Naples Bay Past and Present:
A Chronology of Disturbance to an Estuary

Final Report to the City of Naples
Funded by the South Florida Water Management District

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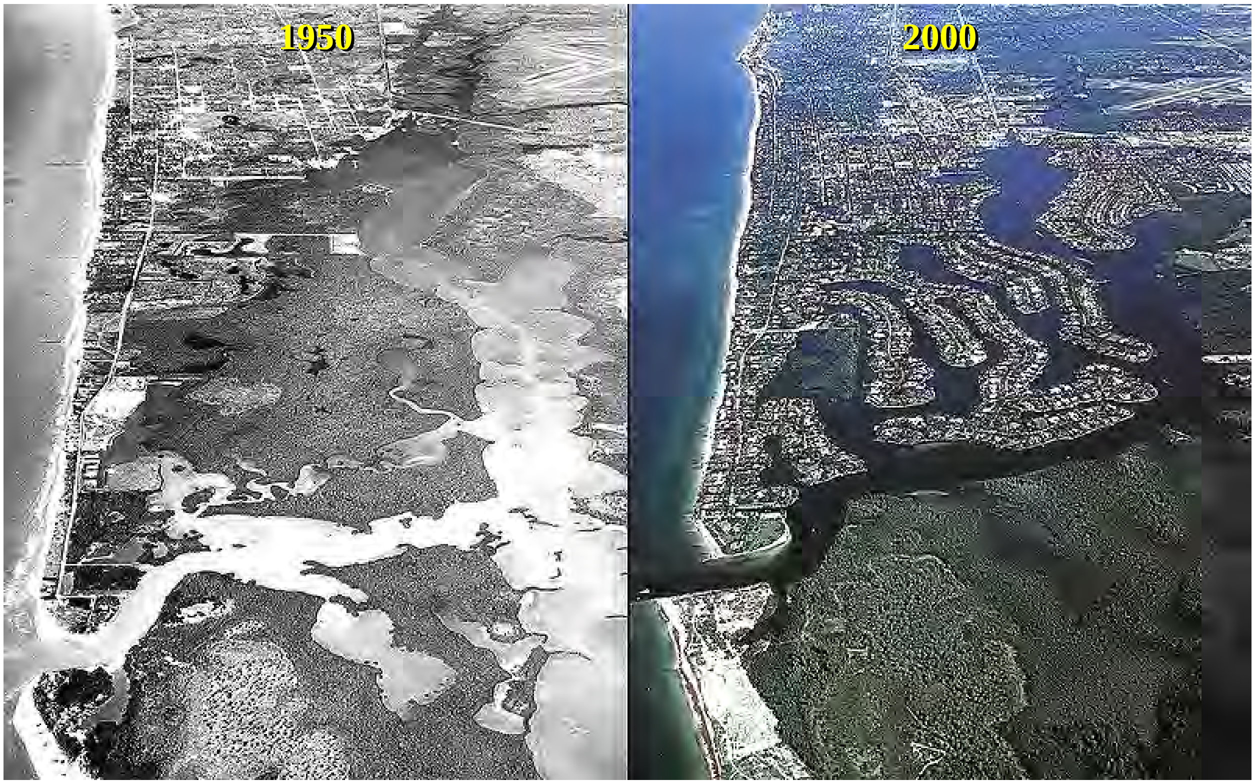
Naples Bay



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Early settlers of southwest Florida Photo courtesy of The Naples Historical Society

"The Bay of Naples has been partially filled with sand from the bay itself and houses and streets occupy what was once good fishing water. The vast number of birds and geese, ducks, curlews, fish crows and others, which would line the beach in the morning for miles so numerous that the sands could hardly be seen are gone and the flocks of curlews which flew steadily over the town for an hour or more every evening are no more." **– Lucien Beckner, who spent the winter of 1889-1890 in Naples and wrote a letter to Marjorie Stoneman Douglas after seeing Naples Bay again in 1955 (Tebeau, 1966).**

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the following individuals for taking the time to share with us their recollections of Naples Bay as it was many years ago: John Beriault, Bill Hartter, Cottie Morris, Rocky Scofield, and Duke Turner. We also thank David W. Ceilley (formerly with the Conservancy of Southwest Florida) for his efforts with project management; Thomas J. Smith III (United States Geological Survey in St. Petersburg), Anthony Polizos (Natural Resources Conservation Service in Collier County), and Larry C. Lawrence (Cartography Department of the Collier County Property Appraiser) for providing many of the aerial images that were used in this report; Lynne Howard-Frazier (Naples Historical Society) for the use of archival photographs; and Elizabeth Abbott (South Florida Water Management District) for providing constructive comments on an earlier draft of the report. This project was funded as part of the Naples Bay Initiative by a contract from the South Florida Water Management District and was administered by the City of Naples.

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EXECUTIVE SUMMARY

Naples Bay is typical of estuarine systems along the coast of Florida that have been altered by human activities, specifically through development and altered hydrology as wetlands were dredged, filled, and impounded. In order to understand the alterations and the response of the system over time, it is necessary to document the historic distribution of estuarine communities within Naples Bay and the conditions that supported their previous existence. Comparison of past versus present habitat distributions and conditions will also help to guide future efforts to restore these communities. The purpose of the current project was (1) to produce a chronological account of human development of Naples Bay, (2) to document changes to the mangrove shoreline and assess past and present distribution of the benthic habitats (i.e., seagrass and oyster) within the bay, and (3) to identify the timing of habitat changes as well as their effect on hydrogeological and biogeochemical cycling within the system.

The first recorded human disturbance in Naples Bay was a canal that was excavated by the indigenous people inhabiting these waters over 2,000 years ago. The first documented settlers in the Naples arrived in the 1860's and, relatively soon thereafter, the area was being promoted as a winter resort. The construction of the pier in the late 1880's and the completion of the Tamiami Trail (i.e., U.S. Highway 41) in 1926 set in motion the urban development that now surrounds Naples Bay. The once extensive mangrove shoreline and abundant seagrass and oyster habitats within the bay have been destroyed, starting with the first dredging of the bay in 1930 and culminating with the extensive dredge-and-fill developments that occurred during the 1950's and 1960's. Nonetheless, Naples Bay still functions as an estuary, albeit heavily influenced by anthropomorphic activities, and those areas that can potentially be restored need to be identified and protected to prevent any further degradation of the system.

The present distribution of benthic habitats within the Naples Bay was determined through the systematic sampling of bottom types, and the historic distribution was determined from interviews with long-time residents and interpretation of aerial imagery. Geographic information system (GIS) technology was used to analyze changes to seagrass and oyster habitats, as well as changes to shoreline characteristics and vegetation/landuse of surrounding areas. Seagrass and oyster habitats within Naples Bay have been reduced 80-90% due to dredging for creation of waterfront property and maintenance of navigational channels. Additionally, over 70% of the fringing mangrove shoreline of Naples Bay has been converted to residential developments. The perimeter of the bay has increased 53% and the water surface area 23% due to the construction of canal systems in residential areas. Naples Bay also receives a seasonal pattern of excessive freshwater inflow because of human-induced changes to the watershed, and this may prove to be problematic to restoration efforts as proper salinity patterns are critical to estuarine functions. Further quantitative studies are needed to determine the effects of inflow alterations on biological activities in Naples Bay.

Although habitat mapping identified the large-scale spatial changes that have occurred in Naples Bay, there is also a need to identify the temporal response of the estuarine system to chemical and hydrological stressors. Sediment cores were collected at 4 sites within Naples Bay and a fifth from a relatively undisturbed reference site to the south of the bay. Radioisotope analyses were used to determine sediment chronology and sediment accumulation rates at each of the sites. Sedimentation rates remained fairly constant (0.4 - 0.8 cm/yr) over the past 100 years. Disturbances were noted at the Gordon River site in the 1920's and 1950's, possibly corresponding to hurricane and channelization events, respectively. Further chemical and

sedimentary analyses will help to add confidence to these interpretations and will add to our understanding of the history of this anthropogenically-altered system.

SECTION 1
HISTORICAL OVERVIEW OF NAPLES BAY

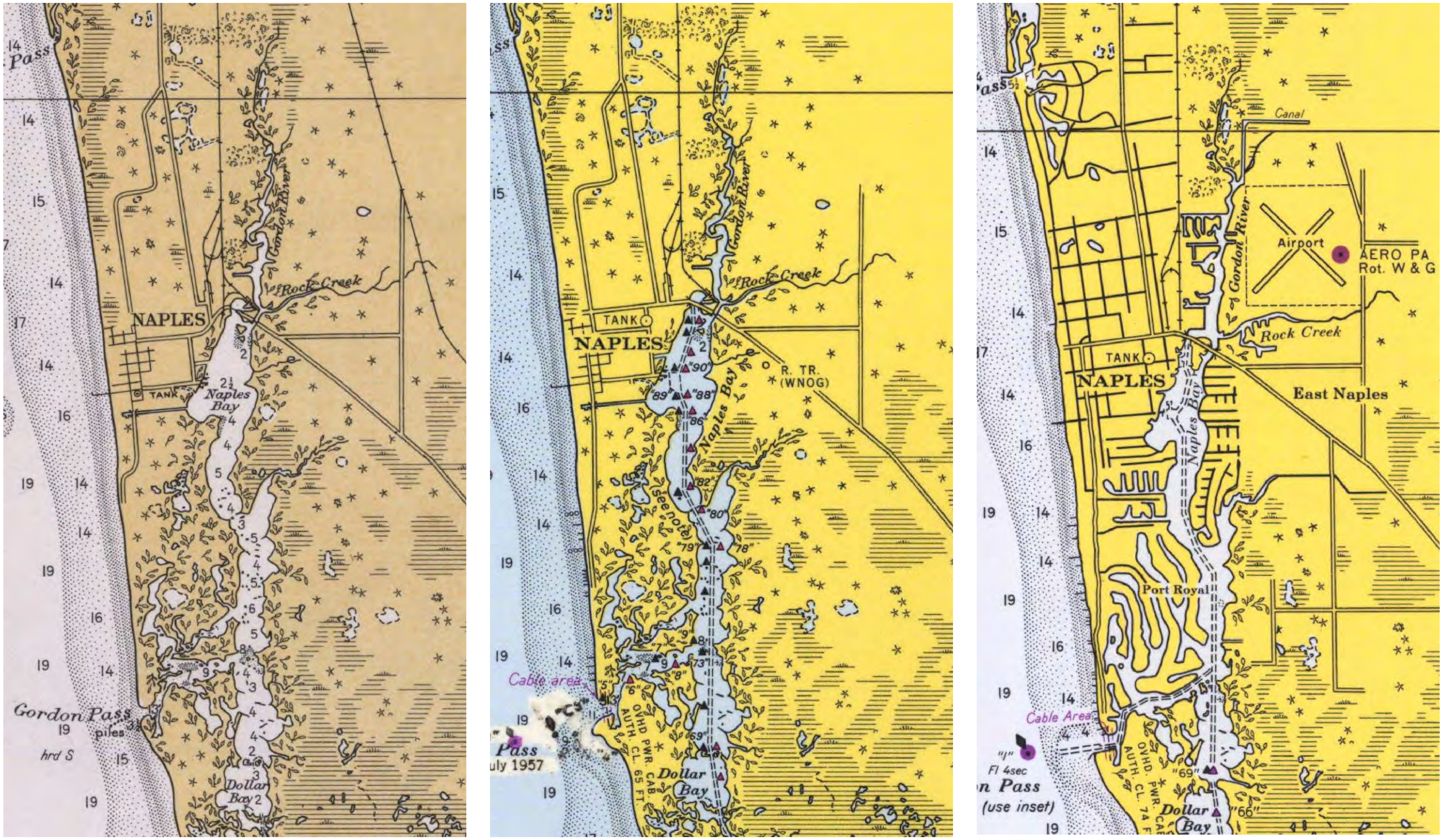
There is little if any published information available regarding the biological attributes of Naples Bay prior to the changes it has undergone since the 1940s. The following is an assessment of Naples Bay during the urbanization of the City of Naples and the surrounding area. This narrative is based on interviews with long-time Naples residents (their recollections from the 1940s though the early 1960s), aerial photographs, nautical charts, and historical publications.

Archeological evidence indicates that the coastal hammocks in the vicinity of Naples Bay were first inhabited by Native Americans over 2,000 years ago (J. Beriault, pers. comm.). The waters of the bay undoubtedly provided them with a ready supply of food as well as a means of travel. Though commonly referred to as Calusa Indians, there is evidence that suggests that they were a peripheral to the Calusa whose cultural center was located further north on Mound Key in Estero Bay (Carr and Beriault, 1984). In either case, the indigenous people who inhabited the environs of Naples Bay had a complex social structure and were excellent watermen. The first recorded human disturbance in Naples Bay was a canal that most likely was excavated by the indigenous people that frequented these waters. It was first noted on a map from 1775 and was described as a "haulover" (Tebeau, 1966). The canal extended a little over a mile over the peninsula between the bay and the Gulf of Mexico. The town plat of 1887 describes it as being 50 ft. wide and 3 ft. deep. Early residents (circa 1904) recall that a bridge on 12th Ave. S was used to cross the canal (Tebeau, 1966).

The first documented settlers in the Naples areas were Joe Wiggins and Roger Gordon, both of whom arrived in the 1860s. A river and two passes in the Naples area were named after them. Gordon Pass is the entrance to Naples Bay from the Gulf of Mexico while the Gordon

River once connected to the freshwater wetlands that bordered the extreme northern portion of Naples Bay. Roger Gordon had a fishing camp at the south end of Gordon Pass in 1874 (Tebeau, 1966). Through the 1870's and 1880's, the area around what is now the City of Naples and its bay was promoted as having excellent hunting and fishing as well as having a mild climate. In 1887, a newspaper publisher, Walter N. Haldeman, and group of wealthy Kentuckians gained controlling interest in the Naples Company, which owned the majority of the acreage upon which Naples proper exists today (Jamro and Lanterman, 1985). A 600 ft. pier was constructed on the Gulf side in 1889, which permitted steamships to transport freight and passengers. Subsequently, Naples quickly became known as a winter resort community. The construction of the pier and the completion of the Tamiami Trail (i.e., U.S. Highway 41) in 1926 set in motion the events that eventually resulted in the urban development that now surrounds Naples Bay (Stone, 1987).

The shallow waters and relatively small size of Naples Bay made it unattractive as a port for large ships. U.S. Coast and Geodetic Survey chart #1254 published in 1931 (Fig. 1-1a) shows mangrove forest and marsh entirely surrounding the perimeter of the bay. The chart also shows a marked channel extending from Gordon Pass to the bridge where the Tamiami Trail crosses the bay. This channel is probably the one dredged by E.W Crayton in 1930. The channel was 40 ft. wide and varied in depth from 3 to 8 ft. and cut through a number of oyster bars in Naples Bay (Antonini et al., 2002). In 1940, the U.S. Army Corps of Engineers dredged a channel from the southern city limits of Naples to Big Marco Pass. Maintenance dredging was performed in the 1950s and a federal project in the 1960s established a control depth of 10 ft. in the marked channel to accommodate the increased boat traffic in the bay (Fig. 1-1b and 1-1c).



(a) 1931

(b) 1957

(c) 1968

Figure 1-1. Excerpts from U.S. Coast and Geodetic Survey nautical chart #1254 (Chatham River to Clam Pass) showing the Naples Bay area in (a) 1931, (b) 1957, and (c) 1968.

Gordon Pass has been dredged periodically for maintenance since then and the most recent dredging in the pass occurred in 2003.

The entrance to Gordon Pass was more dynamic before the construction of the jetties on either side of the inlet. The pass shifted around over time in response to tidal fluctuations and effects of passing weather systems. A local boat captain reported that after the 1910 hurricane the pass had widened to a ½ mile width and was so shallow that his boat touched bottom occasionally while traversing the pass at high tide (Tebeau, 1966). Other residents recall being able to wade across the pass to Keewaydin Island during extreme low tides (Briggs, 1980). There was a large shell mound on the north side of Gordon Pass, which was 10 to 12 ft. high and covered approximately 3 acres (D. Turner, pers. comm.). The City used the shell from the mound to fill in potholes and ruts in the sand roads that served Naples during the 1940s. There were also 3 shell mounds in the vicinity of the area in where the main channel of Naples Bay intersects with Dollar Bay to the south (Fig. 1-2). The Turners obtained a lease from the State to remove oyster shell from these mounds, but the remains can still be seen during extreme low tides. Trees on the south side of the Gordon Pass began washing out in the early 1960's, so landowners paid to have a jetty built to stabilize the pass.

Further into the pass on the south side is the entrance to a small shallow bay referred to as the Cowpens (Fig. 1-2) because the channel leading into the bay could be easily blocked off. When manatees were in the Cowpens, the local residents would seal the channel so they could use the trapped manatees as a source of food. Opposite the Cowpens was an extensive sand shoal known as Fiddler Flats because of the thousands of fiddler crabs that frequented the bar (Briggs, 1980). The remnants of the shoal are still present and, while it is no longer emergent, it is not navigable at low tide.

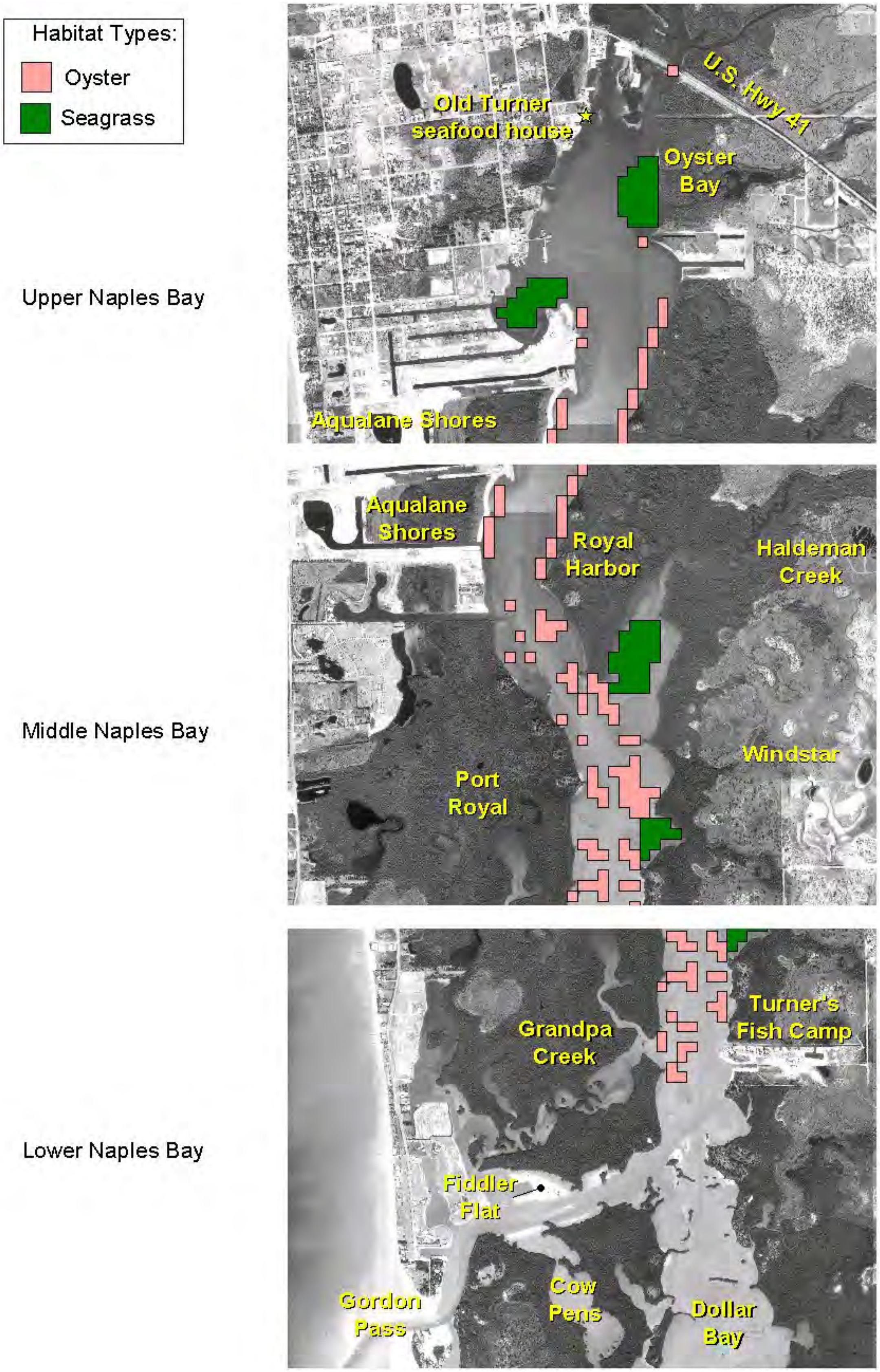


Figure 1-2. Localities and habitats in the Naples Bay area referenced in the historical narrative.

The area where Port Royal is located was once an extensive mangrove forest that was laced with shallow, muddy bays and tidal creeks, the largest of which was known as Grand Dad or Grandpa Creek (Fig. 1-2). The mangrove islands in the creek were surrounded by oyster bars. In some areas of the creek there were also sea grass beds, particularly at the west end of the creek where it turned north. They were most likely composed of either Cuban shoal grass (*Halodule wrightii*) or turtle grass (*Thalassia testudinum*). Several other creeks emptied into Grandpa Creek from the north and at the northern terminus of these creeks were embayments that also contained grass beds. These bays were also very muddy and contained quahog clams that were harvested for food. This system was essentially destroyed when construction of the finger-fill development known as Port Royal began in the late 1950's. A comparison of pre and post-construction aerial photographs indicates that one of the dredged canals began at what was the eastern entrance of Grandpa Creek and then followed a short length of the creek system. The same is true of the western end of the creek. The dredged channels were deeper than the original creek. The connectivity of the creeks was also eliminated and, as such, the previously existing patterns of tidal flushing in this part of the bay were significantly altered.

The central portion of Naples Bay, between the eastern entrance of Gordon Pass and the mouth of Haldeman Creek, was shallow and contained numerous oyster bars and seagrass beds. The oyster bars were particularly abundant on the east side of the bay, where the Windstar development is today, and also at the mouth of Haldeman Creek (Fig. 1-2). The entire shoreline was fringed by mangrove forest with the only exception being several finger-fill canals at Turner's Fish Camp (Simpson et al. 1979), where Bayview Park is presently located. There was a large seagrass bed at the entrance to Haldeman Creek on the east side of the bay. They were also oyster bars scattered throughout this area; however, there were more extensive oyster bars on the west side of the bay, particularly in the vicinity of the point that extends into the bay immediately south of the site where the Naples Yacht Club is presently located. A seagrass bed was also located just north of this point and encompassed some of the area were the docks for the Naples Yacht Club are now located. Residents recall wade-fishing on the east side of this part of the bay at low tide and also gathering oysters to eat. The seagrass beds provided habitat for small shrimp and fish as they used to see them dart away when walking the area at low tide. The mangrove shoreline and the aforementioned habitats were eradicated with the construction of the Aqualane Shores and Royal Harbor developments.

The area of Naples Bay from the Naples Yacht Club to the bridges at U.S. 41 has been dredged extensively. Permits were not required in early days, so the records of dredging are incomplete or nonexistent. The area that fronted Turner's seafood processing houses on the west side of the bay was dredged from 1953-1955. The depth at one of the sites that was dredged was 40 ft., but it has since filled in. Spoil from this dredging was used for fill for land to the east while some was also pumped across 8th St. for fill. Across from Turner's there was an unnamed creek; however, a portion of the creek was known as Mud Bay because the bottom was extremely soupy (referred to as Oyster Bay by Simpson et al. 1979 and herein). There was also a seagrass bed at the mouth of the creek (Fig. 1-2). A lot of fresh water used to flow down this creek, until it was filled as the area was developed. The dredging and filling for Boat Haven began in 1958. An area adjacent to Boat Haven was called Golden Shores by developers; however, residents called it Diamond Shoals because of the hardness of the underlying rock. Three businessmen went broke trying to develop the property. In and around the U.S. 41 bridges, there were extensive oyster beds that were used as a source of food. Duke Turner remembers periodically building a fire under the bridge and roasting them while they were fishing with nets.

North of the U.S. 41 bridges, the bottom was sandy and the water was sometimes clear enough so that one could see the bottom. There were oyster bars around the mouth of Rock Creek. Some people referred to them as “cup” oysters because they were not as elongated as oysters found further south in the bay. Rock Creek extended all the way to Airport Road. There was a swimming hole by the bridge at the road. The water was so fresh that Duke Turner recalls drinking it on occasion. About ¼ mile north of the mouth of Rock Creek there was a seagrass bed. At the extreme northern part of the Gordon River was an orange grove. There was also another swimming hole with a tree overhanging the water that children used to jump from to cool off. Duke Turner mentioned that he and his friends used to net mangrove snapper and snook in the upper reaches of the river and sold them for 2 or 3 cents a pound to earn spending money.

It was also mentioned, that in years past during periods when there was a lot of fresh water flowing into Naples Bay and on out of Gordon Pass that the water off the beach would become so fresh that people would see garfish swimming off the Naples Fishing Pier. Conversely, during very dry periods the greenish water from the Gulf could be seen well into the heart of the bay. These events did not occur often, but they do represent extremes that offer mute commentary on seasonal changes that can occur in south Florida’s shallow estuarine systems.

Naples Bay was once a shallow and productive estuary, based on the comments of the individuals who were interviewed and corroborated by evidence from aerial photographs and nautical charts. Extensive oyster bars were common throughout the bay, especially along the shoreline and at the mouths of tidal creeks, especially Haldeman and Rock Creeks, in the channels where U.S. 41 crosses the bay and is the vicinity of where the Naples Yacht Club. The dredging of the bay bottom and the extensive dredge-and-fill development and attendant shoreline modification that occurred during in the 1950s and 1960s has significantly altered the character and function of Naples Bay as a shallow-water estuary. Ecosystems are dynamic and respond to charges in the physical environment in which they exist. Regardless of the changes that have occurred over the past century, Naples Bay continues to function as an aquatic ecosystem. Efforts are needed to restore the former estuarine characters of the bay and prevent any further deterioration of the existing habitats.

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SECTION 2
SHORELINE AND HABITAT ANALYSES OF NAPLES BAY

The mixing of freshwater from the land and saltwater from the sea creates estuarine conditions that are critical to the survival of many species. Characteristic estuarine habitats include mangrove swamps, tidal marshes, seagrass communities, oyster reefs, mud flats and others. Pollution, development, and excessive use of natural resources deplete estuaries causing changes in ecosystem function. Many pristine estuarine areas have been altered directly or indirectly by human activities, specifically through development and altered hydrology as wetlands were dredged, filled, and impounded. Naples Bay is typical of many areas along the coast of Florida where dredge and fill operations have occurred and these actions have eradicated or degraded the estuarine habitats. During the past 50 years, the bay has experienced an escalation of growth and development along most of its shoreline, thus impacting the fringing mangrove community. In order to understand the alterations and the response of the aquatic system over time, it is necessary to document the present and historic distribution of estuarine communities within Naples Bay and the conditions that supported their previous existence. Comparison of past versus present habitat distributions and conditions will also help to guide future efforts to restore these communities. The objectives of this section of the project are (1) to assess past and present distribution of the benthic habitats (i.e., seagrass and oyster) within the Naples Bay and (2) to document changes to the mangrove shoreline of the bay.

MATERIALS AND METHODS

Study Area

Naples Bay is located on the southwest coast of Florida in west-central Collier County. It is a relatively narrow (width < 0.9 km) and shallow (depth less than 7 m) estuarine system that extends approximately 10 km from Golden Gate Dam, or Weir #1, to Gordon Pass. For the present analyses, the Gordon River was designated as the waterway north of the U.S. Hwy. 41 bridge to the entrance of the Golden Gate Canal (Fig. 2-1). Naples Bay included the waters south of the U.S. 41 to Gordon Pass, and the Bay was subdivided into three 1.8 km sections (upper, middle, and lower). The lower portion of Naples Bay connects to Dollar Bay and the Rookery Bay National Estuarine Research Reserve. Freshwater flows into the system from Golden Gate Canal, Gordon River, and Rock Creek to the north, Haldeman Creek to the east, and urban runoff surrounding the bay. Tidal exchange with the Gulf of Mexico occurs through Gordon Pass. This inflow pattern results in a longitudinal salinity gradient, increasing from north to south. Layering of water (or stratification) is related to the freshwater discharge from the Golden Gate canal, the main contributor of freshwater to the system (Simpson et al., 1979). Stratification decreases in the southern part of the bay because of increased tidal mixing.

Benthic Habitat Mapping

A shoreline polygon of the Gordon River and Naples Bay was digitized from 1999 Digital Orthoquads using ArcView 3.2 (Environmental Systems Research Institute, Redlands, CA) geographic information system (GIS) software. Transects were systematically placed over the study area polygon every 50 m and sampling sites were located at 50 m intervals along each transect. Sampling sites were uploaded to a Garmin (Garmin International Inc., Kansas City, KS) global positioning system (GPS) with Wide Area Augmentation System (WAAS) corrections and navigated in the field using the system's graphic display.

Sediment and biotic characteristics were used to characterize habitats at each sampling site (Schmid et al., 2003). Benthic substrates were classified as shell (mollusc shell fragments retained by a No. 4 sieve), sand (shell and reef particles and coralline algae sediments passing

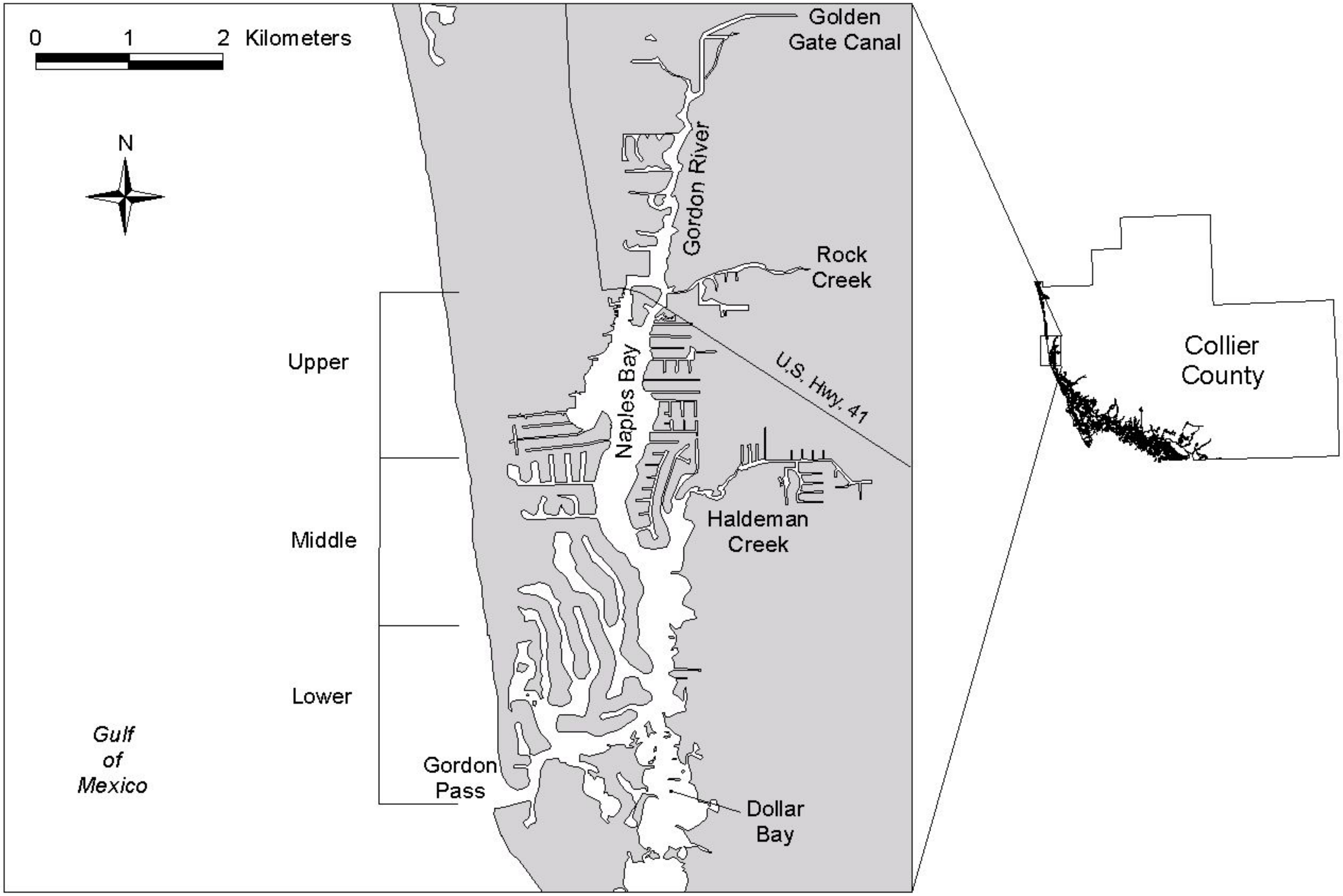


Figure 2.1. Map of west-central Collier County showing the Naples Bay study area.

through a No. 4 sieve and retained on a No. 200 sieve), mud (silt and clay particles passing through a No. 200 sieve), and rock/reef (limestone and vermetid gastropod reef outcroppings). Biological assemblages were classified as tube-building worms (sedentary marine polychaetes), seagrass (such as *Thalassia testudinu*m and *Halodule wrightii*), green macroalgae (species of Chlorophyta such as *Caulerpa* spp.), red macroalgae (species of Rhodophyta such as *Gracilaria* spp.), and live bottom (sessile invertebrates of the phyla Porifera [sponges], Cnidaria [hydrozoans], Bryozoa [bryozoans], and Chordata [tunicates]). The presence of the oyster, *Crassostera virginica,* and clam, *Mercenaria* spp., shells was also recorded at each site.

A grab sampler was deployed at each sample site to collect a benthic sample for substrate characterization and floral/faunal classification. A wet-sieving method was used to sort benthic substrates in the field. Approximately 125 ml of wet sediment was rinsed through No. 4 and No. 200 sieves with seawater pumped through a submersible bilge pump. Percent composition of shell, sand, and mud was estimated from visual inspection of the portions remaining in the sieves. Presence of limestone and vermetid reef was determined by the occurrence of respective fragments and the absence of soft sediments.

The resulting habitat database was used to produce raster maps of the study area using the ArcView Spatial Analyst extension. The maps consisted of 50X50 m grids of the primary benthic substrate (mud, sand, shell, and reef) with floral (seagrasses and algae) and faunal layers (polychaete worm tubes and live bottom [sponges, hydrozoans, bryozoans, and tunicates]). Substrate at each sample site was determined from the highest percentage of mud, sand, or shell, and, in the absence of these strata, the presence of limestone rock or vermetid reef.

Historic Habitat Comparison

Historic coverage of seagrass and oyster habitat in Naples Bay was determined from interviews with long-time Naples residents (see Historical Overview section) and photointerpretation of 1953 aerial images. Areal extent of each habitat type was matched to corresponding points of the 50X50 m sampling grid. Additional points were added when historic habitats occurred outside the boundary of the present study area. Raster maps of each habitat type were produced with the Spatial Analyst extension and compared to those from the aforementioned benthic sampling.

Shoreline Mapping

Digital shoreline shapefiles for Naples Bay were downloaded from the NOAA Shoreline Data Explorer website (http://www.ngs.noaa.gov/newsys_ims/shoreline/index.cfm). Data were available for 1927 (Project ID: FL2701; Description: Ten Thousand Islands, Florida), 1967 (Project ID: PH6605; Description: Naples to Lostmans River, Florida), and 1978 (Project ID: CM-7808; Description: Everglades City to Venice). Polygons were digitized to the vector shoreline data using ArcView and the XTools extension (version 6/1/2001) was used to calculate the perimeter and area for the Naples Bay polygons.

Shoreline Vegetation and Landuse

GIS themes of predevelopment vegetation (obtained from SFWMD Naples office) and 1999 landuse (obtained from Rookery Bay FDEP) were used to analyze changes to habitats fringing Naples Bay. Predevelopment vegetation types were classified as mangrove, upland forest (hydric and mesic flatwood), coastal scrub (xeric hammock), and wet prairie (including marsh). Landuse was classified by the Florida Land Use, Cover, and Forms Classification System (FLUCCS) codes. The predevelopment shoreline of Naples Bay was buffered 500 m and the resulting polygon was clipped from the GIS themes. Area (acres and hectares) of each vegetation type and/or landuse classification was calculated with the XTools extension (version 6/1/2001) for ArcView.

RESULTS

Benthic Habitat Mapping

A total of 109 sites were sampled in the Gordon River and, of this total, 46.8% (*n*=51) were classified as mud, 44.9% (*n*=49) as sand, 5.5% (*n*=6) as shell, and 2.8% (*n*=3) as rock (Table 2-1; Fig. 2-2). For the sites classified as sand, 38.8% (*n*=19) had relatively high proportions (30-40%) of mud. Although not viewed directly, rock sites in the river were probably limestone outcroppings. Eight hundred and sixty-two sites were sampled in Naples Bay and, of this total, 42.5% (*n*=366) were classified as mud, 39.4% (*n*=340) as sand, 17.2% (*n*=148) as shell, and 0.9% (*n*=8) as rock. Mud was the dominant substrate in the upper (49.2% of the sites) and middle (45.6% of the sites) portions of the bay, but there were substantially fewer sites classified as mud (5.2%) in the lower portion (Table 2-1; Fig. 2-2). Furthermore, 52.1% (*n*=50) of the sand sites in the upper portion of the bay and 47.7% (*n*=42) in the middle portion had relatively high proportions (30-40%) of mud in the samples. The percentage of sites classified as shell gradually increased from the upper to the lower portion of the bay (Table 2-1). Rock sites in upper portion of the bay may have been limestone, whereas rock sites in the lower portion appeared to be fossilized vermetid gastropod reef.

Oyster shell was distributed throughout Naples Bay, increasing in occurrence from the Gordon River to the lower bay, but 80% of the living oysters were found mid-bay (Table 2-2). These remnant oyster reefs occur on the east shore of the bay, south of Haldeman Creek and

Table 2-1. Distribution of primary substrates at sampling sites in the Gordon River and Naples Bay. Percent of River and Bay totals, respectively, are given in parentheses.

Substrate	Gordon River	Naples Bay		
		Upper	Middle	Lower
Mud	51 (46.8)	180 (49.2)	167 (45.6)	19 (5.2)
Sand	49 (44.9)	96 (28.2)	88 (25.9)	156 (45.9)
Shell	6 (5.5)	11 (7.4)	58 (39.2)	79 (53.4)
Rock	3 (2.8)	2 (25.0)	0 (0.0)	6 (75.0)

Figure 2-2. Distribution of benthic substrate sites in the Naples Bay study area (white outline).

Table 2-2. Distribution of biological assemblages at sampling sites in the Gordon River and Naples Bay. Percent of River and Bay totals, respectively, are given in parentheses.

Biological Assemblage	Components	Gordon River	Naples Bay		
			Upper	Middle	Lower
Oyster					
	Shell	9 (8.3)	24 (12.1)	82 (41.2)	93 (46.7)
	Living	0 (0.0)	4 (20.0)	16 (80.0)	0 (0.0)
Clam					
	Shell	0 (0.0)	5 (14.3)	27 (77.1)	3 (8.6)
Polychaetes					
	Unidentified worm tubes	10 (9.2)	88 (30.4)	95 (32.9)	106 (36.7)
	Plumed worm tubes	1 (0.9)	29 (17.9)	40 (24.7)	93 (57.4)
	Trumpet worm tubes	1 (0.9)	2 (8.3)	11 (45.8)	11 (45.8)
	Parchment worm tubes	0 (0.0)	1 (14.3)	2 (28.6)	4 (57.1)
Red algae					
	Gracilaria and *Hypnea* sps.	0 (0.0)	34 (73.9)	4 (8.7)	8 (17.4)
Green algae					
	Green filamentous form	2 (1.8)	0 (0.0)	0 (0.0)	11 (100.0)
	Caulerpa prolifera	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)
Seagrass					
	Halodule wrightii	0 (0.0)	0 (0.0)	0 (0.0)	7 (100.0)
Live bottom					
	Sponge	0 (0.0)	0 (0.0)	3 (8.1)	34 (91.9)
	Bryozoan	0 (0.0)	0 (0.0)	0 (0.0)	19 (100.0)
	Hydrozoan	0 (0.0)	0 (0.0)	1 (8.3)	11 (91.7)
	Tunicate	0 (0.0)	0 (0.0)	0 (0.0)	2 (100.0)

adjacent to the Windstar development (Fig. 2-3). Live oyster were also observed attached to red mangrove (*Rhizophora mangle*) prop roots fringing undeveloped areas of the bay. Clam shells were primarily collected in the middle portion of the bay (77% of the Bay sites) and these sites were typically located adjacent to channels.

Sedentary tubiculous polychaetes were the dominant biological assemblage and their tubes were collected throughout Naples Bay and a few Gordon River sites (Table 2-2; Fig. 2-4). Shell-encrusted tubes of plumed worms, *Diopatra cuprea*, increased in occurrence from upper to lower portions of the bay. Parchment worm tubes, *Chaetopterus variopedatus*, had a similar distribution, but to a much lesser degree. Conical sand tubes of the trumpet worm, *Pectinaria gouldii*, were found primarily in the middle and lower portions of the bay.

The red macroalgae assemblage was comprised of unidentified species of *Gracilaria* and *Hypnea*. The highest occurrence of red algae was in the upper portion of the bay (73.9% of red algae sites) and most of these were identified as drift algae (Table 2-2; Fig. 2-5). Red algae in the lower portion of the bay were typically attached to shell-encrusted worm tubes. The green macroalgae assemblage was comprised of unidentified filamentous green algae (probably *Cladophora* and/or *Chaetomorpha* sp.) and 1 site with *Caulerpa prolifera*. All of the green algae sites in Naples Bay (*n*=12) were found in the lower portion, but 2 Gordon River sites (1.8% of river sites) had filamentous green algae (Fig. 2-5). Cuban shoal grass, *Halodule wrightii*, was the only component of the seagrass assemblage and was only collected in the lower portion of the bay (Table 2-2; Fig. 2-5).

Fifty-three sites were classified as live bottom and, of this total, 69.8% (*n*=37) were classified as sponge, 35.8% (*n*=19) as bryozoan, 22.6% (*n*=12) as hydrozoan, and 3.8% (*n*=2) as tunicate. Live bottom sites were primarily located in the channel of the lower portion of the bay

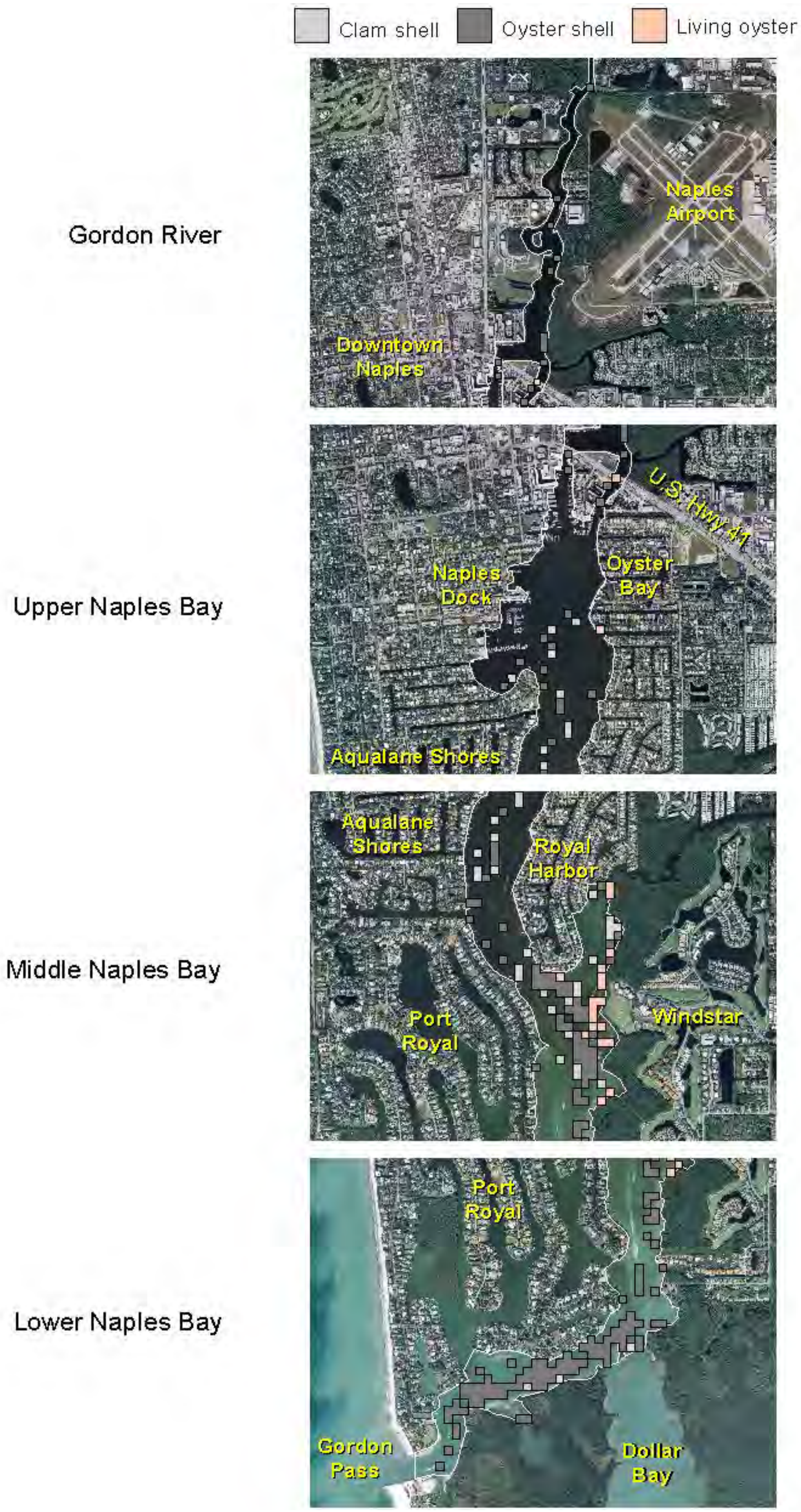


Figure 2-3. Distribution of clam shell, oyster shell and living oyster sites in the Naples Bay study area (white outline).

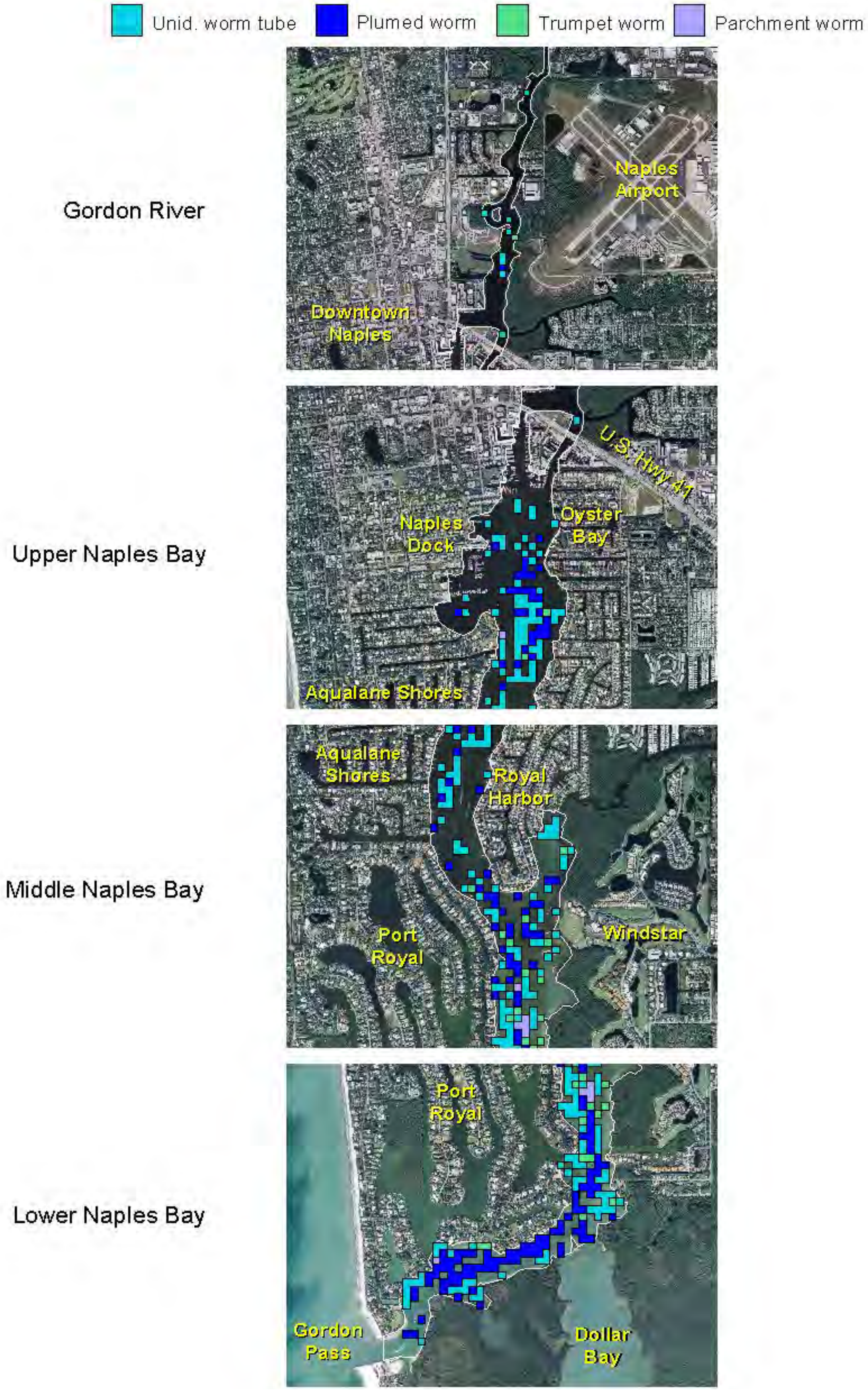


Figure 2-4. Distribution of tubiculous polychaete sites in the Naples Bay study area (white outline).

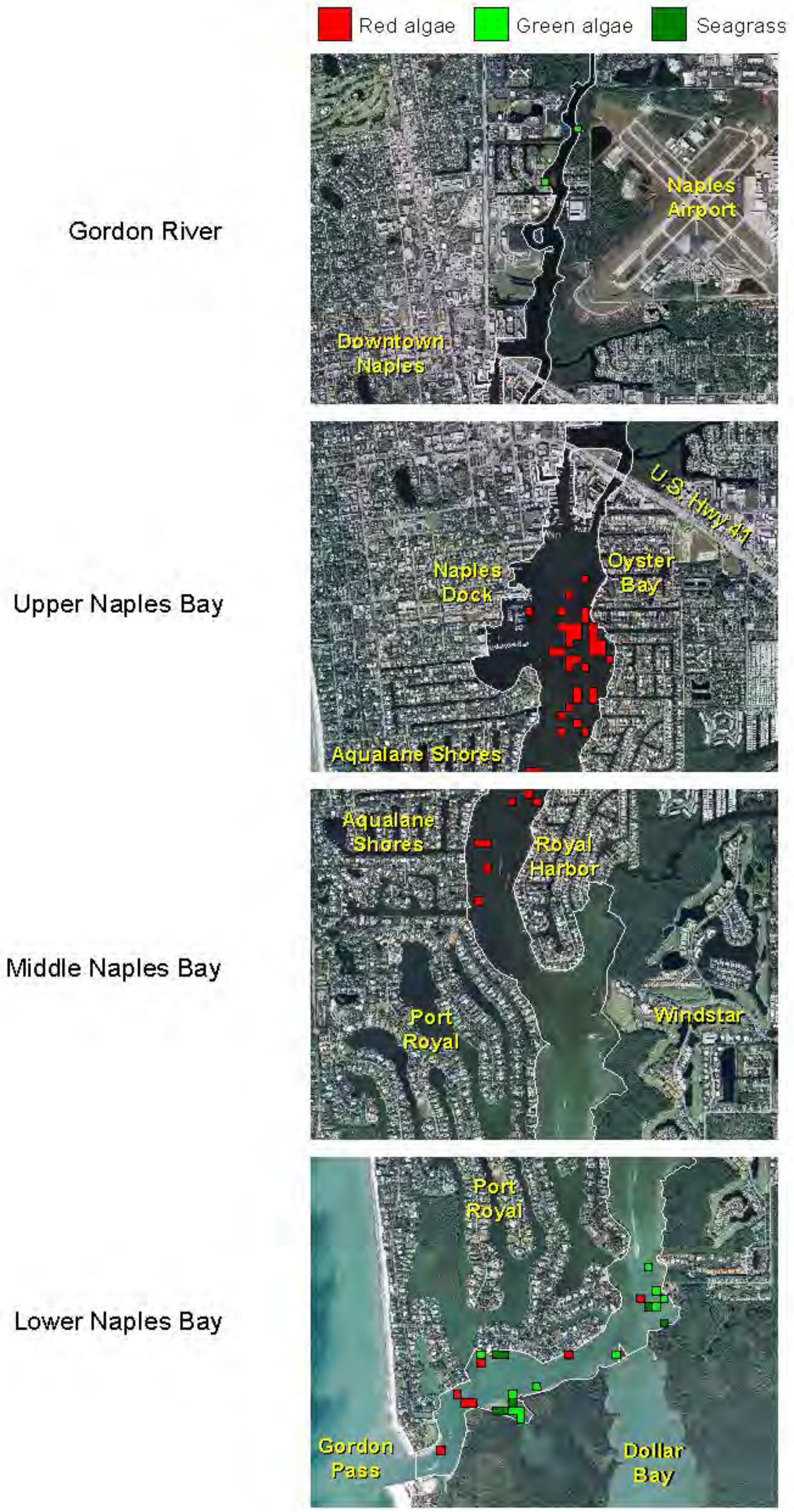


Figure 2-5. Distribution of macroalgae and seagrass sites in the Naples Bay study area (white outline).

(Table 2-2; Fig 2-6). During benthic sample collection, a loggerhead sea turtle (*Caretta caretta*) was observed surfacing to breathe and the turtle was located in the vicinity of live bottom habitat in the channel.

Historic Habitat Comparison

Prior to the development of Naples Bay in the late 1950's, there were approximately 67.6 acres (27.4 ha) of seagrass habitat located at the mouth of Oyster Bay and along the western shoreline of the upper region of the Bay and at the mouth of Haldeman Creek in the middle region (Fig. 2-7). There was also approximately 50.7 acres (20.5 ha) of oyster habitat extending southward from the seagrass beds on either side of the bay from the upper to the lower regions, and oyster beds were particularly extensive in the middle to lower regions south of Haldeman Creek. By comparison, benthic sampling in 2005 revealed approximately 4.3 acres (1.8 ha) of sparse seagrass habitat in the lower region of the bay and 12.4 acres (5.0 ha) of oyster habitat along the eastern shoreline of the middle region (Fig. 2-7). This represents a 91.4% loss in seagrass habitat and 81.7% loss in oyster habitat within Naples Bay over the past 5 decades.

Changes to Naples Bay Morphometrics

The shoreline perimeter of Naples Bay in 1927 extended 45.5 km with a water surface area of 820.3 acres (332.0 ha). By 1965, the shoreline perimeter had increased by 49.8% and the surface area increased by 22.9%. These drastic changes in bay morphometrics (Fig. 2-8) were due to the construction of the canal systems that formed the Aqualane Shores, Port Royal and Royal Harbor residential communities. Between 1965 and 1978, the shoreline perimeter increased by 10.9% and the surface area of the bay increased by only 0.2%. Shoreline changes were primarily limited to construction of canals north of Royal Harbor and the extension of existing canals on the east side of the bay.

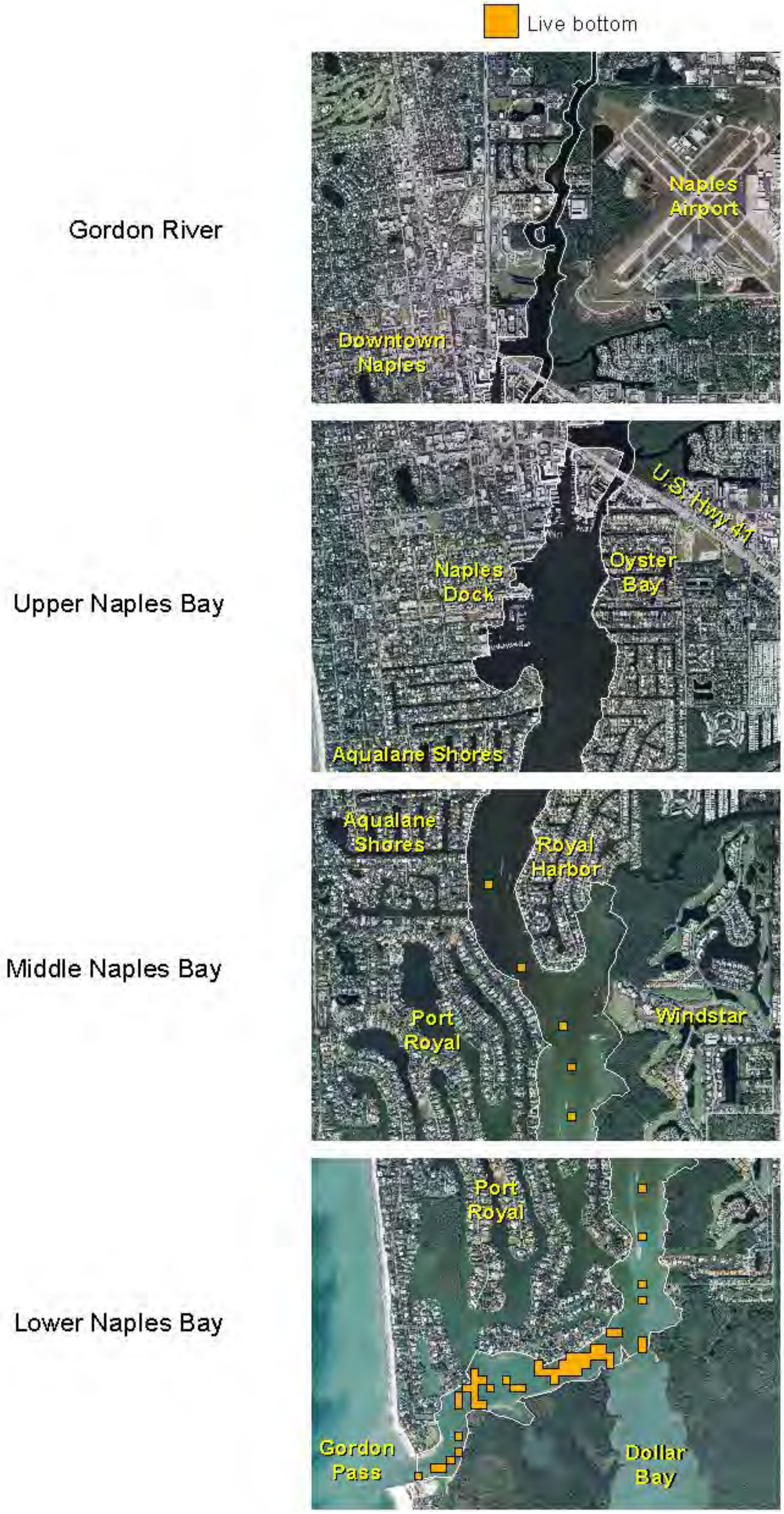


Figure 2-6. Distribution of livebottom sites in the Naples Bay study area (white outline).

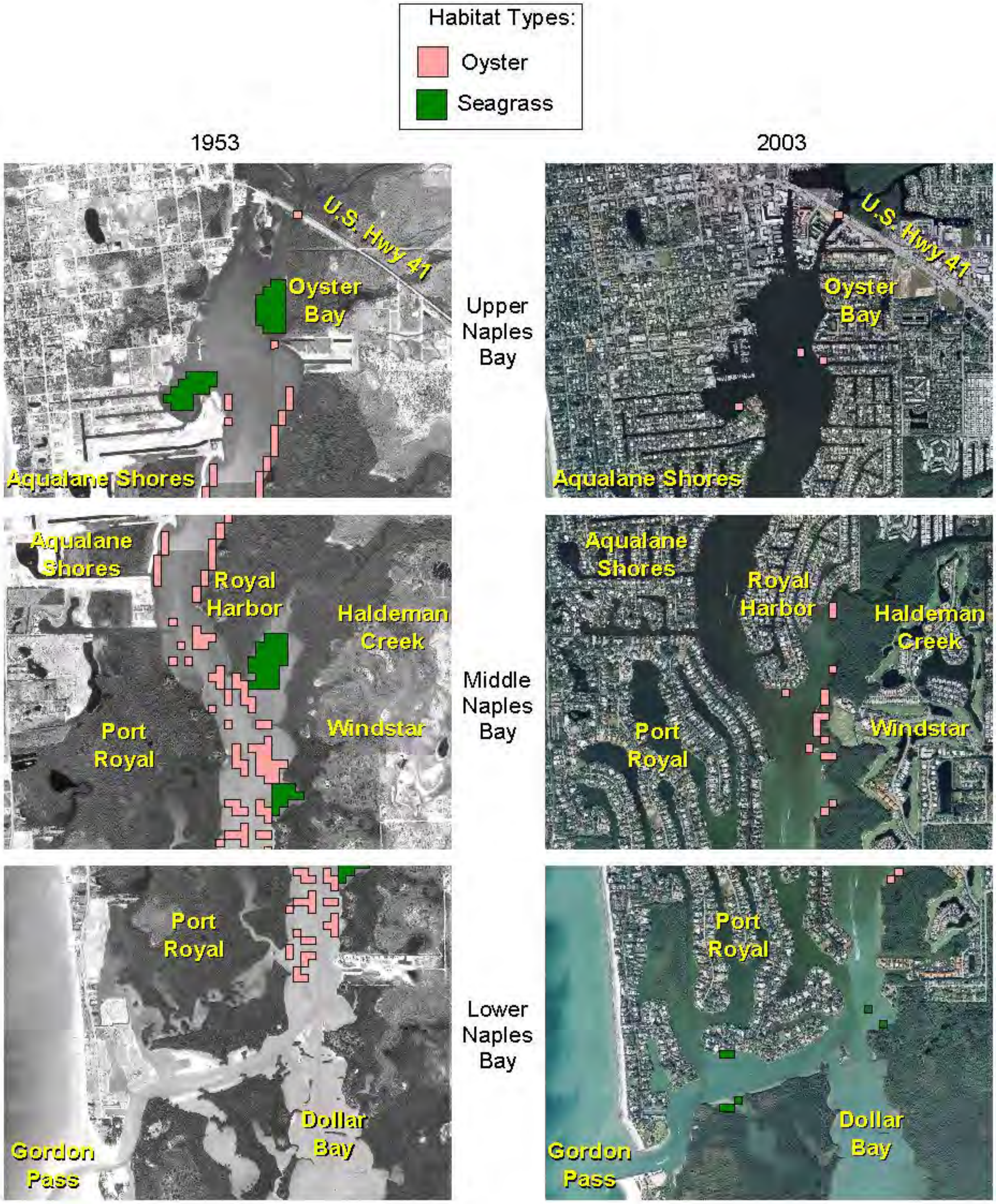
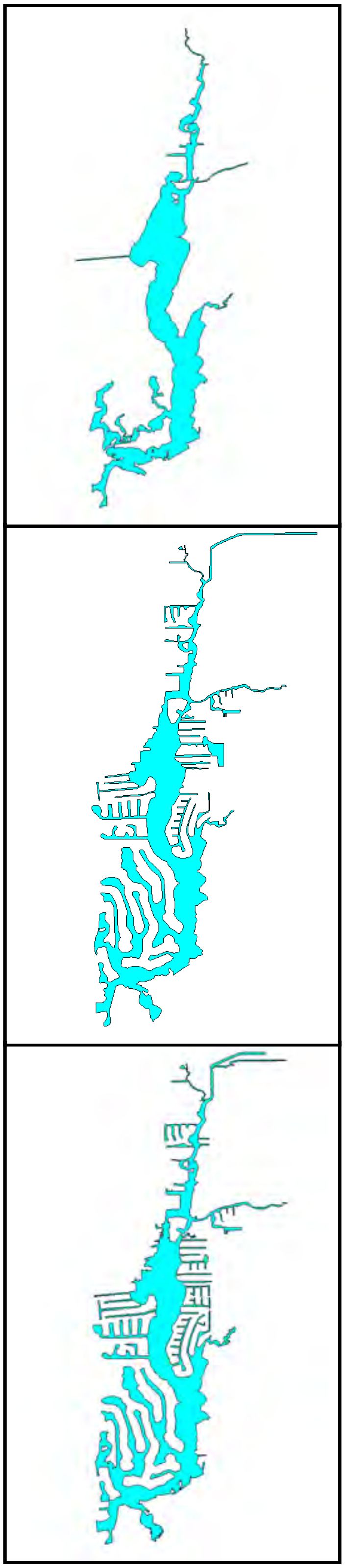


Figure 2-7. Historic and present distribution of oyster and seagrass habitats in Naples Bay. Aerial photography from 1953 and 2003 are displayed in the background.



Naples Bay Shoreline 1927
Perimeter: 45.5 km
Surface Area: 820.3 acres
(332.0 ha)

Naples Bay Shoreline 1965
Perimeter: 90.7 km
Surface Area: 1,064.0 acres
(430.6 ha)

Naples Bay Shoreline 1978
Perimeter: 101.8 km
Surface Area: 1,066.4 acres
(431.6 ha)

Figure 2-8. Maps of the Naples Bay shoreline in 1927, 1965, and 1978. Perimeter of the shoreline and surface area of the Bay waters are also presented.

Changes to Shoreline Vegetation and Landuse

The 500 m buffered area for the predevelopment shoreline of Naples Bay consisted of 41.3% mangrove, 23.4% upland forest, 6.8% coastal scrub, 0.3% wet prairie, 2.1% beach, and 26.1% water (Fig. 2-9); and the area for 1999 shoreline consisted of 11.4% mangrove, 7.2% upland forest, 0.4% coastal scrub, 0.1% wet prairie, 0.7% beach, 25.1% water, 43.3% urban and built-up, 3.6% transportation, and 8.2% canals. There was a 63-94% loss in areal coverage of predevelopment vegetation types owing to the development of areas surrounding Naples Bay (Table 2-3). Urban and built-up areas were the primary loss of predevelopment vegetation types around the Bay (Table 2-4), and these developed areas comprised 52.9% of the predevelopment mangrove, 61.9% of the upland forest, and 75.8% of the coastal scrub, respectively.

DISCUSSION

The shoreline and aquatic habitats of Naples Bay have been severely impacted by decades of human development in the surrounding areas. Dredge-and fill operations that began in the early 1950's transformed mangrove swamps into upland subdivisions and waterfront canal home sites (Antonini et al., 2002). As a result, over 70% of the fringing mangrove shoreline has been converted to residential developments. Intertidal habitats provided by mangrove root systems have been replaced by seawalls and rip-rap. Dredging for both waterfront property and navigational channels has resulted in the complete removal of the benthic communities within Naples Bay. The resulting change in bathymetry and substrate types makes recolonization by these communities difficult, if not impossible. Additionally, the drainage of upland areas via the Gordon River has severely altered the salinity patterns in this estuarine system. Seagrass and

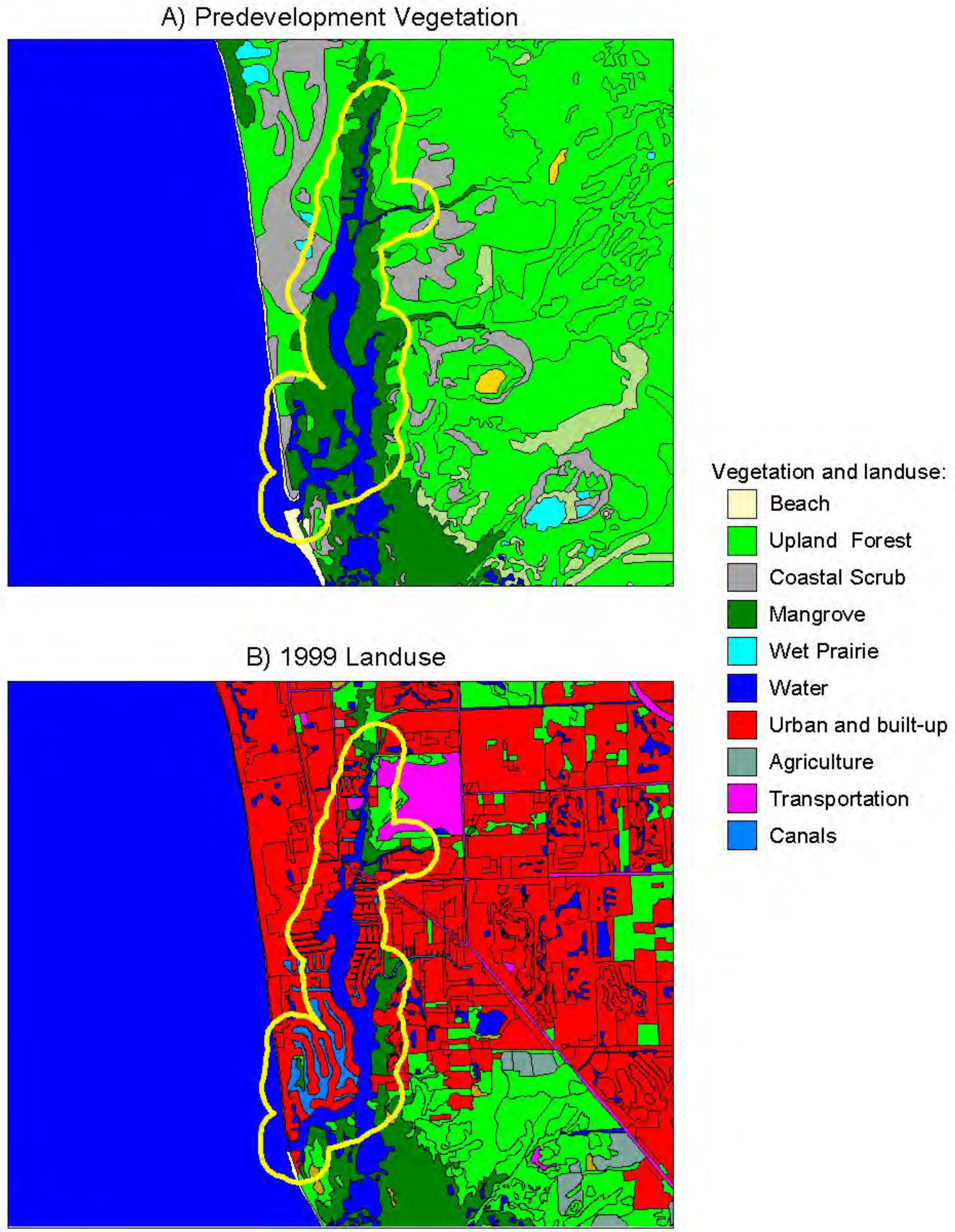


Figure 2-9. Maps of (a) predevelopment vegetation and (b) 1999 landuse for the area surrounding Naples Bay. The yellow outline depicts the 500m buffer.

Table 2-3. Vegetation and landuse cover for 500 m area buffered around predevelopment shoreline of Naples Bay and the Gordon River.

Description	Predevelopment vegetation (acres)	Predevelopment vegetation (hectares)	1999 landuse (acres)	1999 landuse (hectares)	Percent change
Mangrove	153.8	62.2	42.5	17.2	-72
Upland Forest	87.1	35.3	26.7	10.8	-69
Coastal Scrub	25.2	10.2	1.5	0.6	-94
Beach	7.9	3.2	2.5	1.0	-68
Wet Prairie	1.1	0.4	0.4	0.2	-63
Water	97.0	39.3	93.5	37.8	-4
Urban and Built-up	0.0	0.0	161.1	65.2	
Transportation	0.0	0.0	13.3	3.8	
Canals	0.0	0.0	30.7	12.4	

Table 2-4. Areal changes of predevelopment vegetation types to 1999 landuse classes.

	Predevelopment vegetation					
	Mangrove		Upland forest		Coastal scrub	
1999 landuse	(acres)	(hectares)	(acres)	(hectares)	(acres)	(hectares)
Urban and built-up	81.4	33.0	53.9	21.8	19.1	7.7
Transportation	2.0	0.8	10.1	4.1	1.0	0.4
Canals	20.0	8.1	0.5	0.2	0.1	0.04

oyster habitats within Naples Bay have been reduced 80-90% as a consequence of the combined effects of dredging and inflow alterations. Habitat loss resulting from the urbanization of the Naples Bay shoreline will never be restored to former natural conditions, but actions can be taken to remediate some of the habitat destruction that has occurred within the bay.

The distribution and abundance of benthic communities within an estuary are influenced by the physical properties of the sediments (Yokel, 1979 and references therein). Therefore, discerning the sediment characteristics of Naples Bay is vital to planning the restoration efforts, particularly in choosing sites for the placement oyster substrate (Savarese et al., 2004). Coarse substrates (sand, shell, and gravel) are required at sites for future reef development. Mud and muddy sand (i.e., fine-grain substrates) were the dominant strata in the upper and middle portions of Naples Bay, with the highest proportions of mud collected from the dredged channels and the numerous entrances to residential canals. The occurrence of coarse shell substrate increased from the middle to the lower portions of the bay and these areas may be more conducive to restoration efforts. Living oyster reefs located along the eastern shoreline of the middle bay region, particularly to the south of Haldeman Creek, indicate appropriate conditions exist for reef development. There were also suitable substrates in the upper portion of Naples Bay and these areas may become more favorable restoration sites if hydrological conditions improve.

As a regulator of salinity, freshwater inflow is probably the most important function in an estuary (Stickney, 1984). While many estuaries are plagued by reductions in freshwater inflow, Naples Bay receives a seasonal pattern of excessive inflow because of human-induced changes to the watershed. Canals were constructed to drain upland areas for development, which increased the size of the watershed from 10 sq. miles to 130 sq. miles and resulted in a much greater volume of freshwater inflow to Naples Bay. Simpson et al. (1979) estimated that the Bay receives 20-40 times the amount of inflow during the wet season due to the addition of the Golden Gate Canal watershed. Furthermore, the vegetation surrounding the Bay was removed and replaced by impervious surfaces (i.e., concrete bulkheads and asphalt roads). In order to avoid flooding in these urban areas, runoff is removed quickly via storm-water drainage systems and discharged as point sources directly into the estuary. The increased volume of inflow from the canal and storm-water systems has drastically changed mixing and circulation patterns Naples Bay and negatively impacted the survival and health of estuarine-dependent species. Yokel (1979) determined that the excessive discharge from the Golden Gate Canal had resulted in severe reductions in benthic invertebrate communities and may also displace planktonic organisms from the bay. Accordingly, these freshwater pulses may also flush oyster larvae out of the bay or create conditions that are unfavorable for their settlement (Tolley et al., 2003).

Salinity is among the most important features for the organisms comprising estuarine benthic communities (Stickney, 1984), and is therefore an important consideration for future restoration efforts. Permanent or long-term changes to salinity may cause the shifting of organisms to different regions of an estuary or eliminate them altogether. Species of submerged aquatic vegetation have been used to analyze patterns of freshwater inflow of estuarine systems (Doering and Chamberlain, 2000; Doering et al., 2002; Irlandi et al., 2002). Cuban shoalgrass (*Halodule wrightii*) is the most euryhaline (able to tolerate a wide range of salinity) of the seagrasses, turtle grass (*Thalassia testudinum*) is intermediate, and manatee grass (*Syringodium filiforme*) and *Halophila* spp. have the narrowest tolerant range (i.e., stenohaline; Zieman, 1982 and references therein). Historically, Cuban shoalgrass, and possibly turtle grass, extended to the upper regions of Naples Bay. At present, however, seagrass was only found in the extreme lower portions of the bay and the community was only comprised of the most euryhaline species. Wilzbach et al. (2000) indicated that shoalgrass exhibited a primary affinity for mud substrate and secondarily for sand. Therefore, the distribution of shoalgrass in Naples Bay does not appear to be a function of sediment type given the previously described sediment characteristics. The high freshwater inflow in the upper region of Naples Bay during the wet season has shifted the salinity gradient to the lower region of the bay, as evidenced by the apparent shift in seagrass distribution. Additionally, drift algae are sometimes indicative of eutrophic conditions (Thomsen and McGlathery, in press), and the preponderance of red drift algae in the upper portion of Naples Bay may be an indication of increased nutrient levels in the freshwater inflow.

A variety of information exists on the impacts of freshwater inflow alterations on aquatic organisms and their habitats in the estuaries of the Caloosahatchee (Chamberlain and Doering, 1997a, 1997b; Doering and Chamberlain, 2000; Doering et al., 2002; La Peyre et al., 2003; Tolley et al., 2003), the Ten Thousand Islands (Browder, 1988; Browder et al., 1986; Shirley et al., 2004), or both systems (Volety et al., 2004; Tolley et al., 2005). However, this issue has received relatively little attention in the Naples Bay estuary (Simpson et al., 1979; Savarese et al., 2004; present study). There is a need for more empirical studies to document the inflow alterations on biological activities in Naples Bay. Surveys of the benthic macroinvertebrate and fish communities, combined with water quality monitoring, could be used to identify the ecological conditions found in each of the Naples Bay tributaries (Golden Gate Canal, Gordon River, Rock Creek, and Haldeman Creek). The Conservancy of Southwest Florida has recently conducted a similar study for Estero Bay, which would provide a baseline for comparison between bay systems. Oyster reefs in Naples Bay could be sampled using Hester-Dendy substrates and proportions of euryhaline and stenohaline crab species could be compared as indicators of altered freshwater inflow (Shirley et al., 2004). Staff at Rookery Bay National Estuarine Research Reserve have already sampled some localities in Naples Bay using this technique, and expanding these efforts to other oyster areas identified from habitat mapping would provide a thorough assessment of inflow alterations throughout the bay. Furthermore, the results from similar studies (Shirley et al., 2004; Tolley et al., 2005) would serve as reference guides for efforts to restore a more natural volume of freshwater inflow to Naples Bay.

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SECTION 3
CORING ANALYSES OF NAPLES BAY

While habitat mapping will identify the gross-scale biological changes that have occurred in the highly development-impacted Naples Bay, the following portion of the project will focus on identifying the timing of these changes as well as their effect on hydrogeological and biogeochemical cycling within the system. The various physical and biological processes of Naples Bay must be determined to understand the dynamics of this estuarine system, and to make preliminary recommendations targeting possible areas for restoration and further research. The information obtained may be used to better constrain models that predict how changes in land use, hydrologic alteration, or nutrient enrichment may have led and might lead to biological disturbance. The purpose of this section of the project was to establish an approach for the reconstruction of environmental change in the recent time frame using biological and geochemical information.

MATERIALS AND METHODS

Sediment Coring and Handling

Sampling sites were chosen within regions of the estuary to represent a range of environmental conditions (Fig. 3-1): two sites from the mainstem of Naples Bay, a riverine region affected by channelization, a relatively less channelized riverine region (Haldeman Creek), and a relatively undisturbed reference site (Dollar Bay). The exact location for coring within each region was chosen to be those (1) furthest from boating channels, so unlikely to have been affected by dredging, (2) in deep enough water to be a deposition site for sediment, and (3) finer rather than sandy sediment so that a sediment core could be retrieved.

Figure 3-1. Location of the five coring sites in the Naples Bay estuary (April 7, 2005).

Sediment cores for the reconstruction of the history of Naples Bay estuary were collected using a hand-operated locking piston corer. Two cores were collected from each site using a 1 m length x 7 cm inner diameter poly-acrylic tubes, capped with foam inserts and overlying water and kept upright during all periods of transport. Within six hours of collection, one core from each site was sub-sampled by upward extrusion into 1-4 cm intervals and placed into pre-combusted (450^{o}C, 4.5 hours) glass jars for later organic analysis. They were kept on ice for 24 hours until placed in a freezer for storage.

The second core from each site was transported intact back to Gainesville and extruded horizontally into a pre-split section of core liner and then cut lengthwise with a metal wire. A half of the split core was fed through a GeoTek Multi-Sensor Core Logger with a gamma ray source detector (for bulk density/porosity of the sediment), magnetic susceptibility sensor (to quantify magnetic susceptibity), and a line scan camera (image scanning).

Half the split core was archived and the other half sub-sectioned into 1 cm intervals into pre-weighed 120 ml plastic jars within 48 hours of collection. After weighing, these samples were frozen, freeze-dried and re-weighed to determine water content. Finally, these samples were finely ground and used for sediment accumulation rate and bulk elemental chemistry determinations.

Radioisotope Analaysis

Sediment chronology and sediment accumulation rates were determined by ^{210}Pb dating. Radioisotope (^{210}Pb, ^{226}Ra, ^{137}Cs) activities were measured by direct gamma counting (Appleby et al., 1986; Schelske et al., 1994) using an EG&G Ortec GWL low-background high purity germanium well detector.

Dried, ground sediment samples were placed into counting tubes (heights of about 30 ± 2 mm in the tube, 3.5-4.5 g) and sealed with epoxy glue for three weeks to trap any emitted ^{222}Rn gas and establish equilibrium between parent ^{226}Ra and the proxies (daughters) used to estimate its activity. ^{226}Radium activity was measured at each depth to estimate supported ^{210}Pb activity. Unsupported (or 'excess') ^{210}Pb activity was estimated by subtraction of supported activity from the total activity measured at each level. The gamma counting method also permitted the simultaneous measurement of anthropogenic radionuclides such as ^{137}Cs (Krishnaswami and Lal 1978) and ^{241}Am (Appleby et al. 1991) that serve as horizon markers to check calculated ^{210}Pb dates.

Sedimentation Rate Determinations

To correct for differential compaction of the core, depth was normalized to the mean porosity of 0.47 (calculated by drying and reweighing sediments to obtain water content and then correcting for pore water salt content and assuming an average sediment density of 2.6 g cm^{-3} and average salinities of 15, 15, 10, 2, 10 ppt for cores 1-5, respectively). The excess ^{210}Pb activity profiles of the sediment cores were used to determine the chronological age of the sediment as well as the sedimentation rates. For cores with roughly linearly decreasing excess ^{210}Pb, a line was fitted to the linear portion of the core using least-squares technique and the slope of the line was converted to a linear sedimentation rate and applied to the whole of the core. This method is the 'constant initial concentration' (CIC) model (Appleby & Oldfield, 1978) and assumes that the water has a substantial reservoir of excess, that is, unsupported ^{210}Pb. According to this model, the water column contains abundant ^{210}Pb, regardless of the bulk sediment accumulation rate. Sediment scavenging of the radioisotope is proportional to the rate of sediment deposition, which proceeds in such a manner that surface sediments always have the same initial activity (Brenner et al., 2004). Bioturbation, physical mixing, and changes in sediment grain size or mineralogy can cause the initial concentration to vary and violate the assumptions of the model.

Sediment Core Chemistry

The same dried, ground sediment samples used for dating were also used for loss on ignition (LOI) analysis as a measure of total organic matter and carbonate, and bulk elemental (C and N) determination (Dean, 1974). For LOI determination, 1-2 g dried samples were weighed into ceramic crucibles, placed in a furnace for 3 hrs at 550^{o}C, and re-weighed. Weight loss was determined as percent organic matter. Weight loss after an additional 2.5 hrs at 1000^{o}C was determined as weight percent carbonate (Dean, 1974).

The usual method for the analysis of total organic carbon (TOC) and total nitrogen (TN) in sediments includes acidification with HCl in tin capsules to remove carbonate (inorganic carbon; Hedges and Stern, 1979) prior to analysis by high-temperature catalyzed oxidation to CO_2 and N_2 and measurement by IR detector. However, as these sediments were particularly high in carbonate content, we found that large amounts of HCl were needed which led to the precipitation of chloride salts in the capsules as well as the degradation and breakage of the capsules. We therefore switched to the use of a weaker acid, (6% sulfurous acid ; Heron, 1997), requiring larger volumes of acid addition and the use of Al-foil instead of tin. Sediment (6-10 mg) was added to capsules cut out of heavy grade aluminum foil (7/8 in. diameter) and formed around a 1/4 in. diameter glass rod (Verardo, et al., 1990). Sulfurous acid (three 100 µL increments) was added by micropipette. After drying at 75^{o} C overnight, the acidification process was repeated two more times, until bubbling ceased. The capsules were then folded tightly to prevent leaking and analyzed in a Carlo-Erba NA-1500 instrument using atropine as a standard.

RESULTS

Sediment cores were successfully collected on April 7, 2005 from four regions of the estuary; eastern mainstem (south of the Haldeman Creek; Core Sites 1 & 2), Dollar Bay, the Gordon River, and the mouth of Haldeman Creek. Two cores were collected at each site, one for sediment and bulk analysis and one for organic analysis (except Core Site 1 where only a core for sediment analysis was collected). Core designations and locations are listed in Table 3-1. The cores ranged in length from 22 to 54 cm, light to dark brown in color, and consisted mostly of clay and silt sands with many shell fragments (Fig. 3-2). The sediment from the Gordon River site was finer grain and tended to be finer toward the core bottom. The porosity of the sediments ranged from 0.3 to 0.8 but was mainly in the range between 0.4 and 0.6 (Tables 3-2 - 3-6), typical of sandy sediments. Below the uppermost 5 cm, porosity varied little within each core (Figs. 3-3 - 3-7), indicating probable change in sediment grain size or type through time, except in the case of the NB405-4 core collected in the Gordon River which showed a marked change in porosity at 20 cm and 42 cm depth (Fig. 3-6).

Sedimentation Rate and Sediment Dating

Excess ^{210}Pb activity was found to be low, even in uppermost portions of the core (generally less than 1 dpm g^{-1}) . This was probably due to the high sand content of the sediments, which is not very adsorptive of lead. However, in cores, 1, 2, 3, and 5, the linearity of excess ^{210}Pb decrease down-core was significant and the assumption and calculation of a constant sediment accumulation rate was justified (Figs. 3-3, 3-4, 3-5, and 3-7). Linear

Table 3-1. Coring locations in the Naples Bay estuary (April 7, 2005).

Site Designation	Site Location	Latitude	Longitude	‘Dating’ Core Length	‘Organic’ Core Length
NB405-1	Naples Bay Mainstem	26.110590	-81.784970	22 cm	none
NB405-2	Naples Bay Mainstem	26.110272	-81.785198	23 cm	29 cm
NB405-3	Dollar Bay	26.084016	-81.788503	38 cm	32 cm
NB405-4	Gordon River	26.146948	-81.785868	54 cm	51 cm
NB405-5	Haldeman Creek Mouth	26.116958	-81.784933	34 cm	19 cm

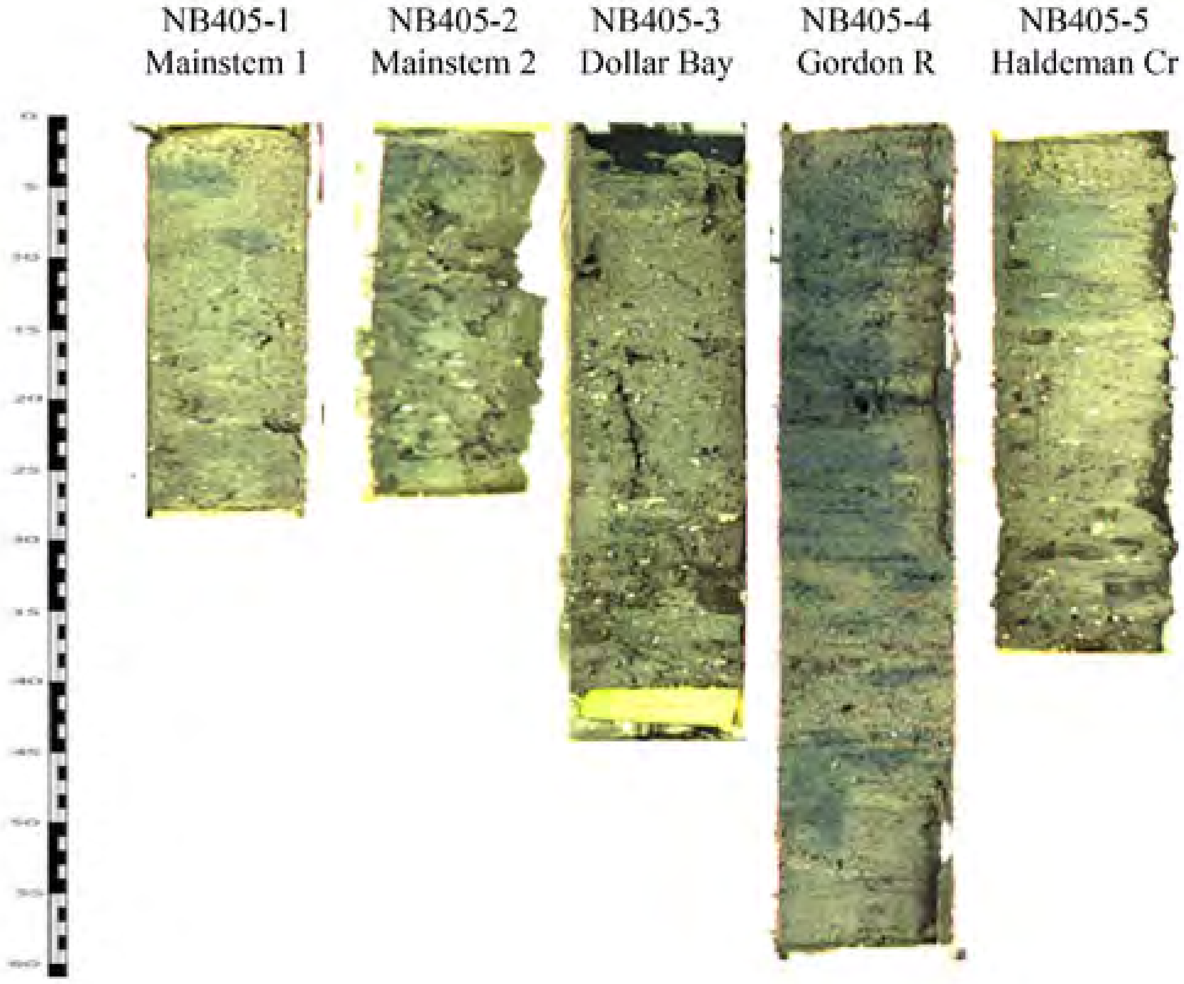
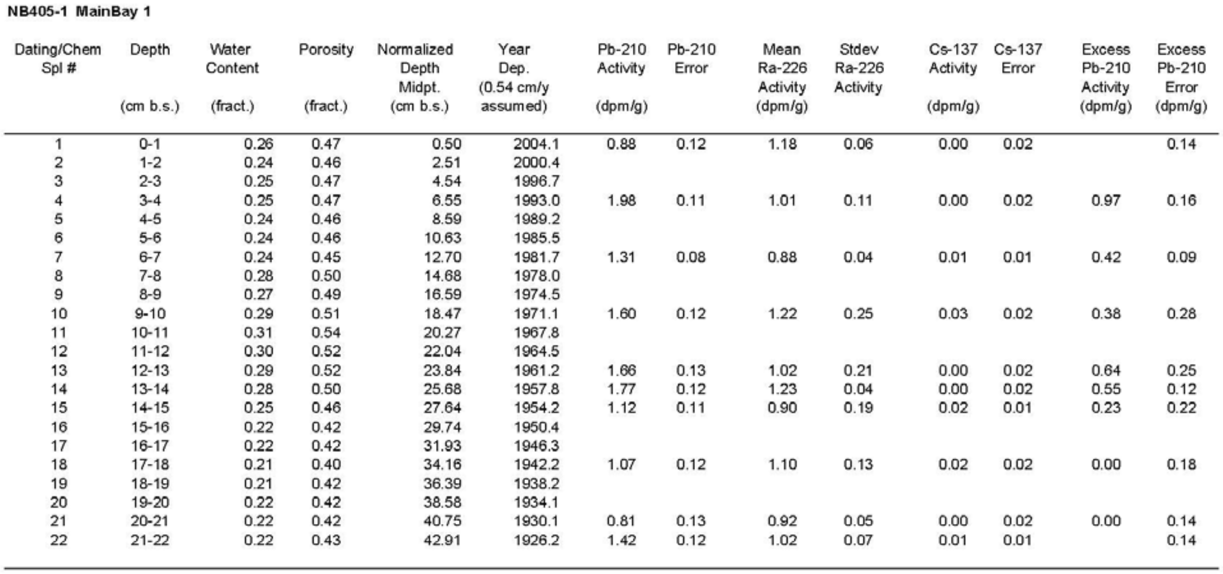


Figure 3-2. Photographic images of Naples Bay cores used for determinations of sedimentation rate.

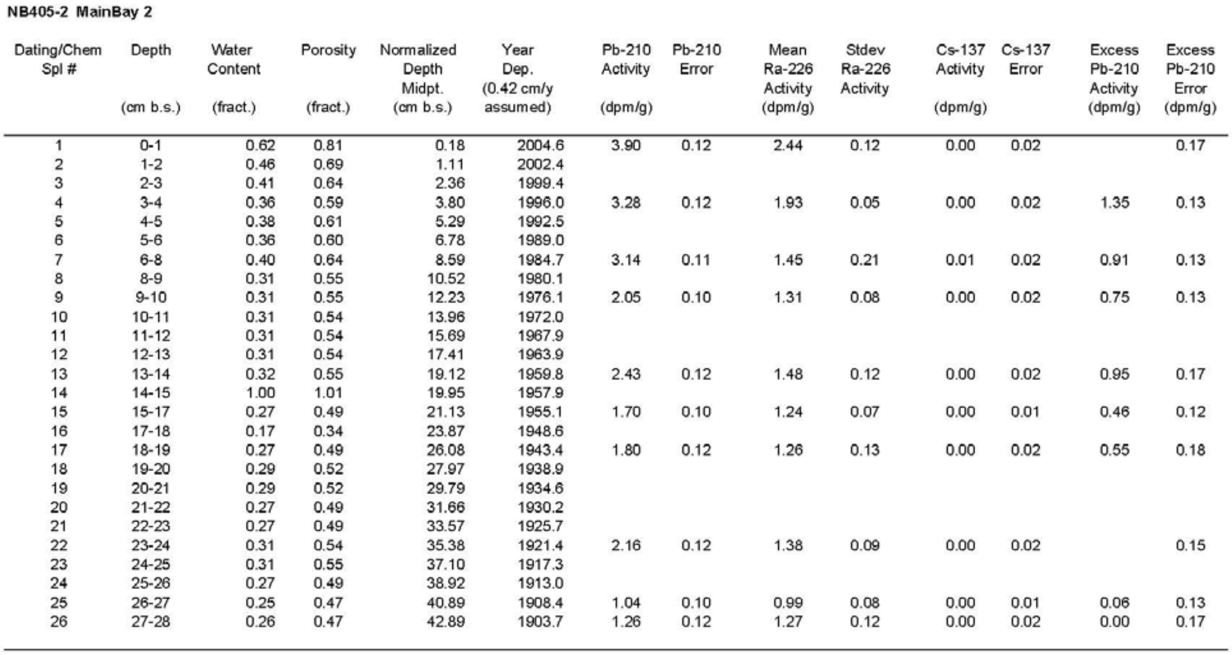
Table 3-2. Dating Information for Core NB405-1.



NB405-1 MainBay 1

Dating/Chem Spl #	Depth (cm b.s.)	Water Content (fract.)	Porosity (fract.)	Normalized Depth Midpt. (cm b.s.)	Year Dep. (0.54 cm/y assumed)	Pb-210 Activity (dpm/g)	Pb-210 Error	Mean Ra-226 Activity (dpm/g)	Stdev Ra-226 Activity	Cs-137 Activity (dpm/g)	Cs-137 Error	Excess Pb-210 Activity (dpm/g)	Excess Pb-210 Error (dpm/g)
1	0-1	0.26	0.47	0.50	2004.1	0.88	0.12	1.18	0.06	0.00	0.02		0.14
2	1-2	0.24	0.46	2.51	2000.4								
3	2-3	0.25	0.47	4.54	1996.7								
4	3-4	0.25	0.47	6.55	1993.0	1.98	0.11	1.01	0.11	0.00	0.02	0.97	0.16
5	4-5	0.24	0.46	8.59	1989.2								
6	5-6	0.24	0.46	10.63	1985.5								
7	6-7	0.24	0.45	12.70	1981.7	1.31	0.08	0.88	0.04	0.01	0.01	0.42	0.09
8	7-8	0.28	0.50	14.68	1978.0								
9	8-9	0.27	0.49	16.59	1974.5								
10	9-10	0.29	0.51	18.47	1971.1	1.60	0.12	1.22	0.25	0.03	0.02	0.38	0.28
11	10-11	0.31	0.54	20.27	1967.8								
12	11-12	0.30	0.52	22.04	1964.5								
13	12-13	0.29	0.52	23.84	1961.2	1.66	0.13	1.02	0.21	0.00	0.02	0.64	0.25
14	13-14	0.28	0.50	25.68	1957.8	1.77	0.12	1.23	0.04	0.00	0.02	0.55	0.12
15	14-15	0.25	0.46	27.64	1954.2	1.12	0.11	0.90	0.19	0.02	0.01	0.23	0.22
16	15-16	0.22	0.42	29.74	1950.4								
17	16-17	0.22	0.42	31.93	1946.3								
18	17-18	0.21	0.40	34.16	1942.2	1.07	0.12	1.10	0.13	0.02	0.02	0.00	0.18
19	18-19	0.21	0.42	36.39	1938.2								
20	19-20	0.22	0.42	38.58	1934.1								
21	20-21	0.22	0.42	40.75	1930.1	0.81	0.13	0.92	0.05	0.00	0.02	0.00	0.14
22	21-22	0.22	0.43	42.91	1926.2	1.42	0.12	1.02	0.07	0.01	0.01		0.14

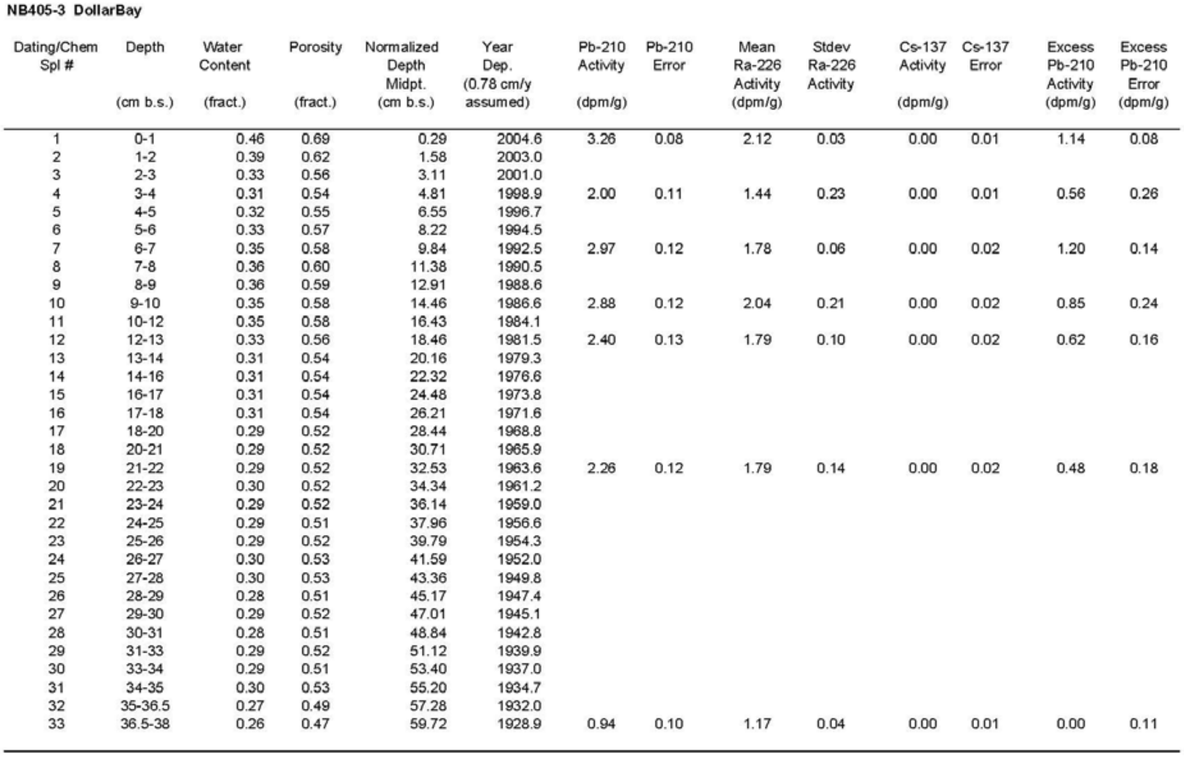
Table 3-3. Dating Information for Core NB405-2.



NB405-2 MainBay 2

Dating/Chem Spl #	Depth (cm b.s.)	Water Content (fract.)	Porosity (fract.)	Normalized Depth Midpt. (cm b.s.)	Year Dep. (0.42 cm/y assumed)	Pb-210 Activity (dpm/g)	Pb-210 Error	Mean Ra-226 Activity (dpm/g)	Stdev Ra-226 Activity	Cs-137 Activity (dpm/g)	Cs-137 Error	Excess Pb-210 Activity (dpm/g)	Excess Pb-210 Error (dpm/g)
1	0-1	0.62	0.81	0.18	2004.6	3.90	0.12	2.44	0.12	0.00	0.02		0.17
2	1-2	0.46	0.69	1.11	2002.4								
3	2-3	0.41	0.64	2.36	1999.4								
4	3-4	0.36	0.59	3.80	1996.0	3.28	0.12	1.93	0.05	0.00	0.02	1.35	0.13
5	4-5	0.38	0.61	5.29	1992.5								
6	5-6	0.36	0.60	6.78	1989.0								
7	6-8	0.40	0.64	8.59	1984.7	3.14	0.11	1.45	0.21	0.01	0.02	0.91	0.13
8	8-9	0.31	0.55	10.52	1980.1								
9	9-10	0.31	0.55	12.23	1976.1	2.05	0.10	1.31	0.08	0.00	0.02	0.75	0.13
10	10-11	0.31	0.54	13.96	1972.0								
11	11-12	0.31	0.54	15.69	1967.9								
12	12-13	0.31	0.54	17.41	1963.9								
13	13-14	0.32	0.55	19.12	1959.8	2.43	0.12	1.48	0.12	0.00	0.02	0.95	0.17
14	14-15	1.00	1.01	19.95	1957.9								
15	15-17	0.27	0.49	21.13	1955.1	1.70	0.10	1.24	0.07	0.00	0.01	0.46	0.12
16	17-18	0.17	0.34	23.87	1948.6								
17	18-19	0.27	0.49	26.08	1943.4	1.80	0.12	1.26	0.13	0.00	0.02	0.55	0.18
18	19-20	0.29	0.52	27.97	1938.9								
19	20-21	0.29	0.52	29.79	1934.6								
20	21-22	0.27	0.49	31.66	1930.2								
21	22-23	0.27	0.49	33.57	1925.7								
22	23-24	0.31	0.54	35.38	1921.4	2.16	0.12	1.38	0.09	0.00	0.02		0.15
23	24-25	0.31	0.55	37.10	1917.3								
24	25-26	0.27	0.49	38.92	1913.0								
25	26-27	0.25	0.47	40.89	1908.4	1.04	0.10	0.99	0.08	0.00	0.01	0.06	0.13
26	27-28	0.26	0.47	42.89	1903.7	1.26	0.12	1.27	0.12	0.00	0.02	0.00	0.17

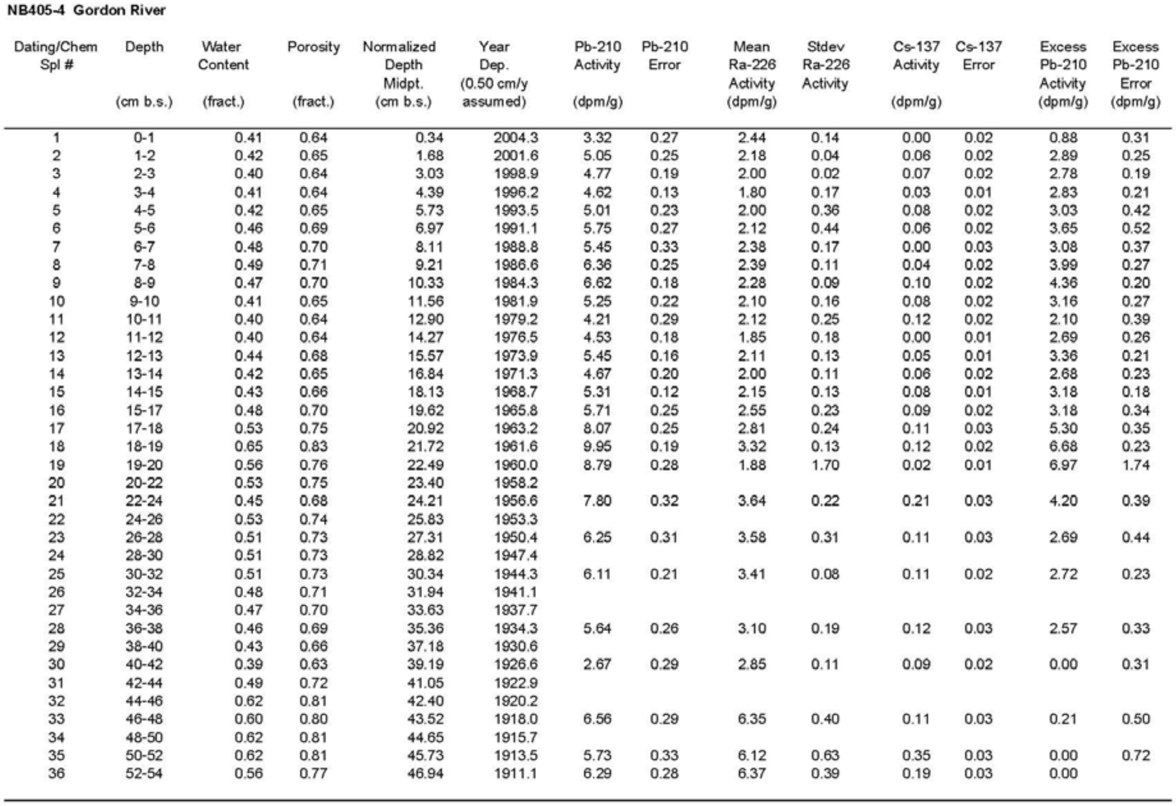
Table 3-4. Dating Information for Core NB405-3.



NB405-3 DollarBay

Dating/Chem Spl #	Depth (cm b.s.)	Water Content (fract.)	Porosity (fract.)	Normalized Depth Midpt. (cm b.s.)	Year Dep. (0.78 cm/y assumed)	Pb-210 Activity (dpm/g)	Pb-210 Error	Mean Ra-226 Activity (dpm/g)	Stdev Ra-226 Activity	Cs-137 Activity (dpm/g)	Cs-137 Error	Excess Pb-210 Activity (dpm/g)	Excess Pb-210 Error (dpm/g)
1	0-1	0.46	0.69	0.29	2004.6	3.26	0.08	2.12	0.03	0.00	0.01	1.14	0.08
2	1-2	0.39	0.62	1.58	2003.0								
3	2-3	0.33	0.56	3.11	2001.0								
4	3-4	0.31	0.54	4.81	1998.9	2.00	0.11	1.44	0.23	0.00	0.01	0.56	0.26
5	4-5	0.32	0.55	6.55	1996.7								
6	5-6	0.33	0.57	8.22	1994.5								
7	6-7	0.35	0.58	9.84	1992.5	2.97	0.12	1.78	0.06	0.00	0.02	1.20	0.14
8	7-8	0.36	0.60	11.38	1990.5								
9	8-9	0.36	0.59	12.91	1988.6								
10	9-10	0.35	0.58	14.46	1986.6	2.88	0.12	2.04	0.21	0.00	0.02	0.85	0.24
11	10-12	0.35	0.58	16.43	1984.1								
12	12-13	0.33	0.56	18.46	1981.5	2.40	0.13	1.79	0.10	0.00	0.02	0.62	0.16
13	13-14	0.31	0.54	20.16	1979.3								
14	14-16	0.31	0.54	22.32	1976.6								
15	16-17	0.31	0.54	24.48	1973.8								
16	17-18	0.31	0.54	26.21	1971.6								
17	18-20	0.29	0.52	28.44	1968.8								
18	20-21	0.29	0.52	30.71	1965.9								
19	21-22	0.29	0.52	32.53	1963.6	2.26	0.12	1.79	0.14	0.00	0.02	0.48	0.18
20	22-23	0.30	0.52	34.34	1961.2								
21	23-24	0.29	0.52	36.14	1959.0								
22	24-25	0.29	0.51	37.96	1956.6								
23	25-26	0.29	0.52	39.79	1954.3								
24	26-27	0.30	0.53	41.59	1952.0								
25	27-28	0.30	0.53	43.36	1949.8								
26	28-29	0.28	0.51	45.17	1947.4								
27	29-30	0.29	0.52	47.01	1945.1								
28	30-31	0.28	0.51	48.84	1942.8								
29	31-33	0.29	0.52	51.12	1939.9								
30	33-34	0.29	0.51	53.40	1937.0								
31	34-35	0.30	0.53	55.20	1934.7								
32	35-36.5	0.27	0.49	57.28	1932.0								
33	36.5-38	0.26	0.47	59.72	1928.9	0.94	0.10	1.17	0.04	0.00	0.01	0.00	0.11

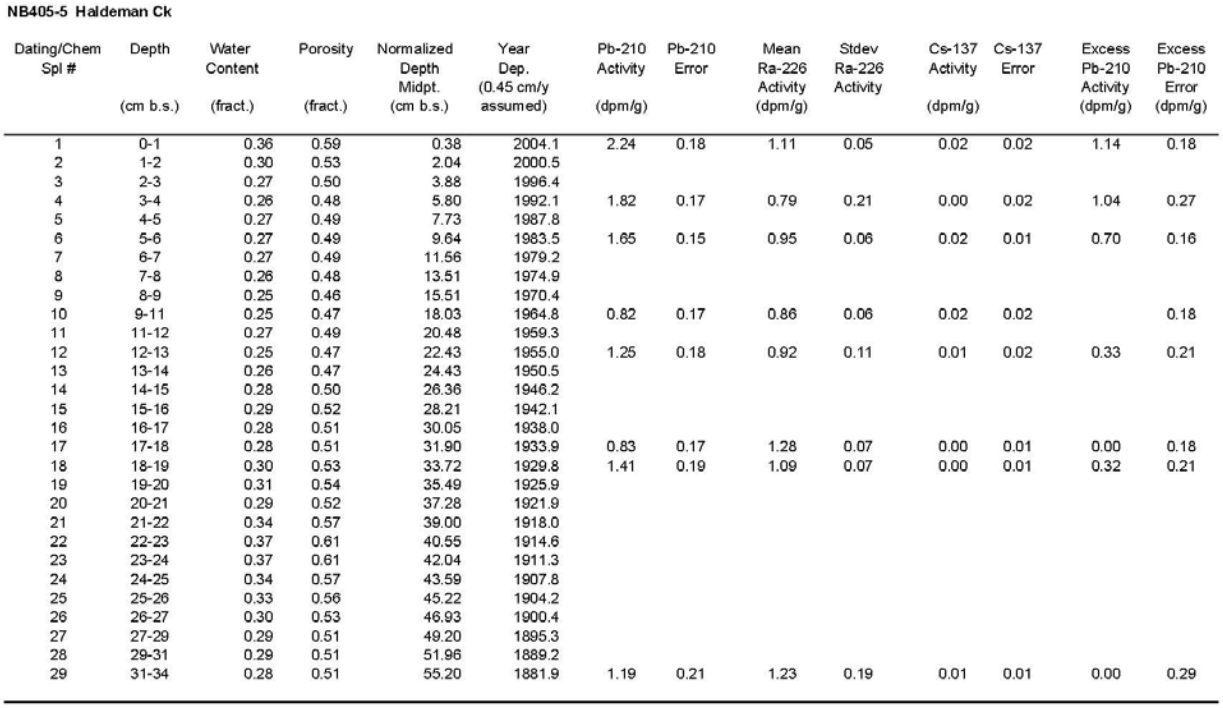
Table 3-5. Dating Information for Core NB405-4.



NB405-4 Gordon River

Dating/Chem Spl #	Depth (cm b.s.)	Water Content (fract.)	Porosity (fract.)	Normalized Depth Midpt. (cm b.s.)	Year Dep. (0.50 cm/y assumed)	Pb-210 Activity (dpm/g)	Pb-210 Error	Mean Ra-226 Activity (dpm/g)	Stdev Ra-226 Activity	Cs-137 Activity (dpm/g)	Cs-137 Error	Excess Pb-210 Activity (dpm/g)	Excess Pb-210 Error (dpm/g)
1	0-1	0.41	0.64	0.34	2004.3	3.32	0.27	2.44	0.14	0.00	0.02	0.88	0.31
2	1-2	0.42	0.65	1.68	2001.6	5.05	0.25	2.18	0.04	0.06	0.02	2.89	0.25
3	2-3	0.40	0.64	3.03	1998.9	4.77	0.19	2.00	0.02	0.07	0.02	2.78	0.19
4	3-4	0.41	0.64	4.39	1996.2	4.62	0.13	1.80	0.17	0.03	0.01	2.83	0.21
5	4-5	0.42	0.65	5.73	1993.5	5.01	0.23	2.00	0.36	0.08	0.02	3.03	0.42
6	5-6	0.46	0.69	6.97	1991.1	5.75	0.27	2.12	0.44	0.06	0.02	3.65	0.52
7	6-7	0.48	0.70	8.11	1988.8	5.45	0.33	2.38	0.17	0.00	0.03	3.08	0.37
8	7-8	0.49	0.71	9.21	1986.6	6.36	0.25	2.39	0.11	0.04	0.02	3.99	0.27
9	8-9	0.47	0.70	10.33	1984.3	6.62	0.18	2.28	0.09	0.10	0.02	4.36	0.20
10	9-10	0.41	0.65	11.56	1981.9	5.25	0.22	2.10	0.16	0.08	0.02	3.16	0.27
11	10-11	0.40	0.64	12.90	1979.2	4.21	0.29	2.12	0.25	0.12	0.02	2.10	0.39
12	11-12	0.40	0.64	14.27	1976.5	4.53	0.18	1.85	0.18	0.00	0.01	2.69	0.26
13	12-13	0.44	0.68	15.57	1973.9	5.45	0.16	2.11	0.13	0.05	0.01	3.36	0.21
14	13-14	0.42	0.65	16.84	1971.3	4.67	0.20	2.00	0.11	0.06	0.02	2.68	0.23
15	14-15	0.43	0.66	18.13	1968.7	5.31	0.12	2.15	0.13	0.08	0.01	3.18	0.18
16	15-17	0.48	0.70	19.62	1965.8	5.71	0.25	2.55	0.23	0.09	0.02	3.18	0.34
17	17-18	0.53	0.75	20.92	1963.2	8.07	0.25	2.81	0.24	0.11	0.03	5.30	0.35
18	18-19	0.65	0.83	21.72	1961.6	9.95	0.19	3.32	0.13	0.12	0.02	6.68	0.23
19	19-20	0.56	0.76	22.49	1960.0	8.79	0.28	1.88	1.70	0.02	0.01	6.97	1.74
20	20-22	0.53	0.75	23.40	1958.2								
21	22-24	0.45	0.68	24.21	1956.6	7.80	0.32	3.64	0.22	0.21	0.03	4.20	0.39
22	24-26	0.53	0.74	25.83	1953.3								
23	26-28	0.51	0.73	27.31	1950.4	6.25	0.31	3.58	0.31	0.11	0.03	2.69	0.44
24	28-30	0.51	0.73	28.82	1947.4								
25	30-32	0.51	0.73	30.34	1944.3	6.11	0.21	3.41	0.08	0.11	0.02	2.72	0.23
26	32-34	0.48	0.71	31.94	1941.1								
27	34-36	0.47	0.70	33.63	1937.7								
28	36-38	0.46	0.69	35.36	1934.3	5.64	0.26	3.10	0.19	0.12	0.03	2.57	0.33
29	38-40	0.43	0.66	37.18	1930.6								
30	40-42	0.39	0.63	39.19	1926.6	2.67	0.29	2.85	0.11	0.09	0.02	0.00	0.31
31	42-44	0.49	0.72	41.05	1922.9								
32	44-46	0.62	0.81	42.40	1920.2								
33	46-48	0.60	0.80	43.52	1918.0	6.56	0.29	6.35	0.40	0.11	0.03	0.21	0.50
34	48-50	0.62	0.81	44.65	1915.7								
35	50-52	0.62	0.81	45.73	1913.5	5.73	0.33	6.12	0.63	0.35	0.03	0.00	0.72
36	52-54	0.56	0.77	46.94	1911.1	6.29	0.28	6.37	0.39	0.19	0.03	0.00	

Table 3-6. Dating Information for Core NB405-5.



NB405-5 Haldeman Ck

Dating/Chem Spl #	Depth (cm b.s.)	Water Content (fract.)	Porosity (fract.)	Normalized Depth Midpt. (cm b.s.)	Year Dep. (0.45 cm/y assumed)	Pb-210 Activity (dpm/g)	Pb-210 Error	Mean Ra-226 Activity (dpm/g)	Stdev Ra-226 Activity	Cs-137 Activity (dpm/g)	Cs-137 Error	Excess Pb-210 Activity (dpm/g)	Excess Pb-210 Error (dpm/g)
1	0-1	0.36	0.59	0.38	2004.1	2.24	0.18	1.11	0.05	0.02	0.02	1.14	0.18
2	1-2	0.30	0.53	2.04	2000.5								
3	2-3	0.27	0.50	3.88	1996.4								
4	3-4	0.26	0.48	5.80	1992.1	1.82	0.17	0.79	0.21	0.00	0.02	1.04	0.27
5	4-5	0.27	0.49	7.73	1987.8								
6	5-6	0.27	0.49	9.64	1983.5	1.65	0.15	0.95	0.06	0.02	0.01	0.70	0.16
7	6-7	0.27	0.49	11.56	1979.2								
8	7-8	0.26	0.48	13.51	1974.9								
9	8-9	0.25	0.46	15.51	1970.4								
10	9-11	0.25	0.47	18.03	1964.8	0.82	0.17	0.86	0.06	0.02	0.02		0.18
11	11-12	0.27	0.49	20.48	1959.3								
12	12-13	0.25	0.47	22.43	1955.0	1.25	0.18	0.92	0.11	0.01	0.02	0.33	0.21
13	13-14	0.26	0.47	24.43	1950.5								
14	14-15	0.28	0.50	26.36	1946.2								
15	15-16	0.29	0.52	28.21	1942.1								
16	16-17	0.28	0.51	30.05	1938.0								
17	17-18	0.28	0.51	31.90	1933.9	0.83	0.17	1.28	0.07	0.00	0.01	0.00	0.18
18	18-19	0.30	0.53	33.72	1929.8	1.41	0.19	1.09	0.07	0.00	0.01	0.32	0.21
19	19-20	0.31	0.54	35.49	1925.9								
20	20-21	0.29	0.52	37.28	1921.9								
21	21-22	0.34	0.57	39.00	1918.0								
22	22-23	0.37	0.61	40.55	1914.6								
23	23-24	0.37	0.61	42.04	1911.3								
24	24-25	0.34	0.57	43.59	1907.8								
25	25-26	0.33	0.56	45.22	1904.2								
26	26-27	0.30	0.53	46.93	1900.4								
27	27-29	0.29	0.51	49.20	1895.3								
28	29-31	0.29	0.51	51.96	1889.2								
29	31-34	0.28	0.51	55.20	1881.9	1.19	0.21	1.23	0.19	0.01	0.01	0.00	0.29

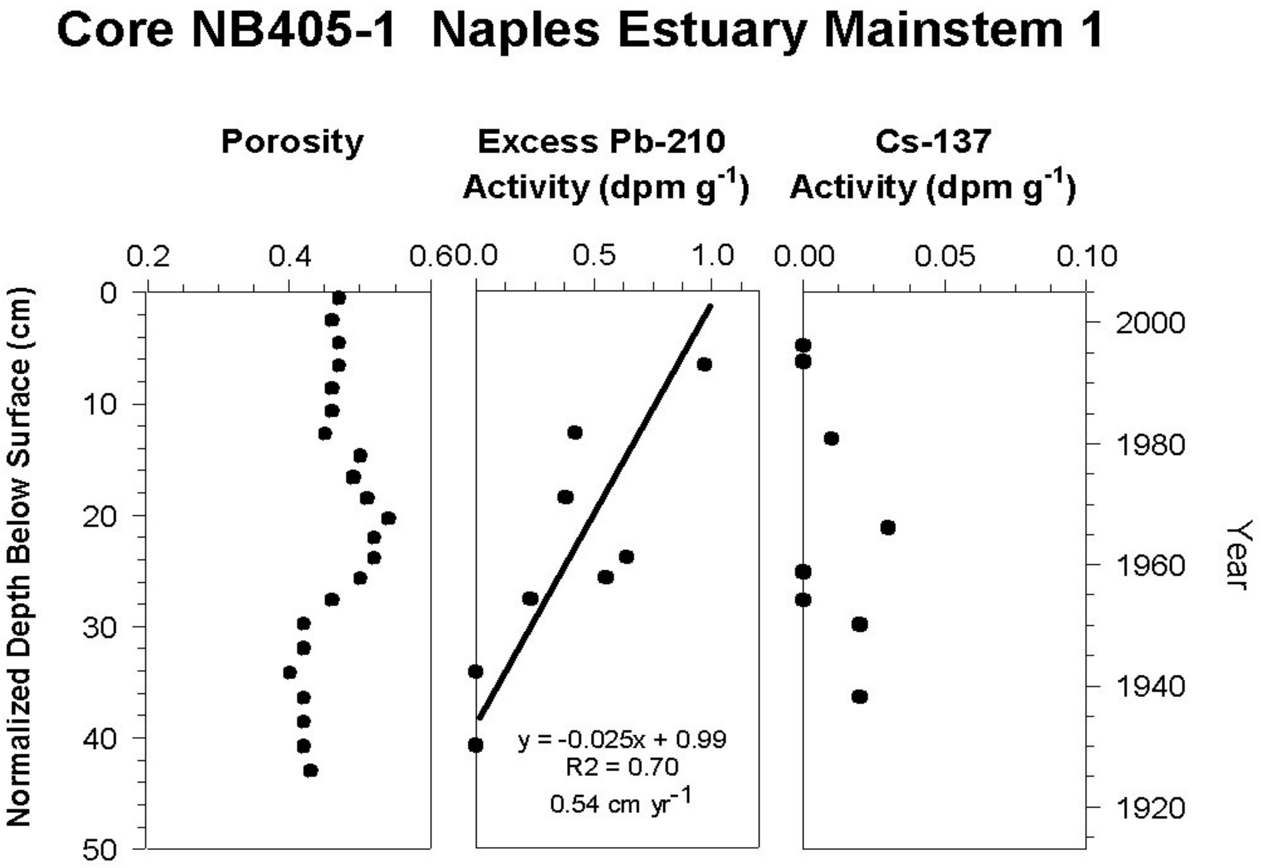


Figure 3-3. Dating information for Core NB405-1.

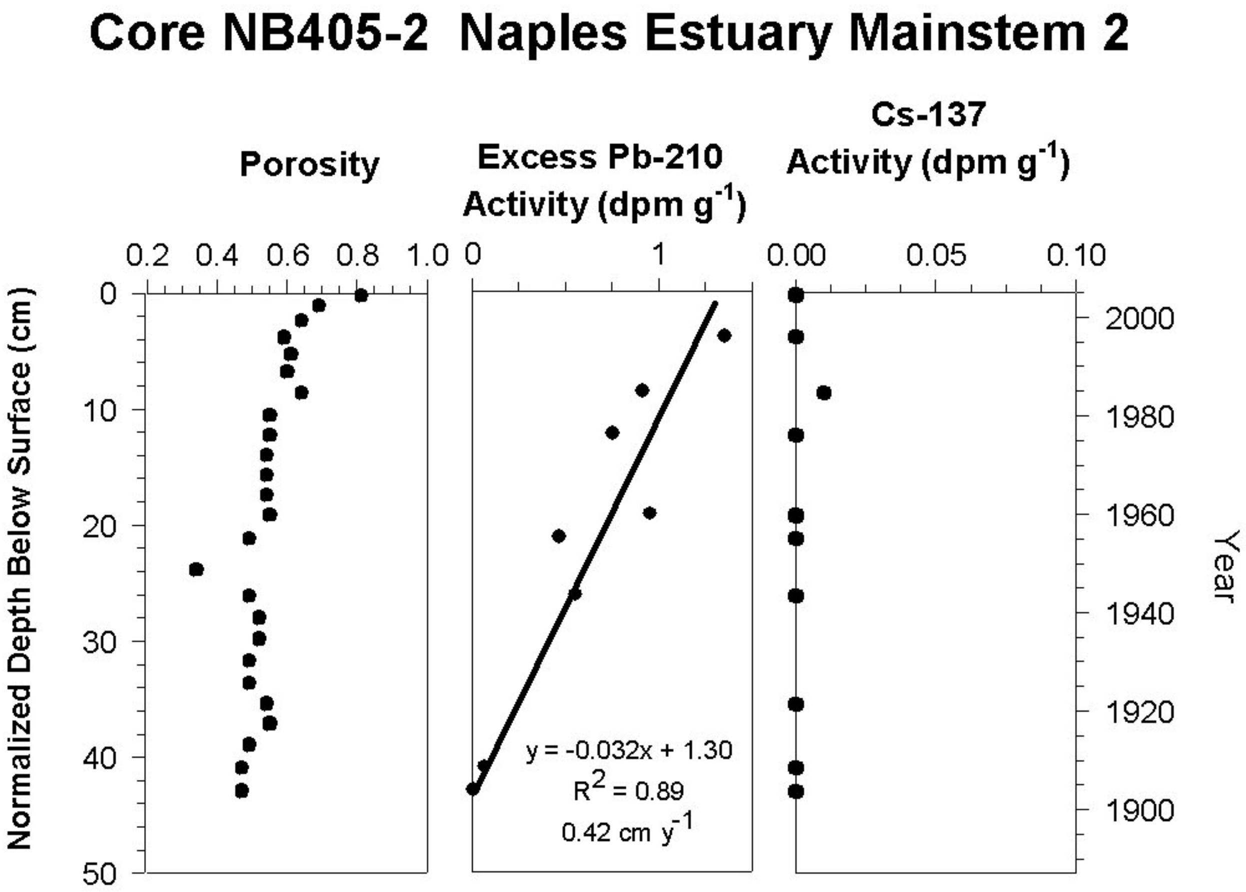


Figure 3-4. Dating information for Core NB405-2.

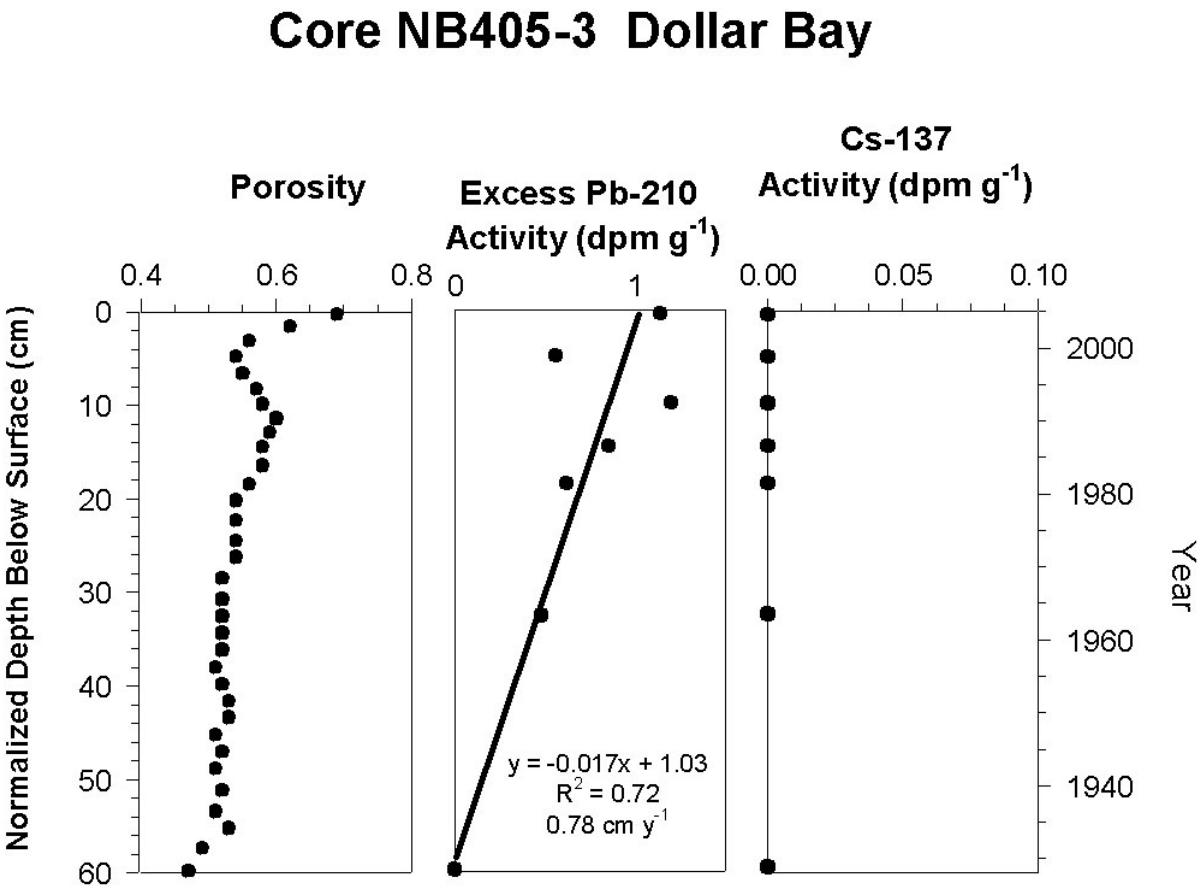


Figure 3-5. Dating information for Core NB405-3.

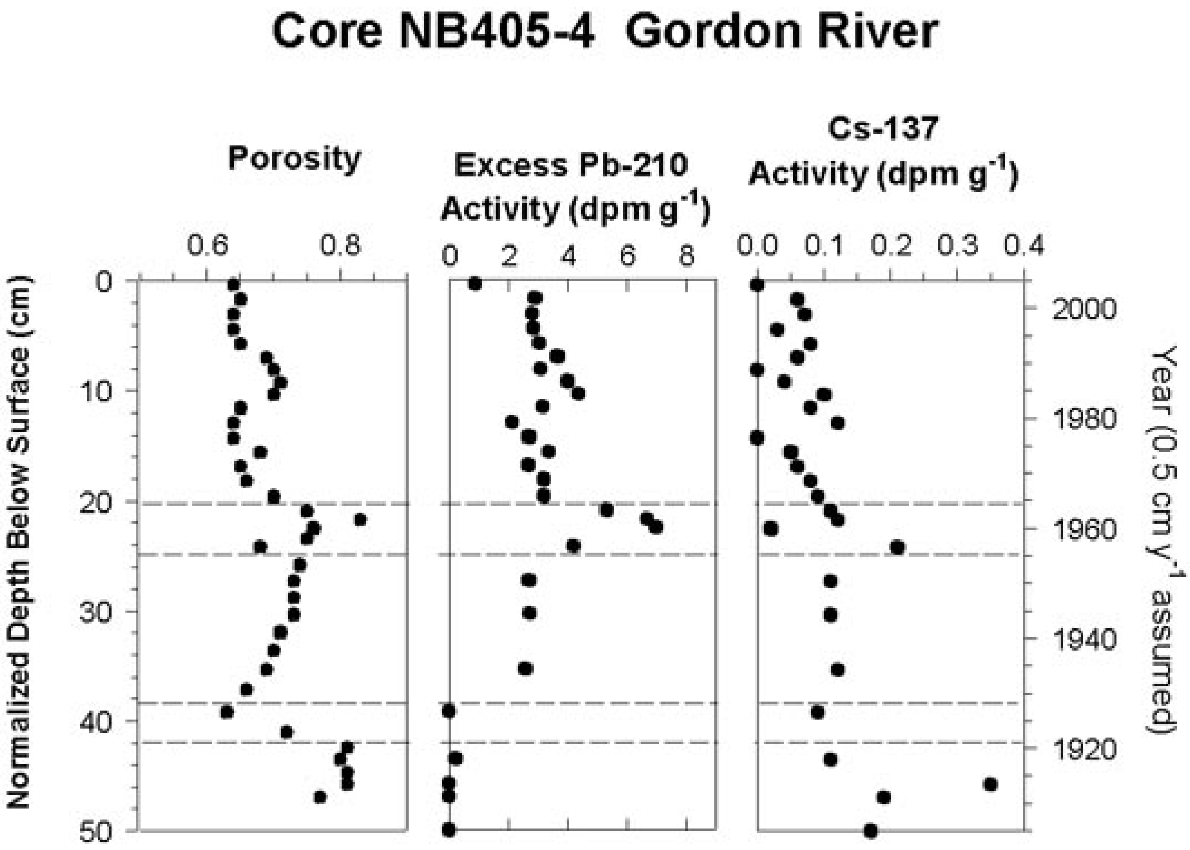


Figure 3-6. Dating information for Core NB405-4. Dashed horizontal line represents distinct change in sedimentation.

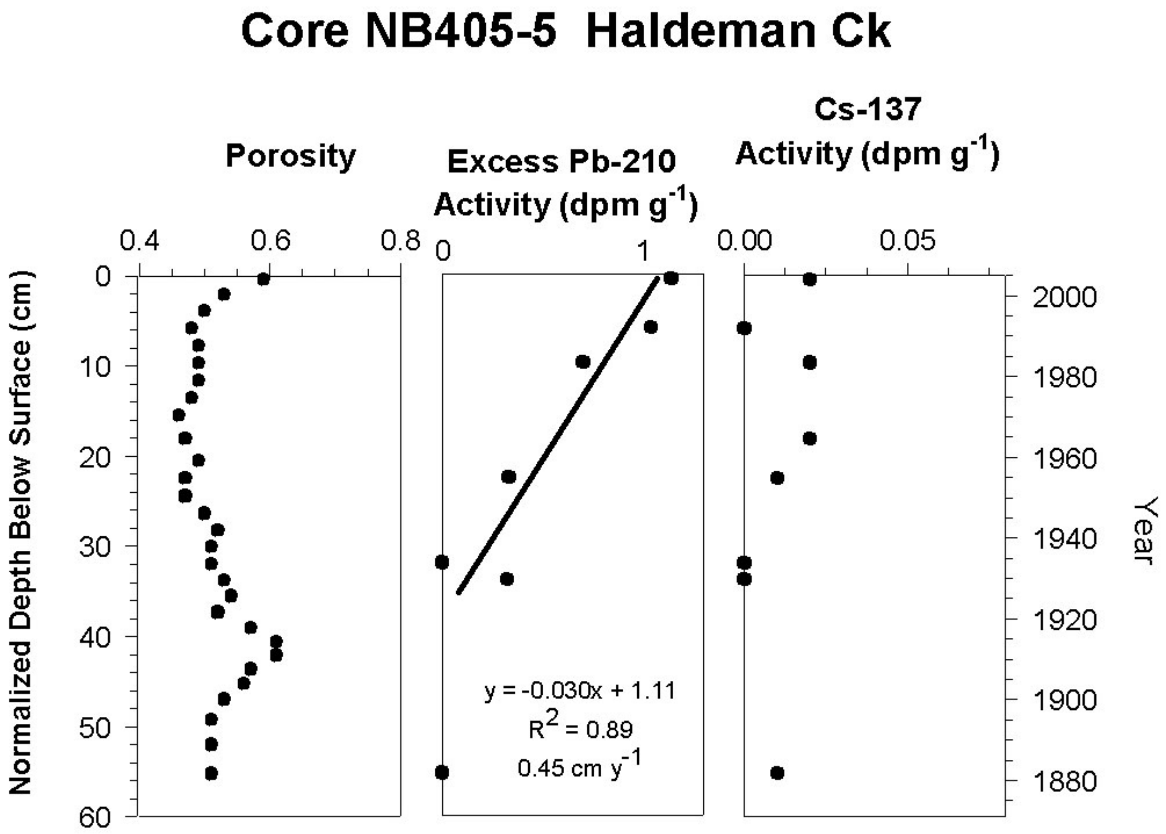


Figure 3-7. Dating information for Core NB405-5.

sedimentation rates for cores 1, 2, 3 and 5, are 0.54, 0.42, 0.78, and 0.45 cm yr^{-1}, respectively. These rates are likely to have large associated error (up to 50%) given the low activity of ^{210}Pb and ^{226}Ra, from which excess ^{210}Pb is calculated, but are likely to be in the correct order of magnitude. They are further corroborated by the disappearance of excess ^{210}Pb in each core at a depth of what would be roughly 100 years before present (four to five ^{210}Pb half-lives) given these sedimentation rates.

The Gordon River core, however, displays higher excess ^{210}Pb activity throughout, likely due to its finer grain size, and has distinctly different profile. Excess ^{210}Pb activity is constant in the upper 20 cm, reaches a peak at 24 cm, decreases linearly from 24 to 40 cm, and is absent below 40 cm. The multiple interpretations that can be made from this radioisotope profile will be discussed in the following section. However, disappearance of excess ^{210}Pb at a depth of 40 cm indicates the 80-120 year period so an overall sedimentation rate of 0.5-0.3 cm y^{-1} can be calculated, though individual time periods could have much higher or lower rates. The default sedimentation rate of 0.5 cm y^{-1} (also the average of that found in the other cores) was chosen and is shown plotted in Figure 3-6.

A peak in the ^{137}Cs down-core profile has been used by many to indicate the 1954 sediment horizon, the time of global maximum atmospheric atomic bomb testing (e.g. Ritchie and McHenrey, 1990). In most of these cores, ^{137}Cs concentrations are extremely low, again likely due to the course sediment rain size (low surface area), and are not statistically significantly different from zero. Only the Gordon River core contains significant ^{137}Cs activities and this core, again, presents an unusual profile. The peak ^{137}Cs activity occurs in the bottom of the core where excess ^{210}Pb is absent. That is, a 1954 indicator occurs in pre-1920 sediment. It is our conclusion that ^{137}Cs has been mobilized in the sediments, possibly due to salinity changes, and cannot be used for dating purposes.

Organic Matter Composition

A few samples were analyzed for total organic carbon and nitrogen in cores NB405-2 and 3. Organic carbon was low, varying from 1.7% in the upper, to 0.8% in the lower portion of the core. Organic nitrogen was extremely low, varying from 0.2% in the upper, to 0.06% in the lower portion of the core. These values are not atypical of sandy sediments, represent the preservation of mainly terrestrially derived organic matter, and display a diagenetic profile indicative of undisturbed sediment.

Total organic matter content was determined in all NB405-4 Gordon River core sediments by loss-on-ignition (Fig. 3-8). This profile is rather unusual in that organic content increases down-core rather than the more typical decrease down-core due to diagenetic degradation. Organic matter represents 5-7 weight % in the upper 20 cm of the core, close to 10% in the 20-30 cm depth interval, about 8% in the 30-40 cm interval and 15% in the lowest portion of the core. Meanwhile, carbonate weight % remains constant throughout at about 5%. A great deal of the variation in organic content of this core is likely due to variations in grain size. That is, sections of finer sediment occur in the 20-30 cm interval and the lowest portion of the core and are associated with greater deposition and preservation of organic matter. Variations in grain size are likely due to disturbance and seasonal variability in flow and are discussed in the following section.

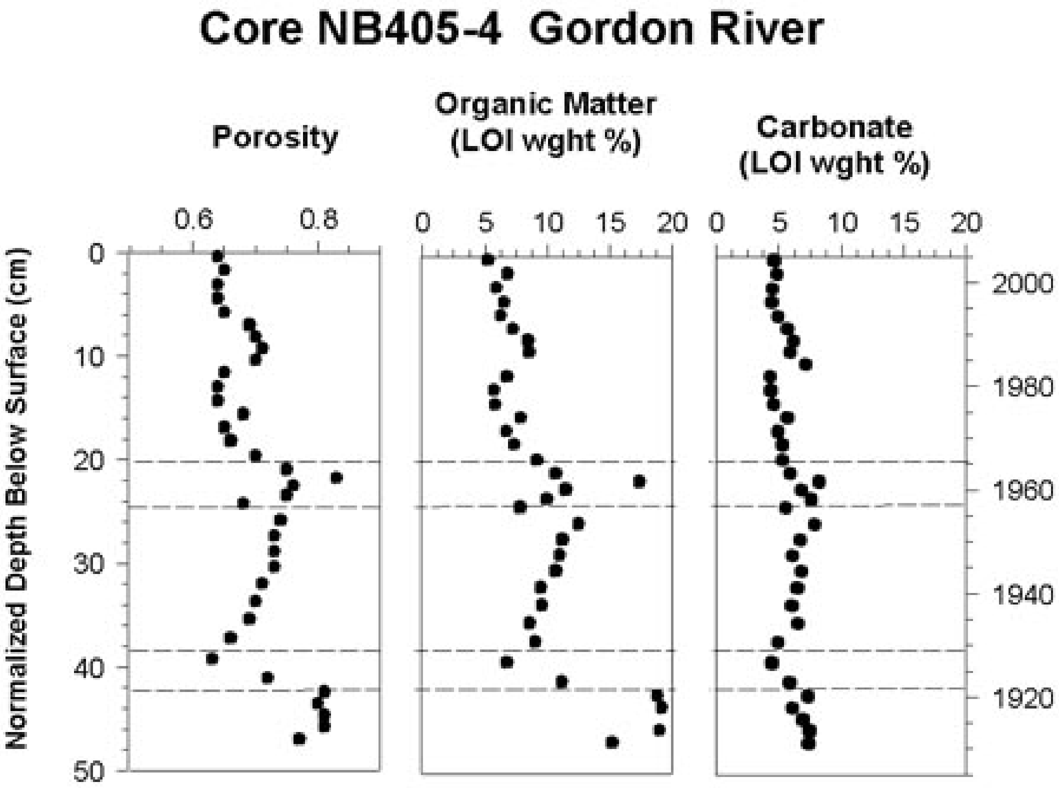


Figure 3-8. Loss on ignition data (LOI) for Core NB405-4. Dashed horizontal line represents distinct change in sediment.

DISCUSSION

The sedimentation rates determined for the four sites in or near the mainstem of Naples Estuary are in the range of 0.4-0.8 cm year and have apparently remained fairly constant over the last 100 years. Additional radioisotope and bulk chemical measurements will be needed to gain further confidence in the rates presented. But there is, at present, no evidence to suggest a different conclusion. These rates are reasonable for the western Florida coastal region (personal comm.; Jon Jaeger) and represent an input of sediment to the system, likely both from riverine and offshore sources, as well as a rise in sea level of about 2 mm yr^{-1}. It is interesting to note that among these sites, Dollar Bay, the more pristine site, has the highest sedimentation rate. This may be attributed to its receipt of greater amounts of sediment from the Bay mouth i.e. natural causes, or to some degree of sediment starvation in Naples Bay sites due to channelization of that watershed. Further analysis of sediment chemistry and grain size may help to distinguish between these possibilities.

The Gordon River core record is atypical and difficult to interpret. The occurrence of disturbance during the past century, however, is clear. During the early to mid-20th-century there was a major sediment erosional event, which was followed by a major sediment depositional event. The material deposited at this time appears to have been pre-20th century-derived, possible supplied by bank or soil erosion. In other words, deposition at this site did not progress in a continuous manner. Possible causes for the disturbance include catastrophic hurricanes that have affected south Florida, construction and connection of the Golden Gate Canal system to the Gordon River, or construction related to the Naples Municipal Airport proximal to the site, all of which occurred during this time frame.

Examining the shifts in organic matter and carbonate content and porosity and the unusual radioisotope profile, one could propose an alternative hypothesis. It may be that periods of erosion, resuspension and re-deposition have been occurring throughout the 20th century. One can pick out perhaps eight packages of sediment with distinct chemical and physical signatures in the Gordon River core. The time of deposition of these sediment packages must be during the 20th century as there is excess ^{210}Pb activity present.

Material deposited at this site may be derived from local sediments or soils and channel bank sediments from upstream. Although natural river channel-shifting can cause this type of deposition pattern, the short time period variation of these events in unusual. Anthropogenic channelization of the river during the 20th century could have led to this type of deposition pattern. That is, concentration of flow within smaller channels leads to greater than normal water velocities at some times of the year (erosive), and slower than normal velocities at other time (depositional). Other parts of the estuary seem unperturbed within the past century by these types of anthropogenic alterations. Further chemical and sedimentary analyses will help to add confidence to these interpretations and will add to our understanding of the history of this anthropogenically-altered system.

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