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ASTRONOMICAL TIDAL REGIME CHANGE AS A CONTROL ON THE HOLOCENE DEVELOPMENT OF AN ORGANIC-RICH COASTAL ZONE, NORTH CAROLINA, USA

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ABSTRACT

Sediment core and age data from the Alligator River tributary of Albemarle Sound, North Carolina suggest that coastal geomorphology-dependent variations in the astronomical tidal regime played a key role in the Holocene development of this presently nano-tidal estuarine system. The low lying, peatland-dominated study area is surrounded on three sides by drowned tributaries of the Alligator River estuarine system and underlain by a late Pleistocene topographic high. During the last glacial stage (MIS 2), drainage systems became established on the emergent terrain. As Holocene sea level rose, stream valleys became progressively inundated with concomitant up-gradient migration of wetlands. With open interchange between paleo-Albemarle Sound and the Atlantic Ocean, sea level was sufficiently high ca. 3 ka to produce bay/tidal ravinement inland of the present peatland shoreline. Gradual closure of the coastal barrier-island system (the Outer Banks) within the last approximately 2.5 ka resulted in decreasing astronomical tides, decreasing salinity, and marsh progradation seaward over the earlier Holocene ravinement surface with concurrent peat accumulation. Within the last ca. 1 ka, fresh to low-brackish marsh was replaced by forested wetlands in response to further barrier-island closure and elimination of astronomical tides as swamp-forest woody peat continued to vertically accumulate in response to rising base level.

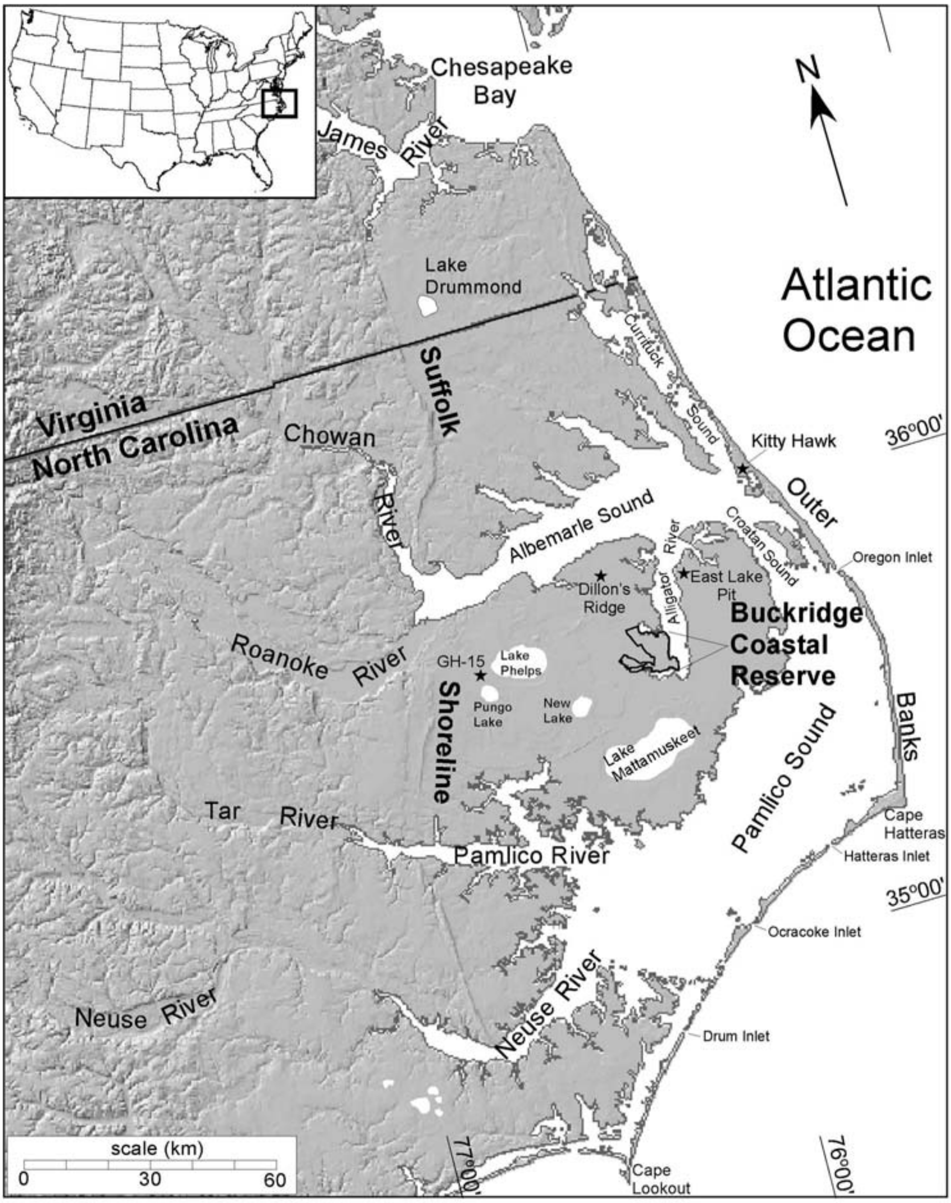

Figure 1. Shaded relief map (*http://nationalatlas.gov/*) of northeastern North Carolina and southeastern Virginia showing the location of the Buckridge Coastal Reserve study area. Major geographic features including the Suffolk Shoreline are also indicated. Core holes and pits from which additional stratigraphic and age data were derived are indicated by black stars. Insert map indicates location of Figure 1.

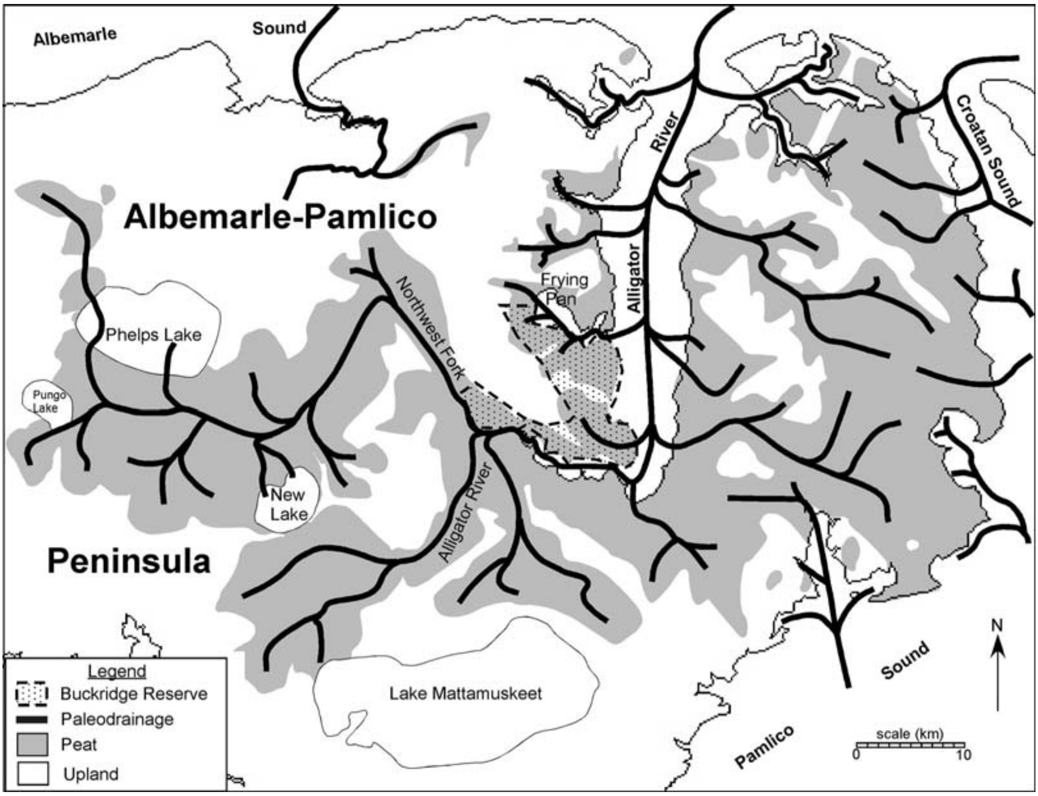

Figure 2. Map of the Albemarle-Pamlico Peninsula shows the distribution of peat (Ingram 1987) and paleo-drainage system of the Alligator River.

Table 1. Geoprobe (GH) and vibra-cores (BVC) for Buckridge Coastal Reserve (See Fig. 3 for core locations). Elevation of Geoprobe cores determined using the North Carolina Department of Transportation LiDAR database.

Core	Locality	Lat	Long	Elevation (m above MSL)	Water depth (m below MSL)	Penetration relative to surface (m)	Penetration relative to MSL (m)
GH-26	Buckridge	35 43.568	76 05.960	+0.8	NA	20.7	19.9
GH-27	Buckridge	35 43.043	76 03.653	+0.3	NA	8.2	7.9
GH-28	Buckridge	35 43.381	76 11.473	+0.3	NA	10.5	10.3
GH-29	Buckridge	35 41.828	76 06.570	+0.6	NA	8.5	7.9
GH-30	Buckridge	35 44.769	76 06.624	+0.4	NA	6.1	5.7
GH-31	Buckridge	35 43.993	76 03.690	+0.6	NA	7.3	6.7
GH-32	Buckridge	35 42.394	76 08.359	+0.3	NA	8.5	8.2
GH-33	Buckridge	35 46.188	76 08.908	+0.6	NA	6.1	5.5
GH-34	Buckridge	35 47.993	76 06.258	+0.3	NA	6.1	5.8
GH-35	Buckridge	35 44.012	76 10.521	+0.3	NA	4.9	4.6
GH-36	Buckridge	35 41.059	76 03.907	+0.6	NA	7.3	6.7
GH-37	Buckridge	35 45.565	76 05.990	+0.3	NA	4.9	4.6
BVC-1	Alligator River	35 41.945	76 10.163	0	0.3	7.3	7.3
BVC-2	Alligator River	35 41.439	76 07.339	0	0.6	6.4	6.4
BVC-3	Alligator River	35 43.608	76 02.556	0	0.4	8.9	8.9
BVC-4	Straits	35 45.741	76 03.938	0	0.4	9.2	9.2
BVC-5	Frying Pan	35 46.159	76 09.922	0	1.0	4.1	4.1
BVC-6	Frying Pan	35 46.756	76 07.407	0	1.2	4	4

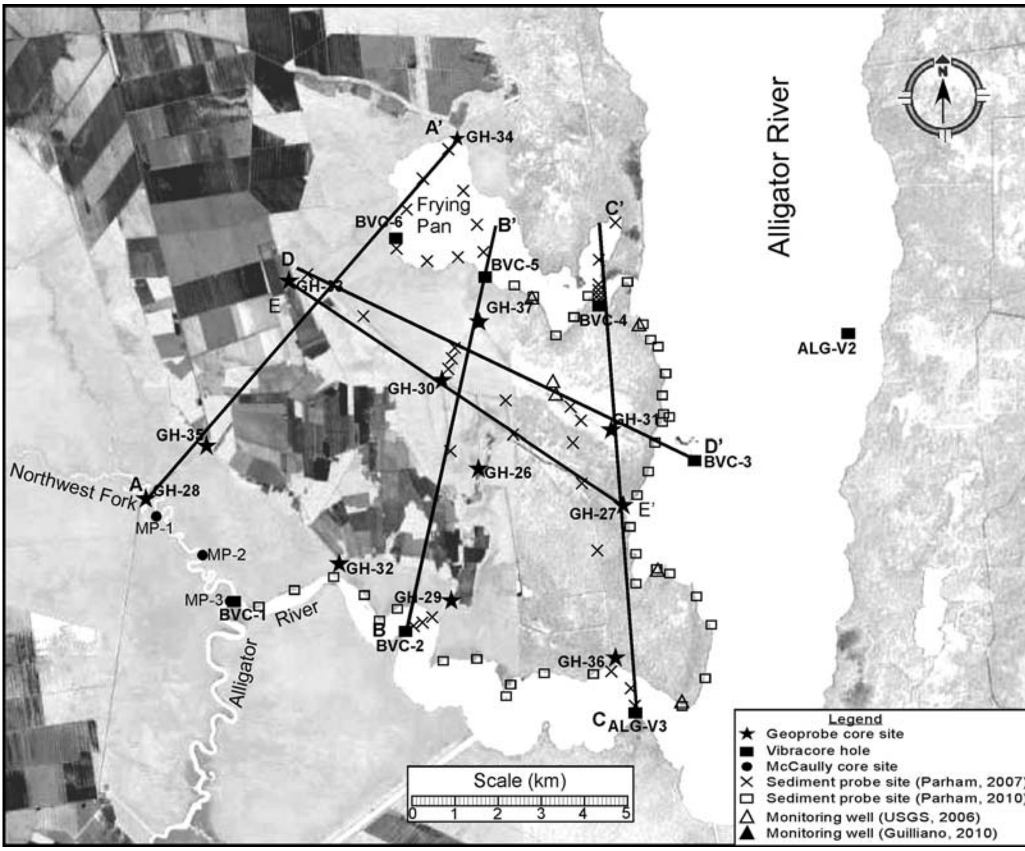

Figure 3. Map of the study area shows the locations of core holes, sediment probe sites, and transects (black lines) for which stratigraphic cross sections were prepared. B-B' cross section is shown in Figure 4. USGS (Ferrell et al. 2007) hydrologic survey wells also shown.

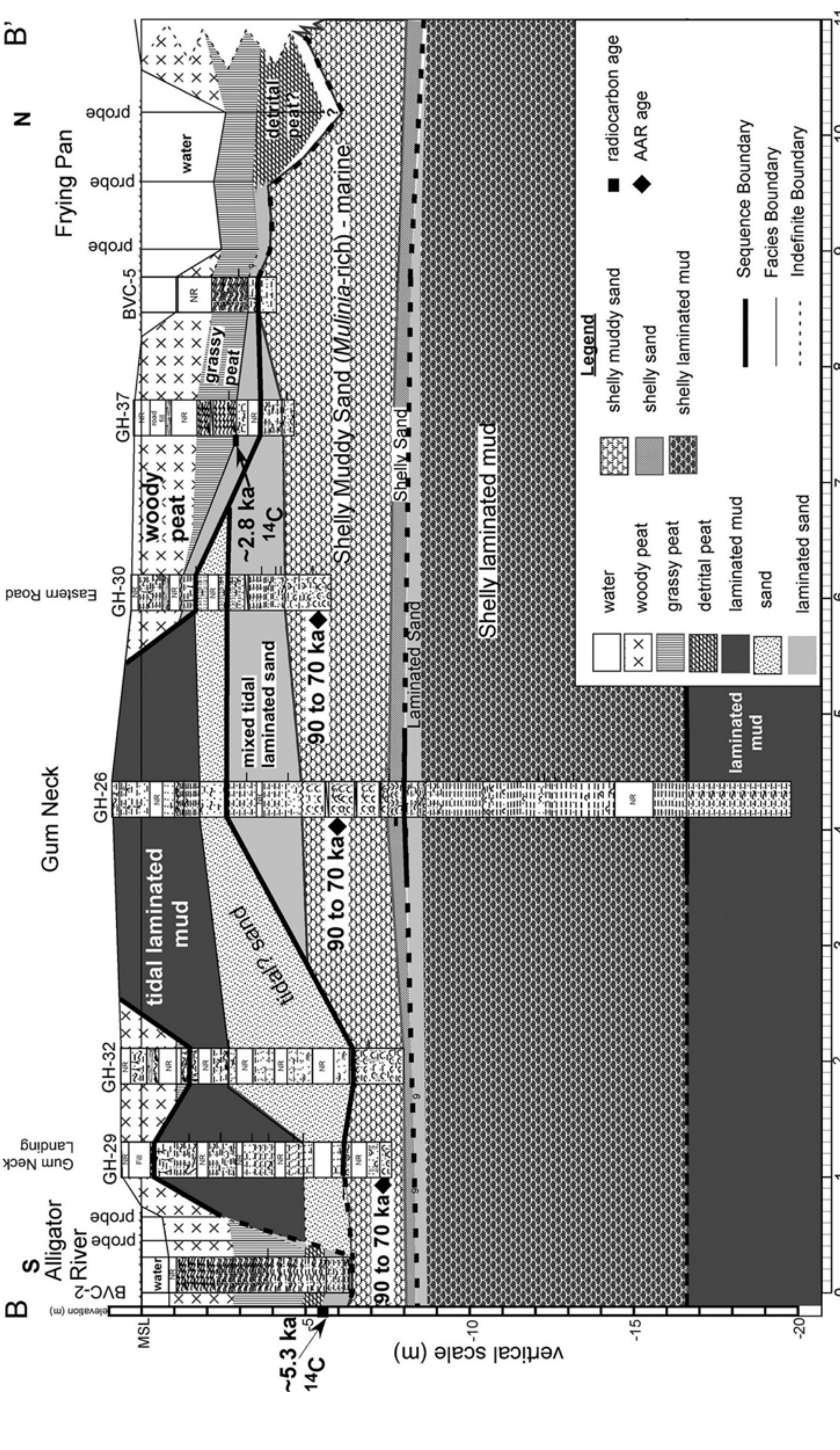

Figure 4. Stratigraphic cross-section of B-B' showing lithofacies and sequence boundaries. See Figure 3 for section location.

Table 2. Radiocarbon and amino acid racemization (AAR) age data for the Buckridge Coastal Reserve area (core locations in Fig. 3). Also shown are optically stimulated luminescence (OSL) age data from the Albemarle/Pamlico Peninsula.

Sample #	Locality	Latitude	Longitude	Depth bMSL (m)	Sample Type	Conventional Age (yr)	Age Error (+/- yr)	Calibrated 2σ age range (yr)
National Ocean Sciences Mass Spectrometry (NOSAMS) Radiocarbon Age Data								
GH-28-557	NW Fork Alligator River	35 43.381	76 11.473	5.57	muddy grassy peat	3290	20	3568 - 3462
GH-36-220	End Buck Island Rd.	35 41.059	76 03.907	2.20	grassy peat	1510	45	1447 - 1313
GH-37-300	N End Connector Rd.	35 45.565	76 05.990	3.00	grass in muddy sand	2790	35	2966 - 2788
BVC-2-561	Upper Alligator River	35 41.439	76 07.339	5.61	peaty mud	4590	40	5460 - 5263
BVC-3-725	Alligator River	35 43.608	76 02.556	7.25	detrital peat in mud	4710	35	5418 - 5322
BVC-4-672	Frying Pan Straits	35 45.741	76 03.938	6.72	detrital wood over cse sand	5050	40	5908 - 5710
BVC-4-708	Frying Pan Straits	35 45.741	76 03.938	7.08	detrital wood under cse sand	5200	40	6021 - 5897
BVC-4-768	Frying Pan Straits	35 45.741	76 03.938	7.68	detrital peat in mud	8910	65	10,214 - 9856
BVC-6-335	Western Frying Pan	35 46.756	76 07.407	3.35	laminated peaty mud	3450	35	3831 - 3635
Radiocarbon age data (S. Riggs, unpublished)								
ALG-V3-70	Big Bend Alligator River	35 40.671	76 03.062	0.70	muddy detrital peat	NA	NA	1660 - 1520
ALG-V3-97	Big Bend Alligator River	35 40.671	76 03.062	0.97	laminated detrital peat/ mud	NA	NA	1800 - 1640
ALG-V3-154	Big Bend Alligator River	35 40.671	76 03.062	1.54	detrital peat	NA	NA	2640 - 2460
ALG-V3-270	Big Bend Alligator River	35 40.671	76 03.062	2.70	muddy detrital peat	NA	NA	3670 - 3510
ALG-V3-370	Big Bend Alligator River	35 40.671	76 03.062	3.70	laminated mud with detrital peat	NA	NA	4470 - 4330
AAR age data						Replicates		Estimated Age (ka)
GH-26-601	Buckridge interior	35 43.568	76 05.960	6.01	*Mulinia* (dwarf surf clam)	3		90 – 70
GH-27-760	Grapevine Landing	35 43.043	76 03.653	7.60	*Mulinia* (dwarf surf clam)	4		90 – 70
GH-29-760	Gum Neck Landing	35 41.828	76 06.570	7.60	*Mulinia* (dwarf surf clam)	3		90 – 70
GH-30-533	Buckridge interior	35 44.769	76 06.624	5.33	*Mulinia* (dwarf surf clam)	6		90 – 70
GH-33-400	Buckridge interior	35 46.188	76 08.908	4.00	*Mulinia* (dwarf surf clam)	2		90 – 70
GH-33-510	Buckridge interior	35 46.188	76 08.908	5.10	*Mulinia* (dwarf surf clam)	6		90 – 70
OSL age data from Albemarle/Pamlico Peninsula (Parham 2009)								
ELP-01	East Lake Pit, Dare Co.	35 53.122	75 57.434	8	shelly muddy sand	na		100.3+/-9.5
ELP-05	East Lake Pit, Dare Co.	35 53.122	75 57.434	0.5	laminated mud and sand	na		66.9+/-6.7
DR-2	Dillon's Ridge, Tyrrell Co.	35 55.776	76 11.252	0.2	laminated sand	na		62+/-12
GH-18	New Lake, Hyde Co.	35 37.212	76 21.409	3.4	laminated sand	na		76.9+/-7.1

Table 3. General character and interpreted depositional environments of lithofacies observed in the Buckridge Coastal Reserve study area. Patterns and shades correspond to lithofacies on stratigraphic cross sections.

Observed Depositional Succession

General Character	Lithofacies	Depositional Environment
Peat	WP woody peat	swamp forest/shrub-scrub pocosin
	GP grassy peat	fresh to low-brackish marsh
	DP detrital peat	fluvial or estuarine
Non-Shelly Deposits	LM laminated mud	tidal fresh to low-brackish estuarine
	LS laminated sand	tidal fresh to low-brackish estuarine
	S sand	fluvial or tidal estuarine
Shelly Deposits	SSd shelly sand	shallow marine/shoreface
	SMS shelly muddy sand	shallow marine/open embayment
	SLM shelly laminated mud	low energy, brackish to marine, outer estu-arine or open embayment

Table 4. Plant macrofossil analysis results.

Sample #	Lithofacies	Latitude	Longitude	Depth bMSL (m)	Sample Type	Depositional Environment
GH-28-570	Detrital peat	35 43.381	76 11.473	5.7	Roots in mud, *Nyssa* seed, *Carex trigonous* seed	probably fresh water, swamp forest
GH-30-120	Woody peat	35 44.769	76 06.624	1.2	Lots of grass epidermis, charcoal, *Polygonum* seed, roots, wood, organic-rich mud	brackish or fresh water
GH-30-145	Woody peat	35 44.769	76 06.624	1.45	Epidermis, charcoal	brackish or fresh water
GH-31-235	Grassy peat	35 43.993	76 03.690	2.35	Detrital grass, wood, charcoal	brackish or fresh water
GH-36-200	Grassy peat	35 41.059	76 03.907	2.0	Shredded epidermis and roots, *Cladium* seed, *Scirpus* seeds	possibly brackish water
GH-36-235	Grassy peat	35 41.059	76 03.907	2.35	Epidermis of grass, roots, fungal sclerota, charcoal	brackish or fresh water
GH-37-250	Grassy peat	35 45.565	76 05.990	2.5	Fine rootlets, hyphae, *Betula* twig, charcoal, insect parts	probably fresh water
GH-37-290	Grassy peat	35 45.565	76 05.990	2.9	Sedge stems, charred sedge stems, charcoal	brackish or fresh water
GH-37-310	Grassy peat	35 45.565	76 05.990	3.1	Bark, sedge stems, insect bristle, no charcoal	brackish or fresh water
BVC-3-350	Grassy peat	35 43.608	76 02.556	3.5	Much sedge with many sedge nodes, *Cladium* seeds, *Compositae* seed, *Scirpus* seed, charcoal, insect (beetle?) wings	possibly brackish water
BVC-3-635	Detrital peat	35 43.608	76 02.556	6.35	Wood, grass stems	probably fresh water
BVC-3-725	Detrital peat	35 43.608	76 02.556	7.25	3-needle and 2-needle pine needles, bark	fresh water
BVC-5-325	Grassy peat to woody peat	35 46.159	76 09.922	3.25	Wood fragments, charcoal, quartz sand, grass epidermis?	probably fresh water
BVC-6-340	Woody peat	35 46.756	76 07.407	3.4	Wood, twigs (*Betula*), charcoal, *Scirpus* seed	probably fresh water
BVC-6-355	Laminated mud/wetland soil	35 46.756	76 07.407	3.55	Wood, rootlets	?

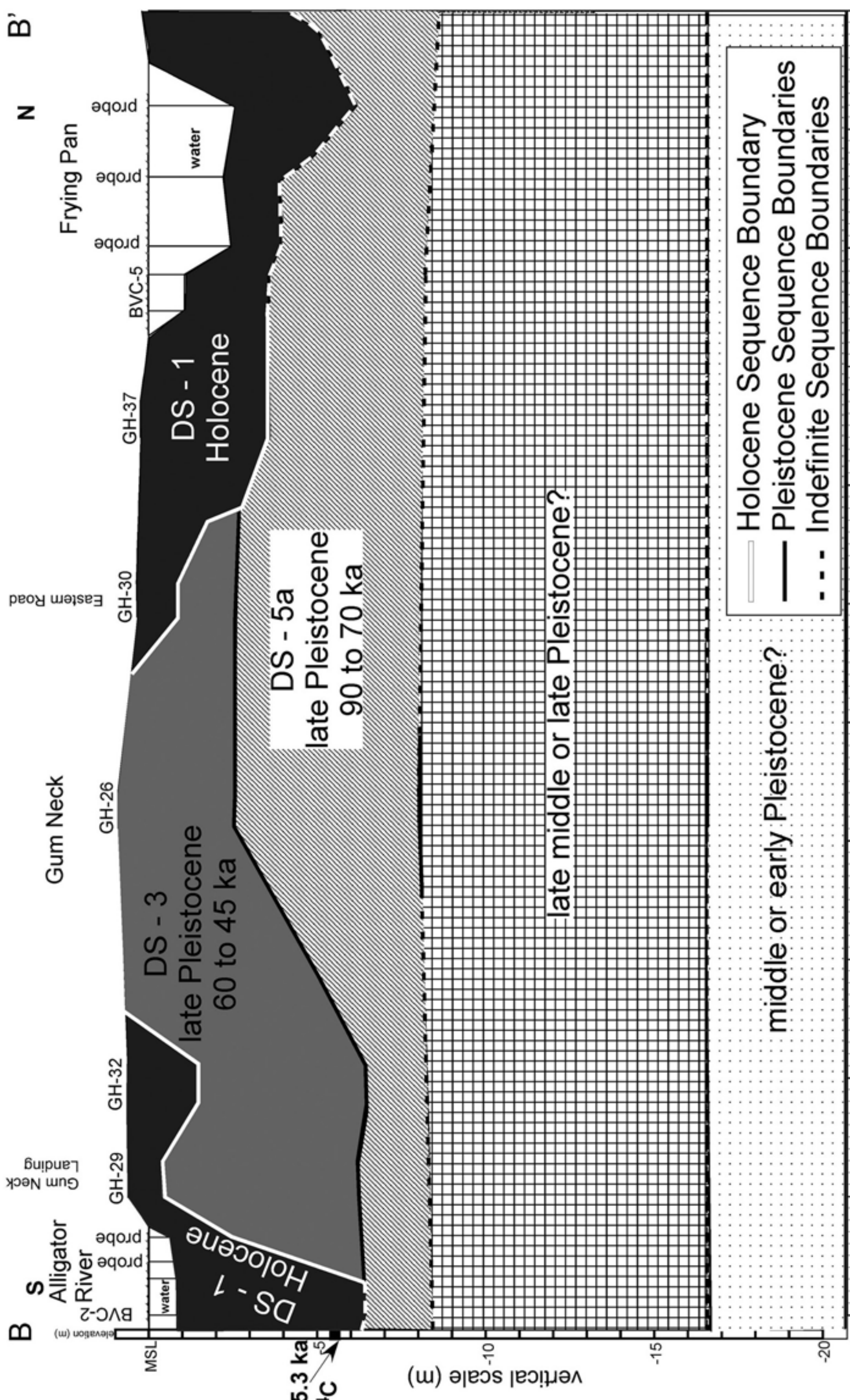

Figure 5. Depositional sequence (DS) relationships along transect B-B'. See Figure 3 for section location.

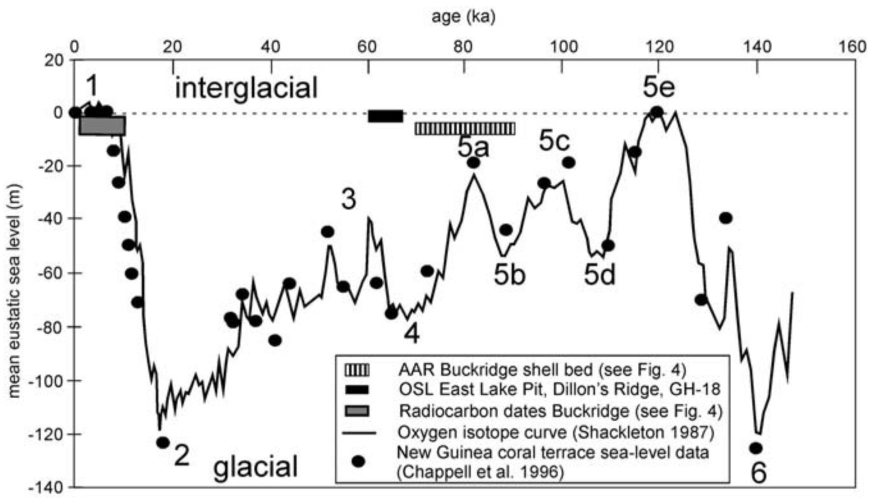

Figure 6. The timing and vertical occurrences of age-dated samples from Buckridge are compared with an oxygen isotope curve (Shackleton 1987) that has been calibrated with sea-level data from New Guinea to represent changes in eustatic sea level over the last ca. 150 ka (Chappell et al. 1996). Numbers along curve correspond with marine isotope stages.

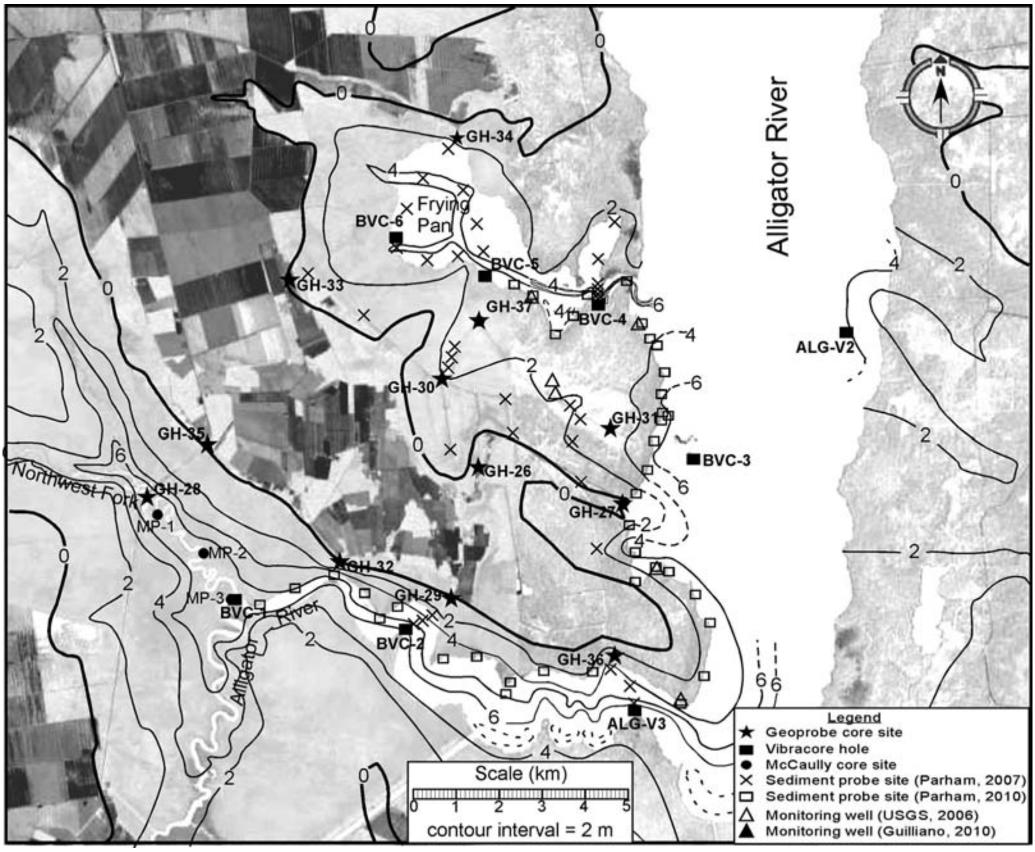

Figure 7. Structure contour map of the southern Alligator River area shows the paleo-topography of the pre-peat surface. Data are based on this study and Ingram (1987).

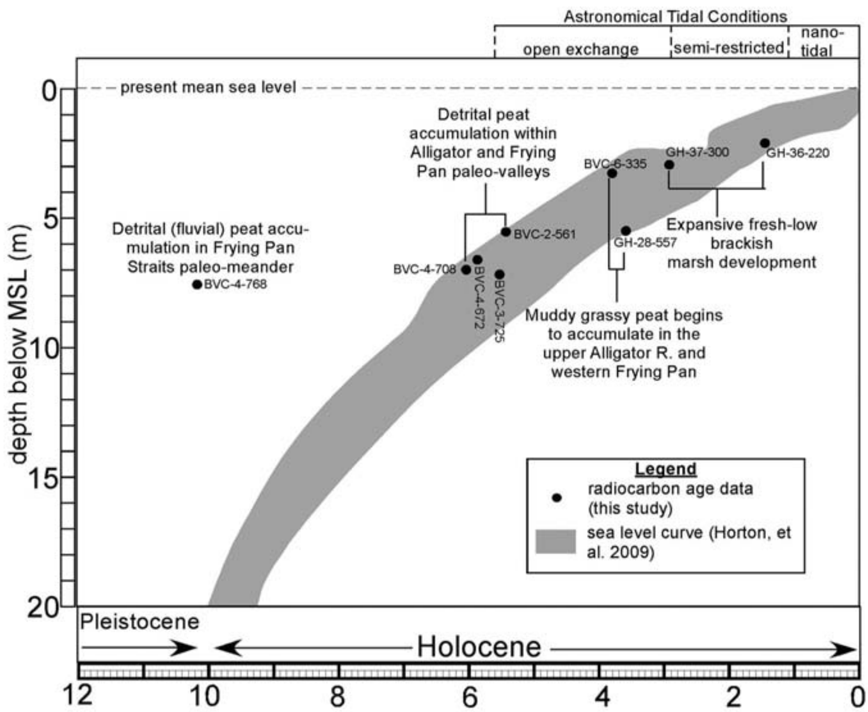

Figure 8. Plot of radiocarbon ages and sample depths from the Buckridge study area with a relative sea-level curve (grey field from Horton et al. 2009) based on sea-level index points and terrestrial and marine limiting data from northeastern North Carolina. Astronomical tidal conditions are based on data from Sager and Riggs (1998), Riggs et al. (2000), and Culver et al. (2008).

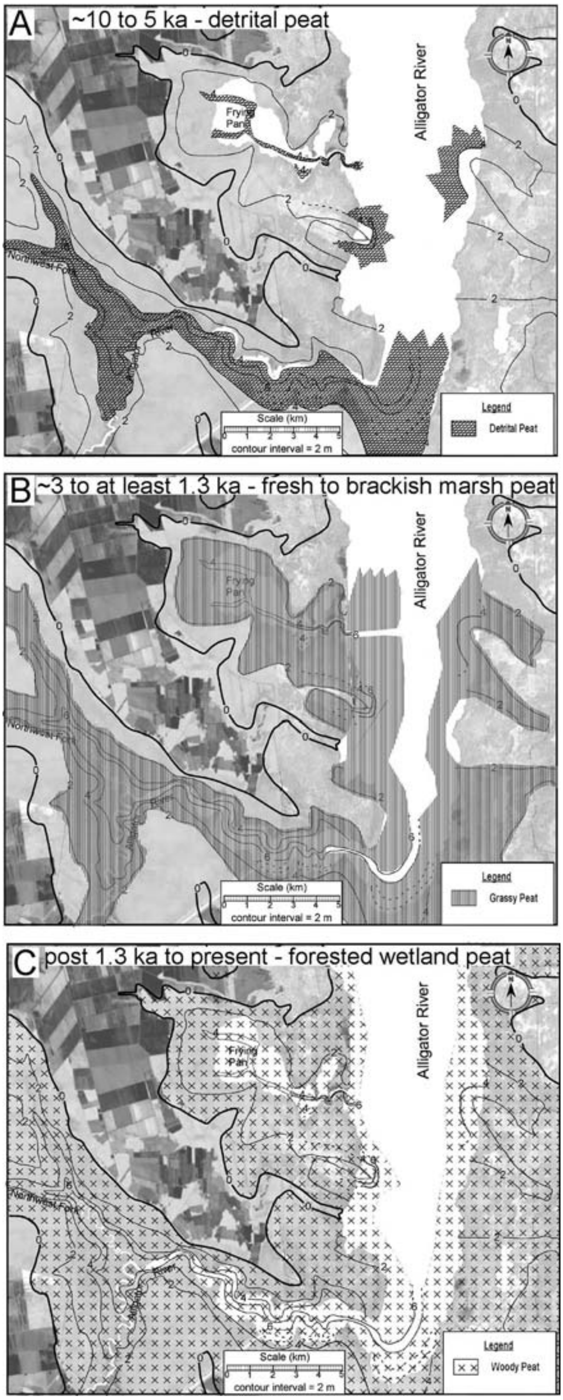

Figure 9. Evolutionary development of peaty deposits in the southern Alligator River area based on age data and peat stratigraphy.

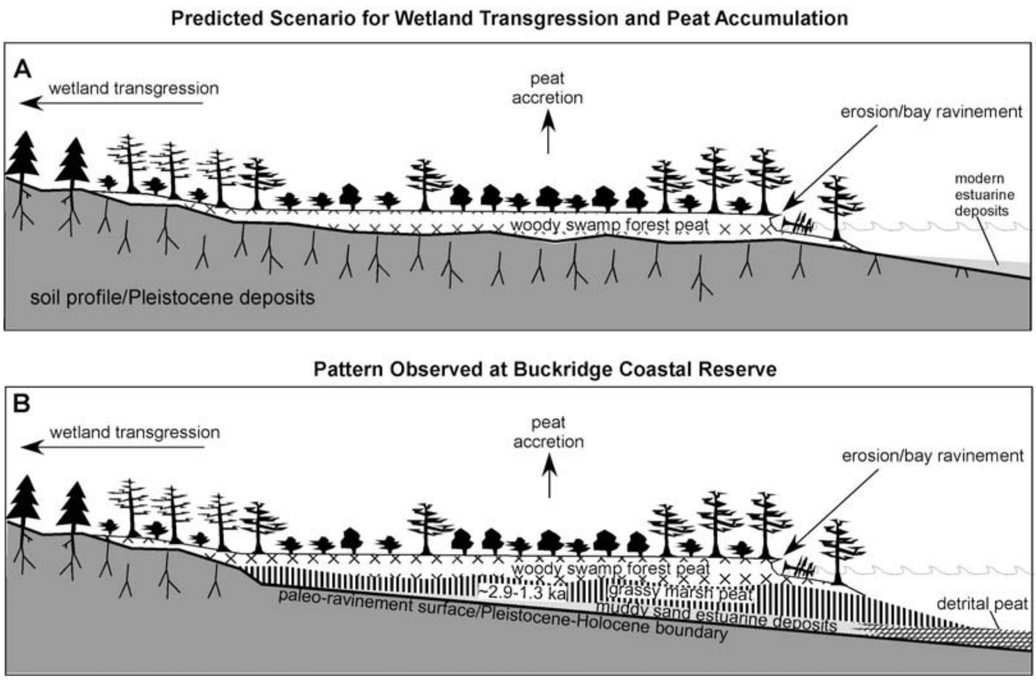

Figure 10. Schematic models comparing the stratigraphic patterns expected (Panel A) with those observed at Buckridge Coastal Reserve (Panel B).

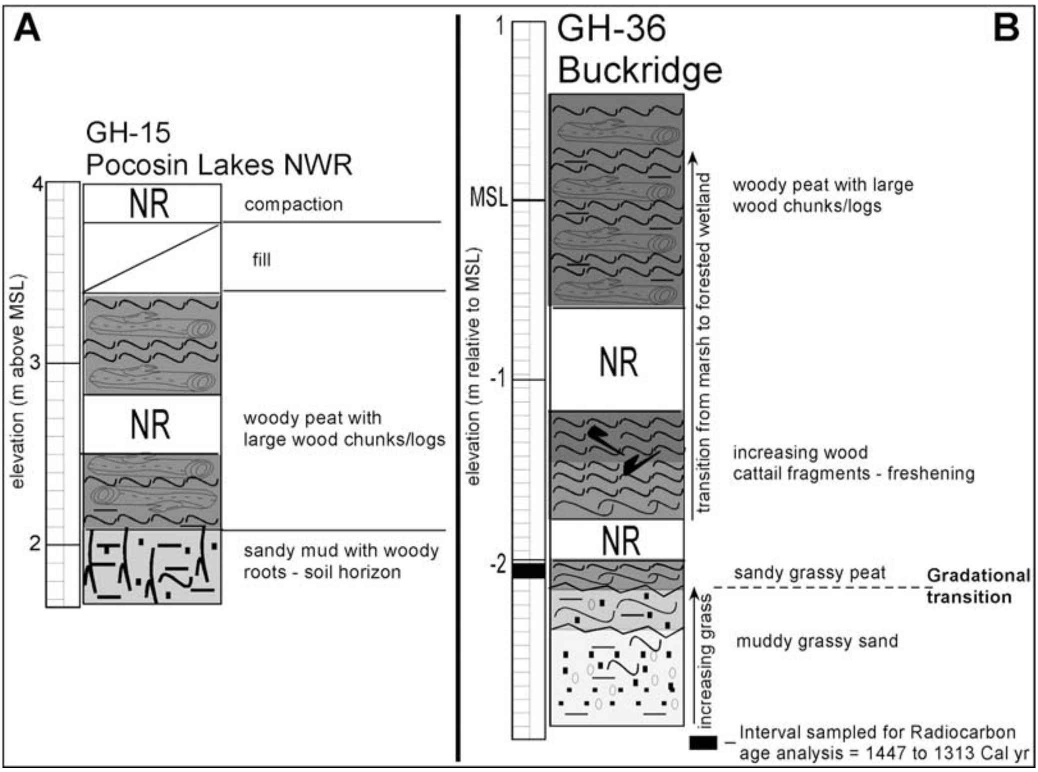

Figure 11. Peat cores from two different areas on the Albemarle/Pamlico Peninsula reflect different successions of environments. In GH-15 (A) from the western portion of the peninsula (see Fig. 1), a rooted soil profile is overlain by woody *in situ* peat indicating a transition from uplands to forested wetlands. However, GH-36 (B) from Buckridge (Fig. 3 for core location) shows no evidence of a rooted soil profile suggesting erosional removal prior to peat accumulation. Note: in order to maximize detail, only portions of each core are shown and elevations of sections are different.

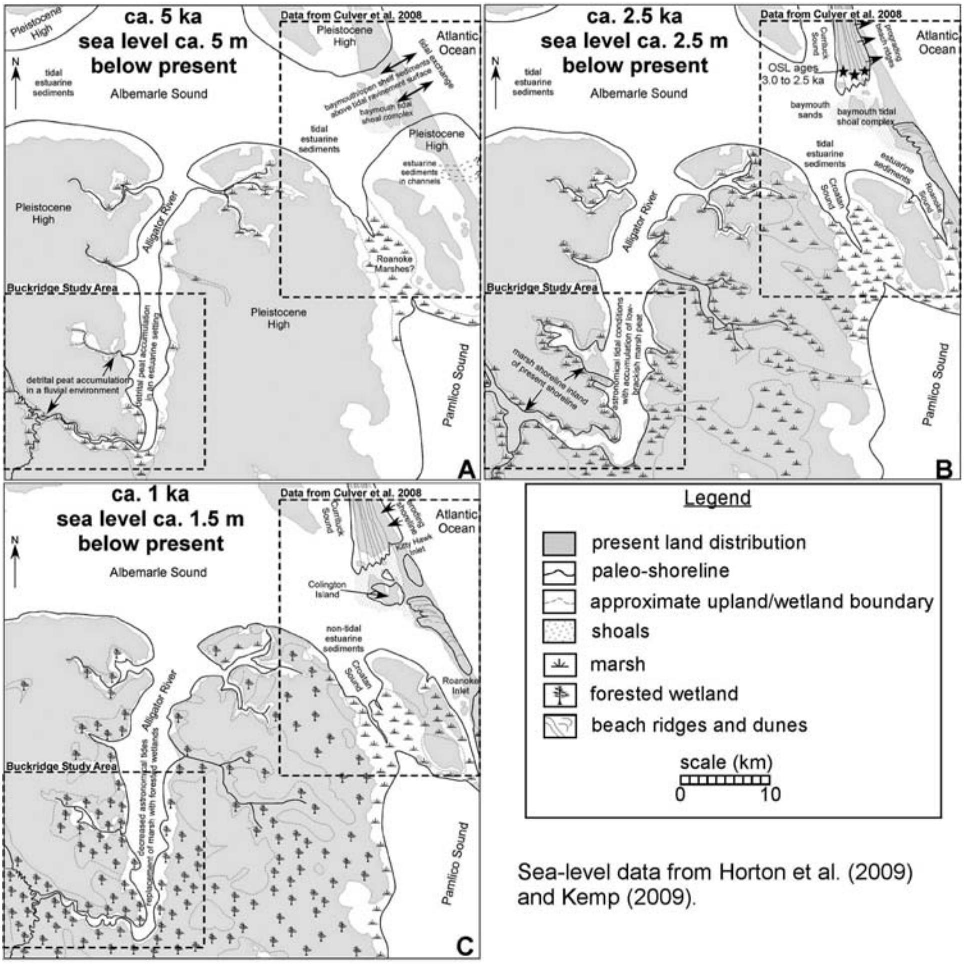

Figure 12. Paleogeographic reconstruction of the Alligator River area based on this study, micro-paleontologic and stratigraphic data from the northern Outer Banks area (Culver et al. 2008), and paleo-environmental data from Albemarle Sound (Sager and Riggs 1998) and Croatan Sound (Riggs et al. 2000; Riggs and Ames 2003). Paleo-wetland distribution outside the study areas is based on peat-thickness data (Ingram 1987). Panel A: Albemarle Sound ca. 5 ka was an open embayment with astronomical tidal exchange with the Atlantic Ocean. Detrital peat accumulated at Buckridge and the funnel-shape of the Alligator River probably produced amplified tides. Panel B: By ca. 2.5 ka, sea level was ca. 2.5 m below present and beach ridges prograded across the mouth of Albemarle Sound (Mallinson et al. 2008). Decreased astronomical tidal range promoted marsh progradation over the earlier Holocene tidal ravinement surface in the southern Alligator River area. Panel C: Continued closure of the barrier-islands by ca. 1 ka resulted in much reduced tidal exchange between Albemarle Sound and the Atlantic Ocean and replacement of marsh with forested wetlands in the upper Alligator River area.