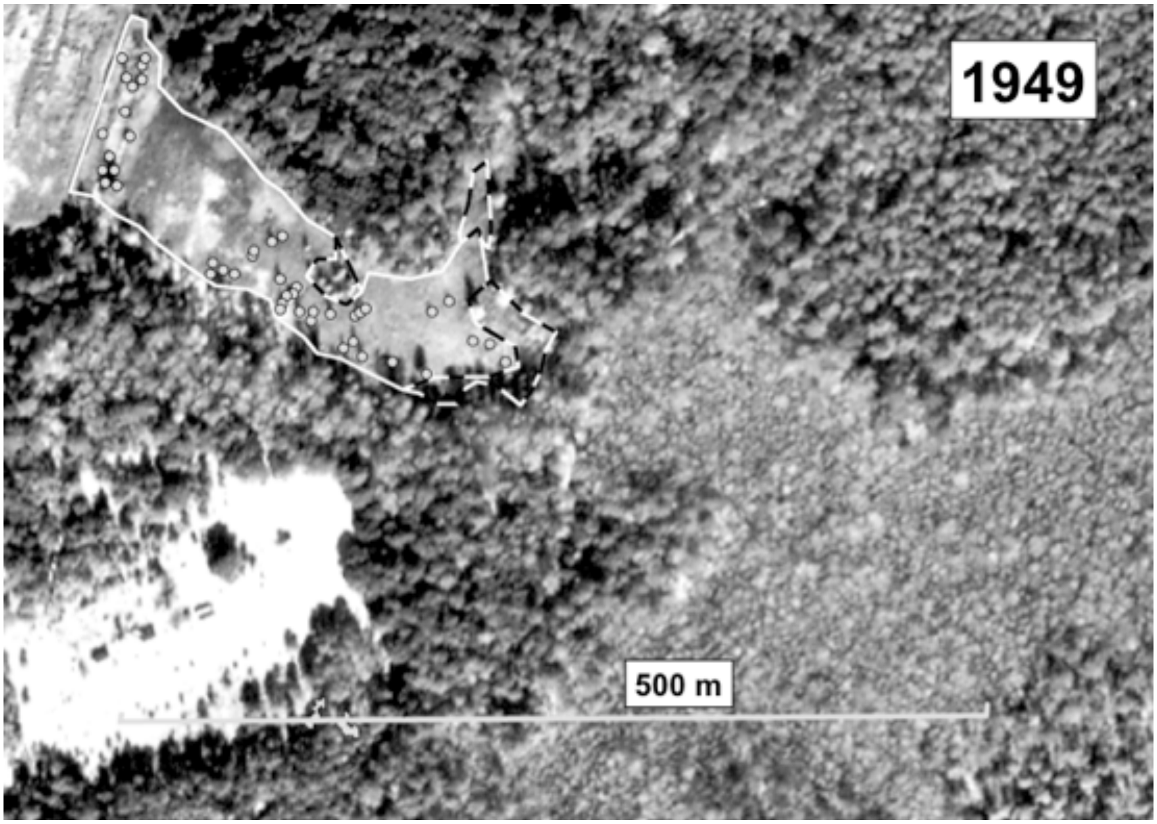

Figure 1a: Shows the forest-marsh landscape in 1949. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh.

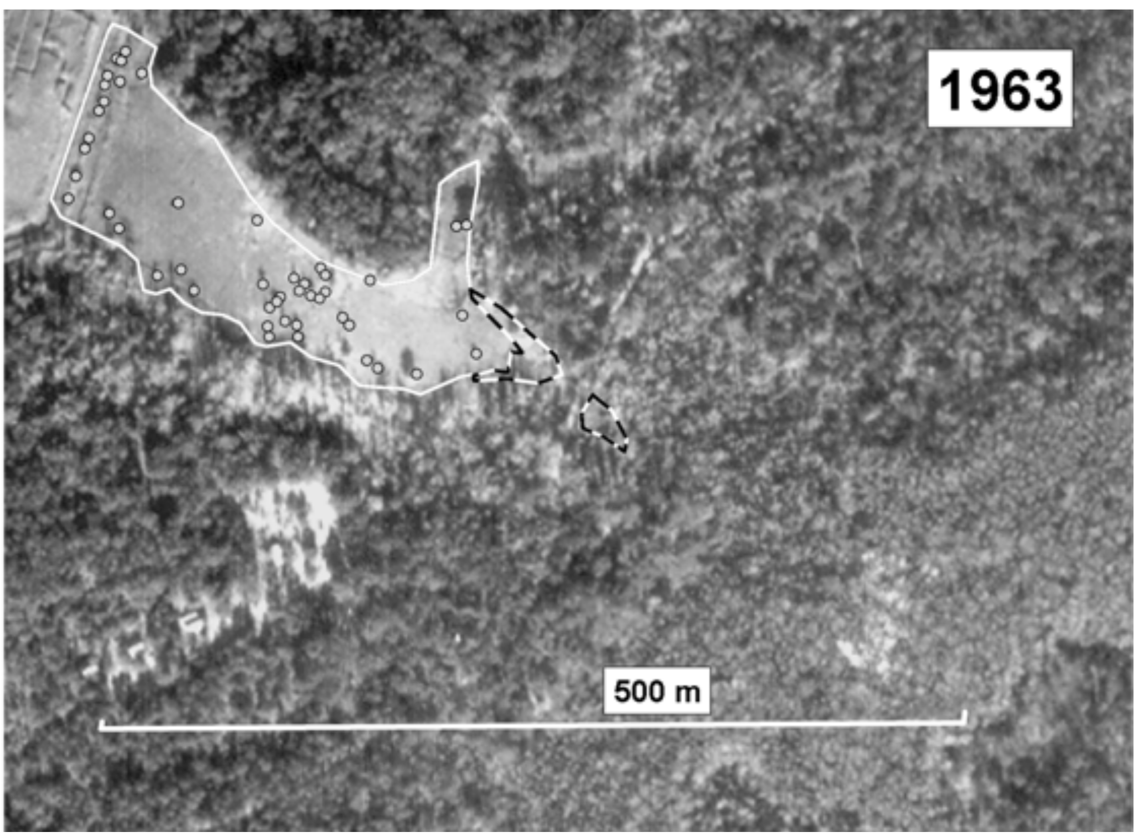

Figure 1b: Shows the forest-marsh landscape in 1963. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh.

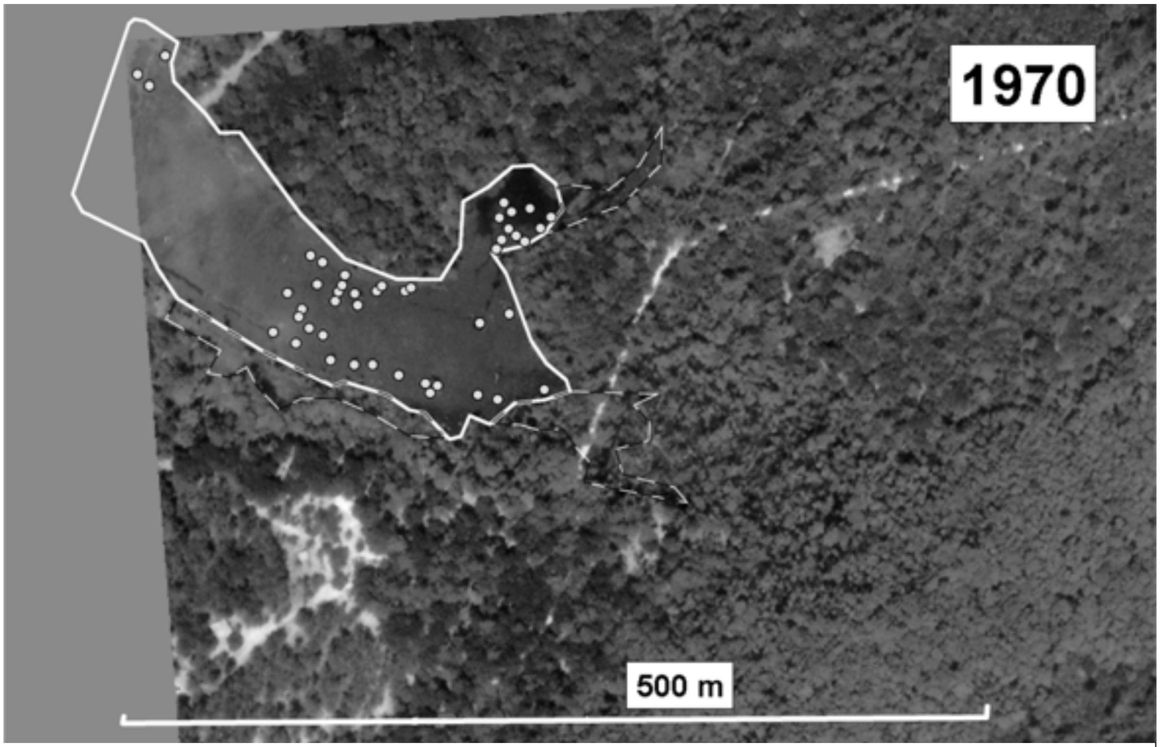

Figure 1c: Shows the forest-marsh landscape in 1970. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh. The line at the bottom of each figure is a 500 m mark for comparison purpose. Aerial photos taken from different angles are rectified to the same orientation and scale.

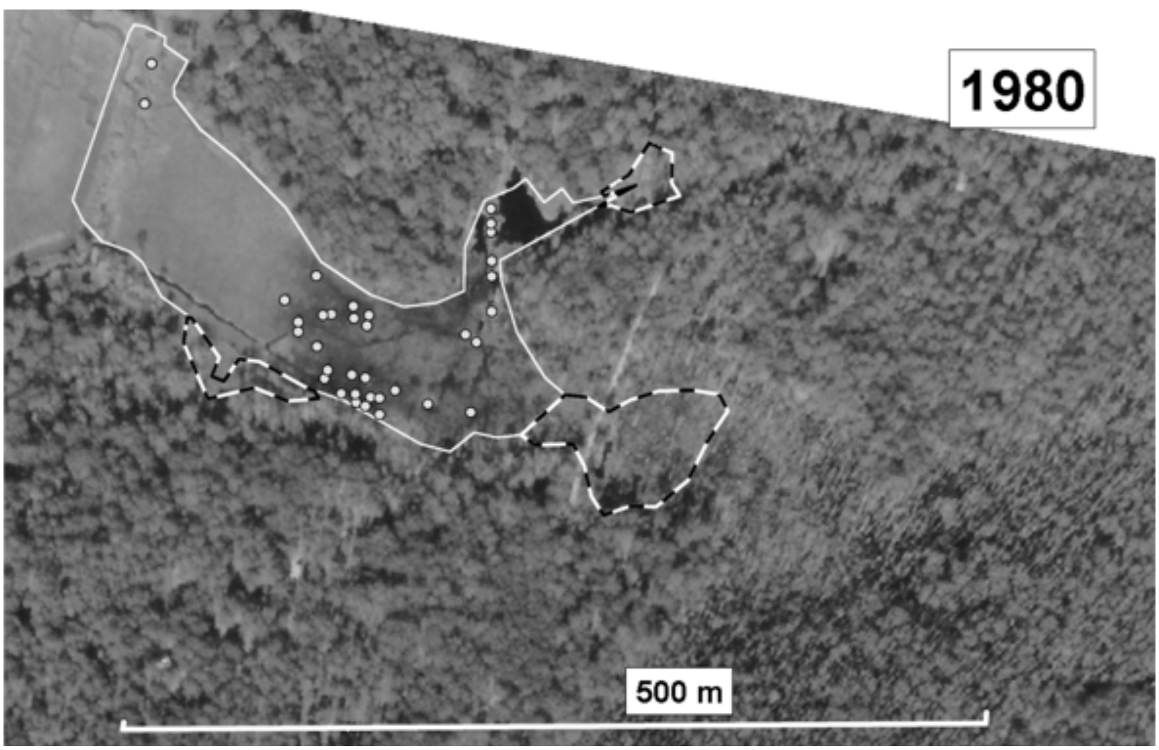

Figure 1d: Shows the forest-marsh landscape in 1980. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh. The line at the bottom of each figure is a 500 m mark for comparison purpose. Aerial photos taken from different angles are rectified to the same orientation and scale.

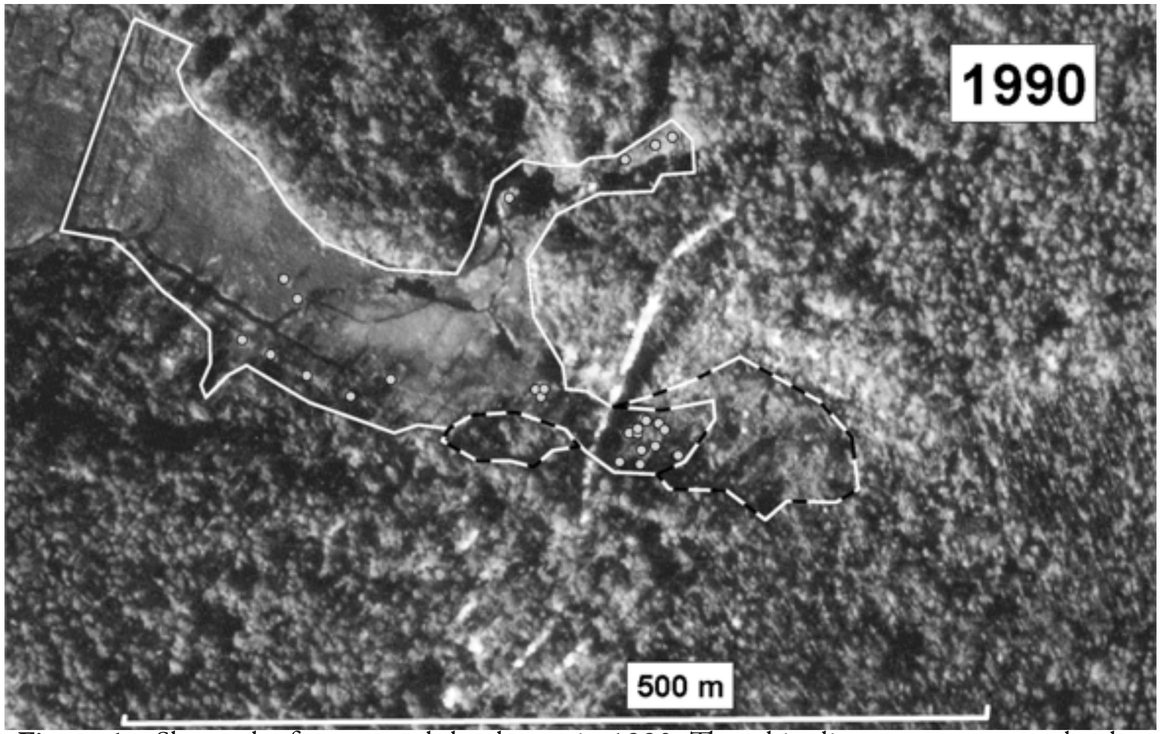

Figure 1e: Shows the forest-marsh landscape in 1990. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh.

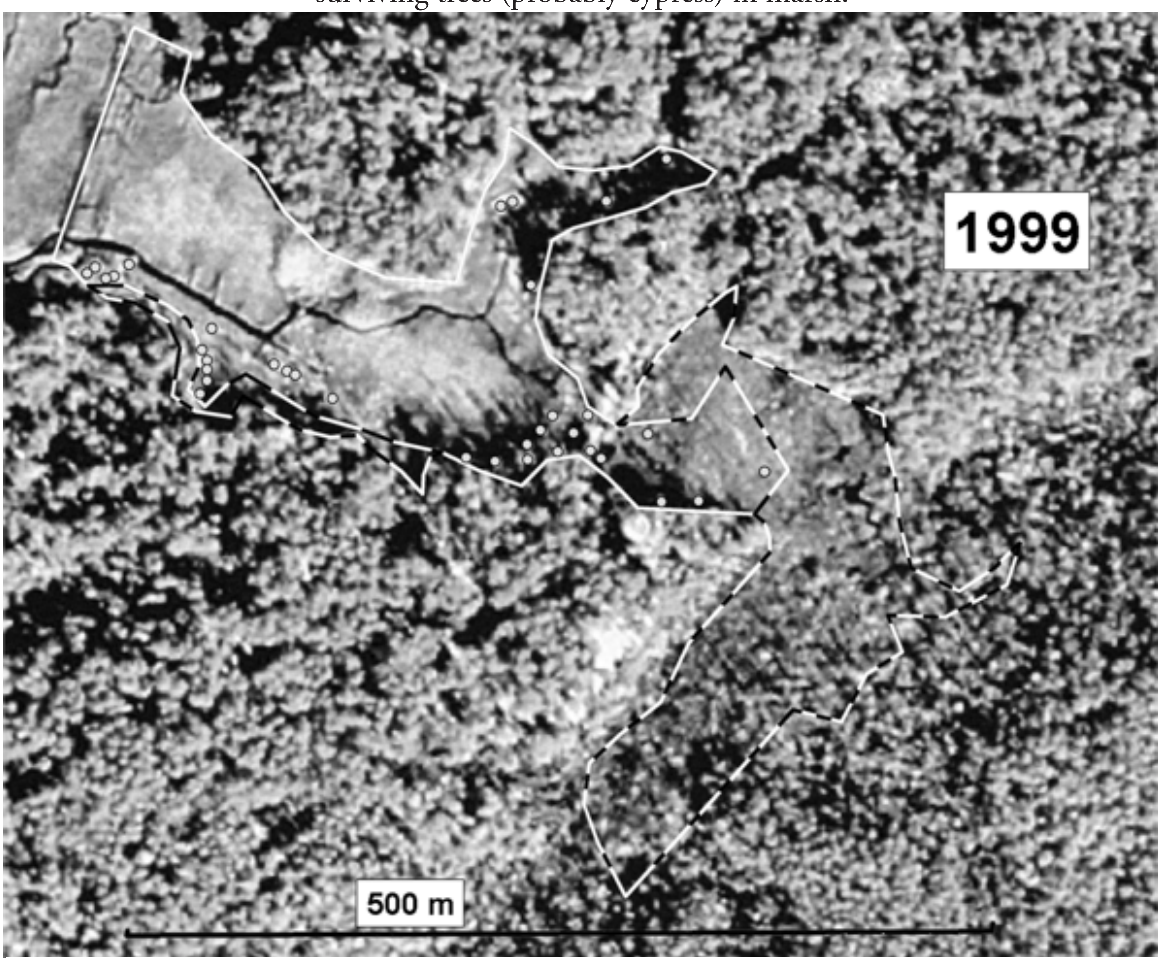

Figure 1e: Shows the forest-marsh landscape in 1999. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh.

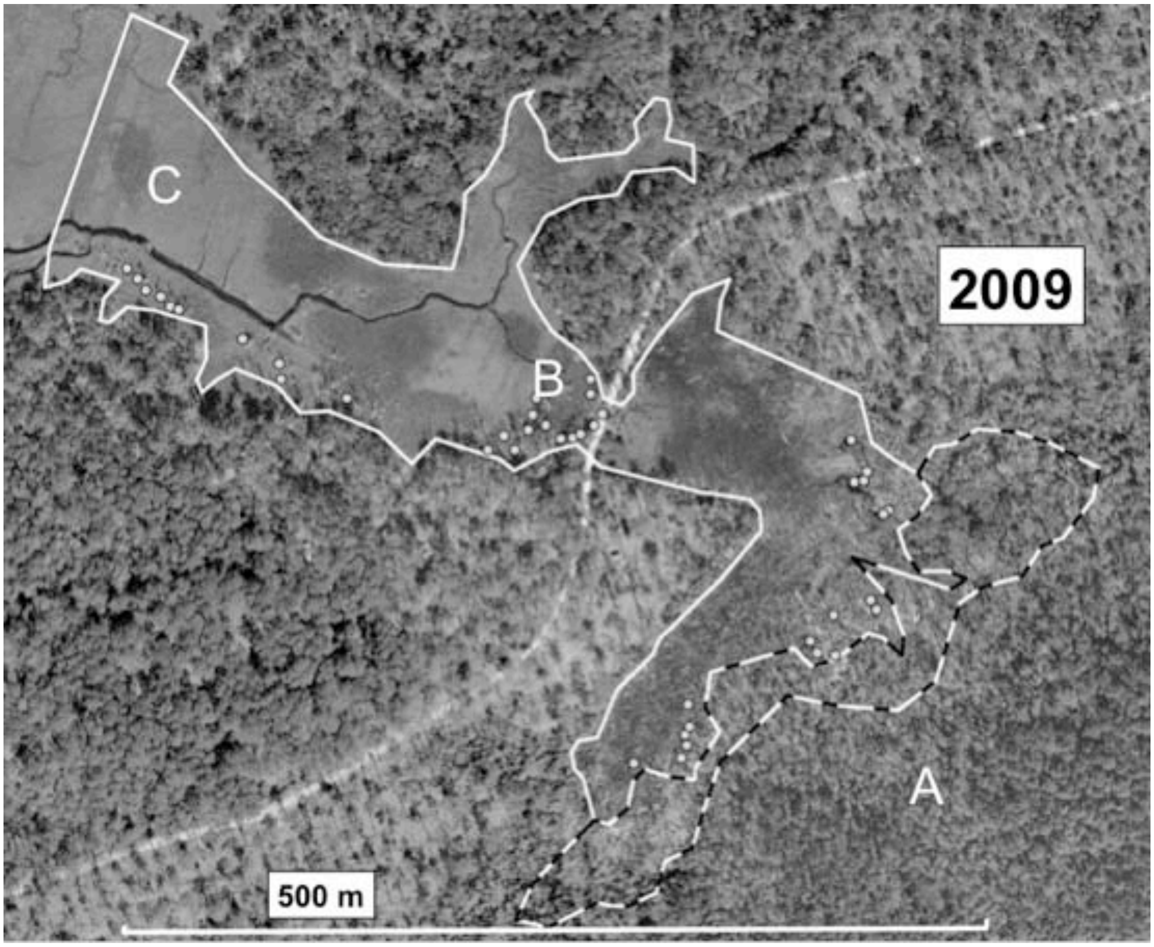

Figure 1g: Shows the forest-marsh landscape in 2009. The white line represents marsh edge (Steps 1 - death of tupelo and Step 2 - invasion of grasses), and the dashed line represents edge of enhanced mortality (Step 3 – death of cypress). White dots within the lines show the surviving trees (probably cypress) in marsh. Point A, B, and C indicated freshwater forested wetland, degraded sites, and salt marsh as in Figure 2, respectively.

Figure 2a: Forested wetland, photo taken at point A in Figure 1g.

Figure 2b: Degraded wetland, photo taken at point B in Figure 1g.

Figure 2c: Salt marsh, photo taken at point C in Figure 1g, respectively.

a single valley between ancient dunes. After 1980, the marsh expanded into the confluence of three tributaries and has begun to advance into each of them (Figures 1e - f). Marsh progression did not seem impacted by the presence of the Hobcaw road, with mortality first crossing the road in 1963 (Figure 1b) and marsh crossing the road in 1990 (Figure 1e).

Expansions of Salt Marsh

The data in Table 1 show a steady increase in marsh size over the 60-year period. A simple regression of time and marsh size indicates a steady, exponential expansion of marsh size over time and explains over 95% of the variation in marsh size. ($y = 1.59e^{0.0216x}$, $r^2 = 0.95$, $p < 0.01$; where y is area in hectares and x is number of years since 1949). This steady increase is also supported by the area of enhanced mortality. Marsh size is well predicted by the size of marsh plus mortality a decade earlier ($y = 1.13x - 0.390$, $r^2 = 0.96$, $p <0.01$, where y is marsh area at present and x is area of marsh plus mortality in the previous decade in hectares). While the overall progression is well predicted by time and presumably by sea level, there are noticeable differences in some decades.

Area (ha)				Evelation of Polygons in 2003 (cm NAVD 1988)		
Year	**Marsh**	**Mortality**	**Total**	**Maximum**	**Mean**	**Standard Error of Mean**
1949	1.72	0.306	2.026	168	52.1	0.195
1963	2.13	0.139	2.269	166	50.1	0.184
1970	2.7	0.632	3.332	177	49.6	0.184
1980	2.71	0.721	3.431	178	50.5	0.194
1990	3.56	0.726	4.286	206	53.2	0.185
1999	4.38	2.973	7.353	243	56	0.183
2009	6.74	1.834	8.574	306	64.6	0.244

Table 1: Areas of marsh and forest mortality interpreted polygons for each year of photography and elevations of those areas derived from 2003 LIDAR points within each marsh polygon.

Between 1970 and 1980 the overall trend greatly over predicts the actual small change in marsh area while in 2000-2009 the trend under predicts the change in area.

There has been a clear progression of marsh into the forested wetland at strawberry swamp during the past 60 years. Throughout that period there has been a steady rise of relative sea level along this portion of the SC Coast. This rise is part of a geologic relative sea level rise that has been occurring for the last 6,000 years (Gardner and Porter 2001; Sharma et al. 1987) in the nearby North Inlet Marsh. This geologic setting provides an ideal area for a retrospective examination of the progression of forest to marsh under a rising sea level. The local rate of rise (3-4 mm/y) is in similar to the lower estimates of general sea level rise for the next century (Church et al. 2001), suggesting that historical changes in Strawberry Swamp may be instructive in making predictions about future impact of sea level rise on coastal wetland ecosystems.

Management and Practical Implications

This study demonstrates an application of historical aerial photos and LIDAR data to examine the impacts of sea level rise on coastal wetland ecosystems. In particular, results of this study show that the marsh size at any time could be predicted by the area of marsh plus enhanced forest mortality a decade earlier. In other words, the expansion of salt marsh in a coastal ecosystem could be simply estimated by examining the current areas forest dieback. The advantage of this retrospective method provides an understanding of long-term effect of sea level rise in regional coastal wetland ecosystems and the cost for this examination should be minimal. Aerial photos and LIDAR data could be available from the U.S Department of Agriculture, state, county, or local city offices.

Summary

Strawberry swamp is a small watershed that happens to be located along Winyah Bay slightly seaward of the normal 1 ppt brackish boundary and slightly landward of the estuarine turbidity maximum zone. Between 1949 and 2009 the area of marsh expanded from 1.72 to 6.74 ha corresponding to the sea level rise. The rate of marsh expansion was well explained (> 95%) by an exponential equation using years since 1949 as the known variable. An increase loss of forested wetland to salt marsh in strawberry swamp is expected with the continued increase in sea level rise.

Acknowledgments

This material is based upon work supported by NIFA/USDA, under project number SC-1700409. This research was partially supported by Clemson University Research Grant Council. Technical Contribution no. 8888 of the Clemson University Experiment Station.

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