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Introduction:

The management and restoration of the Biscayne Bay Coastal Wetlands (BBCW) is a complex issue. Unlike other natural areas under the supervision of the National Park System, the BBCW had endured many years of neglect and abuse by homesteaders who, prior to the establishment of Biscayne National Monument in 1968, had free reign of the area and tried to farm and develop the land by ditching and infilling. Furthermore, public works projects, dating back to the early 1900's for mosquito control, land reclamation, and storm surge protection along with homesteader activities have combined to compartmentalize the coastal wetlands of present Biscayne National Park and adjacent marshes.

Today, nearly 25 years after its commission as a national park, the conditions of the BBCW have improved but as a consequence of these earlier activities the wetlands of Biscayne National Park and adjacent marshes have become hydrologically isolated from the interior freshwater watershed that once flowed freely by sheet flow and through tidal creeks into Biscayne Bay. As a result, the historical seasonal variability of surface water salinities throughout the coastal wetland ecotone has been altered; there has been a marked decrease in the volume and kinetics of freshwater runoff into Biscayne Bay via tidal creeks, and fire has been excluded. All of these factors in conjunction with the steady rise in sea level over the last century (2.2 mm/yr, Ross et al. 1994) have yielded large-scale changes in the vegetation composition and structure of the BBCW and adjacent marshes.

Recent restoration and monitoring projects in Biscayne National Park have called for the de-compartmentalization of the BBCW (Meeder and Harlem 2004, Ross et al. 2003, Ruiz et al. 2002). These authors maintain that the removal of all mosquito and drainage ditches east of the L-31E levee should be considered as a means and first step in facilitating the management and hydrologic re-connection of the wetlands and mangroves of the Biscayne Bay watershed.

At present the only information available about the construction, condition and environmental impact of these ditches are from historical documents (see Dade County Anti-Mosquito District Annual Reports) and anecdotal field observations and notes.

Based on county records, the construction of mosquito ditches by the county started in the early 1930's with the creation of the Dade County Anti-Mosquito District in 1933. The District was charged with controlling and eliminating the spread of the disease-bearing yellow fever mosquito *Aedes aegypti* and the black salt marsh mosquito *Aedes taeniorhynchus* (Annual Report of the Dade County Anti-Mosquito District 1940). However, by this time, landowners and homesteaders had already begun ditching and draining the BBCW for agriculture and land reclamation. These agricultural ditches generally ran from west to east, and were 1.2 meters wide by 1.2 meters deep (**Figure 1**). In later years, they were used by the Anti-Mosquito District to drain their smaller 1 meter wide by 0.60 meter deep north-south running mosquito ditches (Annual Report of the Dade County Anti-Mosquito District 1940). The District also constructed 1.2 meters wide by 2 meter deep drainage ditches which ran west to east and drained directly into Biscayne Bay. These larger ditches were also used to drain the smaller mosquito ditches. Ditches prior to 1954 were hand dug at a cost of approximately $200 per mile (Annual Report of the Dade County Anti-Mosquito District 1941). In 1954, manual labor for ditch construction and cleaning was partially replaced by a Shield Bantam crane with backhoe, drag bucket and clamshell attachments and a D-2 caterpillar at a cost of approximately $230 per mile (Annual Report of the Dade County Anti-Mosquito District 1954). In later years, rotary rock cutting machines and dynamite were used to construct new ditches in the shallow marl soils of the southern BBCW (Annual Report of the Dade County Anti-Mosquito District 1959).

As a consequence of drainage, ditching, and several years of drought (1943-1945), which exacerbated saltwater intrusion (Hull and Meyer 1973), abandoned farmlands and coastal graminoid communities were rapidly being colonized by *Myrica cerifera*, *Rhizophora mangle*, and *Laguncularia racemosa* (Annual Report of the Dade County Anti-Mosquito District 1945) in 1945. By 1952, ditch banks were heavily vegetated by mangroves and other halophilic macrophytes and mangroves were found further inland than in years past (Annual Report of the Dade County Anti-Mosquito District 1952 & 1953). Along with mangrove encroachment, exotic species began to colonize the area and by 1956 *Casuarina equisetifolia* had become well established between SW 320th and SW 344th street (Annual Report of the Dade County Anti-Mosquito District 1956).

It is unclear from the county records when mosquito ditch construction and maintenance was abandoned for more passive, less destructive, and effective means of mosquito control (e.g. aerial spraying). However, field observations and aerial photograph analysis clearly show that new ditch construction and maintenance has not taken place in the last 40 years or so. As a result, there is great uncertainty as to the present conditions of these ditches. Therefore a comprehensive census and inventory of the mosquito and drainage ditches found within the BBCW is presented in this paper for the purpose of evaluating the feasibility of decompartmentalizing the BBCW by removing these barriers from the landscape.

Methods:

All mosquito (N-S running) and drainage (E-W running) ditches visible on the 1994 and 1999 NAPP CIR photos within the mangrove swamp forest and marshes delimited by Old Cutler Road, SW 87th Avenue, and SW 107th Avenue in the west and SW 344 Street (Palm Drive) in the south and SW 184th Terrance (Eureka Drive) in the north were digitized using Arcview GIS 3.2a (**Figure 2).** Within this region four sub-units were established: Reach 1, the area east of the L-31E Levee between the Mowry Canal and 700 meters north of the Princeton Canal; Reach 2, immediately west of the southern end of Reach 1; Reach 3, north of Black Point and east of 87th Avenue; and Reach 4, east of Saga Bay and south of Eureka Drive (**Figure 3**). A basin was selected within each Reach to characterize the morphology of all the ditches within the Reach. At each basin the following measurements were taken:

- ditch width
- ditch soil depth
- ditch water depth
- ditch & adjacent marsh conductivity
- spoil mound dimensions
- spoil mound soil & litter depth
- spoil mound spacing
- spoil mound vegetation

Results:

A total of 554 mosquito ditches and 102 drainage ditches were found within the study area (**Table 1** & **Figure 2**). Drainage ditches were generally deeper and longer than the mosquito ditches but not necessarily wider (**Table 1**). Drainage ditches on the west side of the L-31E levee (Reach 2) tended to be uniform in depth, partially silted-in, and stagnant. On the other hand, the drainage ditches on the other three Reaches (1, 3, & 4) tend to widen and deepen towards the coast, with few silted-in. For the most part, these drainage ditches emptied directly into Biscayne Bay. However, some ditches were found draining into existing creeks which then emptied into Biscayne Bay. Mosquito ditches, in turn, were found partially or fully connected to the east-west running drainage ditches. In general, mosquito ditches where found in one of the following three conditions: 1) silted-in and hydrologically inert (**Figure 4a**), 2) not fully silted-in but hydrologically inert (**Figure 4b**), or 3) partially silted-in but hydrologically active (**Figure 4c**).

Table 1: Number, total length, and mean length, width, and depth of mosquito and drainage ditches for each Reach and for the entire study area. See **Figure 2** & **3** for extent of study area and Reach location.

Area	Type									
	Mosquito Ditch					Drainage Ditch				
	Number	Total Length (km)	Mean Length (m)	Mean Width (m)	Mean Depth (cm)	Number	Total Length (km)	Mean Length (m)	Mean Width (m)	Mean Depth (cm)
Reach 1	93	27.3	294	2	63	25	25.1	1000	3	102
Reach 2	13	25.9	365	3.5	118	13	8.4	642	3	125
Reach 3	77	14.3	186	3	46	13	12.0	920	3.5	136
Reach 4	93	20.4	220	2	60	21	13.6	646	2	120
Total Study Area	554	174	314	---	---	102	89	876	---	---

Only in Reaches 1, 2, and 3 were spoil mounds associated with each mosquito ditch. Where spoil mounds existed, they were generally found paralleling the mosquito ditches 5 to 10 meters on either side at four meter intervals. Mounds were generally 5 x 3 x 0.35 meters in size (L x W x H). However, mounds in Reach 2 tended to be twice as long (ca. 11 meters) and slightly higher (0.5 m) than those of Reach 1 and 3. Spoil mounds were also found adjacent to the drainage ditches. However, these mounds tended to be larger (ca. 5 x 15 meters in size in some places) and not as evenly distributed as along the mosquito ditches. In general, mounds consisted of a hardened marl substrate with some or no vegetation (**Figure 5**). However some mounds (Reach 2) were heavily vegetated and covered by a deep litter layer (ca. 30 cm deep) of *C. equisetifolia* detritus.

Beside the adjacent spoil mounds, the adjacent ditch banks were generally well vegetated (**Figure 6**). The type, density, and height of the vegetation varied throughout the study area. Mosquito ditch bank vegetation in Reach 1 was exclusively mangrove except for some of the northernmost mosquito ditches near the L-31E Levee where dead and living *C. equisetifolia* trees, some > 12 meters tall were found with *Conocarpus erectus*, *R. mangle*, and *L. racemosa*. In Reach 2, mosquito ditches were flanked on either side by dense *C. equisetifolia* along with *M. cerifera*, *C. erectus*, *R. mangle*, and *L. racemosa*. In Reaches 3 and 4 the vegetation was predominantly a thick mangrove wall < 3 meters tall. Vegetation composition along the drainages ditches resembled that of the mosquito ditches, though vegetation height and density tended to be greater in the former.

In general, surface water specific conductivity in Reach 1, 3, and 4 was slightly greater in the drainage ditches than in the mosquito ditches. In Reach 1, mosquito ditch specific conductivity increased from 4.98 mS/cm near the L-31E Levee to 15.0 mS/cm 450 meters from the bay. This trend was also observed in Reaches 3 and 4. Marsh surface water specific conductivity exhibited no clear pattern, because the marsh rarely had significant amounts of surface water available for sampling.

Discussion:

The removal of the drainage barriers within the BBCW is the first step toward hydrologically reconnecting the BBCW into several larger hydrologic basins. However, as with all restoration efforts, great care should be taken to understand the benefits and consequences associated with the restoration project. To that end, **Table 2** outlines some of the obvious benefits and consequences associated with the removal of these ditches. However, it is likely that as restoration efforts continue, other benefits and possibly a few other consequences might emerge. Nevertheless, the benefits to ecosystem health and function as a result of these restoration efforts will likely outweigh any consequence already outlined or unforeseen. Furthermore, before full scale restoration efforts are carried out throughout the BBCW complex, restoration efforts should focus on a few select sites (outlined below) that allow for the development, assessment, perfection, and monitoring of restoration goals and techniques.

Table 2: Benefits and consequences of mosquito and drainage ditch removal

Benefits	Consequences
Reestablishes hydrologic connectivity between basins	Possible increases to mosquito population
Reduces saltwater intrusion	Damage to wetland soils and vegetation
Reduces import of mangrove propagules	Mangrove mortality
Increases freshwater (rainwater) retention	Invasion of exotics to disturbed areas
Simplifies management	Cost

Within the BBCW complex, Meeder and Harlem (2004) have identified and outlined a set of restoration goals for three potential restoration sites: Black Point, Princeton Canal, and Campbell Drive Canal (**Figure 7**). The Princeton Canal and Campbell Drive Canal restoration sites are located in Reach 1 while the third restoration site, Black Point, is located in Reach 3. The two sites in Reach 1 along with an additional site, Block 9-Creek Restoration (**Figure 7**), also located in Reach 1, will be expounded upon in this document while the Black Point site in Reach 3 will not (see Meeder and Harlem (2004) for Black Point restoration plan).

Campbell Drive Canal Restoration Site— Based on the 1928 U.S. Coast and Geodetic Survey map, the proposed Campbell Drive Canal (CDC) restoration site was once a sawgrass marsh with a thin mangrove fringe on the coast. At present, the mangrove fringe has expanded inland by several hundred meters, and a dense dwarf mangrove forest has replaced the sawgrass marsh to and beyond the L-31E Levee. The CDC, which once extended for several kilometers inland, is now bisected by the L-31E Levee and serves no practical function.

At this site (**Figure 7**) we suggest that the CDC be modified to allow water delivery from the L-31E to enter the northern and southern marsh basins bisected by the construction of the CDC. Furthermore, the mouth of the CDC should be plugged and infilled approximately 200 meters to the point where a ditch branches from the southern east-west drainage ditch (**Figure 8**). This ditch, which connects to a tributary that historically emptied into Biscayne Bay, should be joined to the CDC to allow freshwater delivery into Biscayne Bay (**Figure 8**). The two east-west drainage ditches and the levees that parallel the CDC should be removed, and the two mosquito ditches in the northern marsh should be plugged at the ends or infilled to ensure that they are hydrologically inert (**Figure 8**).

This restoration project, in essence, converts the CDC, east of the L-31E Levee, from a mostly stagnant brackish canal to a creek that not only hydrates both of the adjacent marshes but also restores one of the historical freshwater flow-ways into Biscayne Bay. Additionally, the removal of the levees paralleling the CDC will eliminate a refuge for exotics species within the BBCW (e.g. *Schinus terebinthifolius*, *C. equisetifolia*, and *Colubrina asiatica* to name just a few).

Block 9-Creek Restoration—Like the CDC restoration site, the Block 9-Creek restoration site (**Figure 7**) was historically a sawgrass marsh with a coastal mangrove fringe (1928 U.S. Coast and Geodetic Survey map). However, running west to east through the area was a relatively large creek which extended for nearly 2 km inland. The construction of the L-31E Levee cut across the creek, eliminating all upstream freshwater delivery into Biscayne Bay through this artery. At present, like the CDC site, the sawgrass marsh has been replaced by a dense dwarf mangrove forest which rapidly grades into the coastal mangrove forest. Near the L-31E Levee, the creek is all but undistinguishable from the surrounding marsh. However, about 500 meters east of the Levee, the creek is approximately 1 meter deep by 3 meters wide.

At this site (**Figure 9**) we recommend that several culverts similar to or larger than the ones used in the L-31E Freshwater Rediversion Pilot Project (Ross et al. 2003) be installed along this section of the L-31E Levee (**Figure 9**). One of the culverts should be placed at the location where the creek would have historically crossed the L-31E Levee (**Figure 9**). The mosquito ditch 30 meters east of the levee should be plugged at either end and made hydrologically inert. The same should be done to the northern and southern drainage ditches which bound the area (**Figure 9**).

This restoration project will restore a historical freshwater flow-way into Biscayne Bay. Furthermore, the additional input of freshwater into the nearshore benthic environment could reestablish estuarine conditions conducive to oyster colonization (see Meeder et al. 1999). Enhanced input of freshwater via the installation of multiple culverts might also facilitate and hasten the low recolonization rate of freshwater macrophytes observed at the L-31E Freshwater Rediversion Pilot project study site, where only one 36” diameter culvert was employed (Ross et al. 2003).

Princeton Canal Restoration Site— As recently as 1928, this area (F**igure 7**) was a sawgrass marsh with a relatively narrow mangrove fringe with upland trees lining the natural drainages (Teas et al. 1976). However, by 1938 salt tolerant graminoid species were beginning to invade the area adjacent to the mangrove fringe in response to saltwater intrusion caused by the construction of mosquito ditches (Teas et al. 1976). By 1963 a dense mangrove scrub had begun to develop within this basin and *C. equisetifolia* was well established on the upland portions of the tract (Teas et al. 1976). With the completion of the L-31E Levee and the Princeton Canal by 1968, the scrub mangrove forest had expanded and mangroves had completely replaced the upland trees along the natural drainages and within the large tree island found within this basin (Teas et al. 1976). At present, this area has an extensive salt marsh bisected by two east-west drainage ditches and thirteen north-south mosquito ditches (**Figure 10**). The north marsh tends to be wet and dominated by *Juncus roemerianus* with scattered dwarf *R. mangle* trees while the southern marsh is drier and co-dominated by dwarf *R. mangle* and *Distichlis spicata* (**Figure 10**).

At this site (**Figure 10**) we recommend that hydrologic restoration efforts include fire as a means of maintaining and stimulating the expansion of the graminoid communities found within this section of the BBCW. With fire as a possible management tool, we suggest that the ditches within the region be left as is to serve as fire breaks. The presence of these ditches will help control and exclude fires from adjacent areas or control units. Though both marshes have sufficient fine fuel accumulation, the southern marsh is better suited for the introduction of fire at this time because of its drier environment during the dry season and the abundance of *R. mangle* which, if left unmanaged, will clearly outcompete and displace *D. spicata* from this basin in a few short years.

Conclusion:

It is clear from this report that the decompartmentalization and restoration of the BBCW will require the development of new and innovative restoration techniques. However, since environmental and physical conditions throughout the BBCW are not uniform, initial restoration efforts need to be focused, carefully planned, and not overly ambitious, since results will vary throughout the BBCW in response to: 1) vegetation type and community inertia; 2) the underlying drainage pattern; 3) sea level rise; and 4) the occurrences of natural disturbances (freeze events and wind storms). In undertaking these activities, it should be recognized that hydrologic restoration alone is unlikely to push back the hands of time and reestablish the entire gradient of halophilic and non-halophilic graminoid and shrub communities which once prevailed throughout the BBCW. However, in conjunction with fire, hydrologic restoration might prove successful at sustaining and maintaining the remaining graminoid communities within the BBCW by eradicating existing mangroves and impeding further encroachment of mangroves and exotic plants into these areas.

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Figure 1: Agricultural drainage ditch in the East Glade agriculture area. Photograph courtesy the Jean Taylor Collection, Historical Museum of Southern Florida.

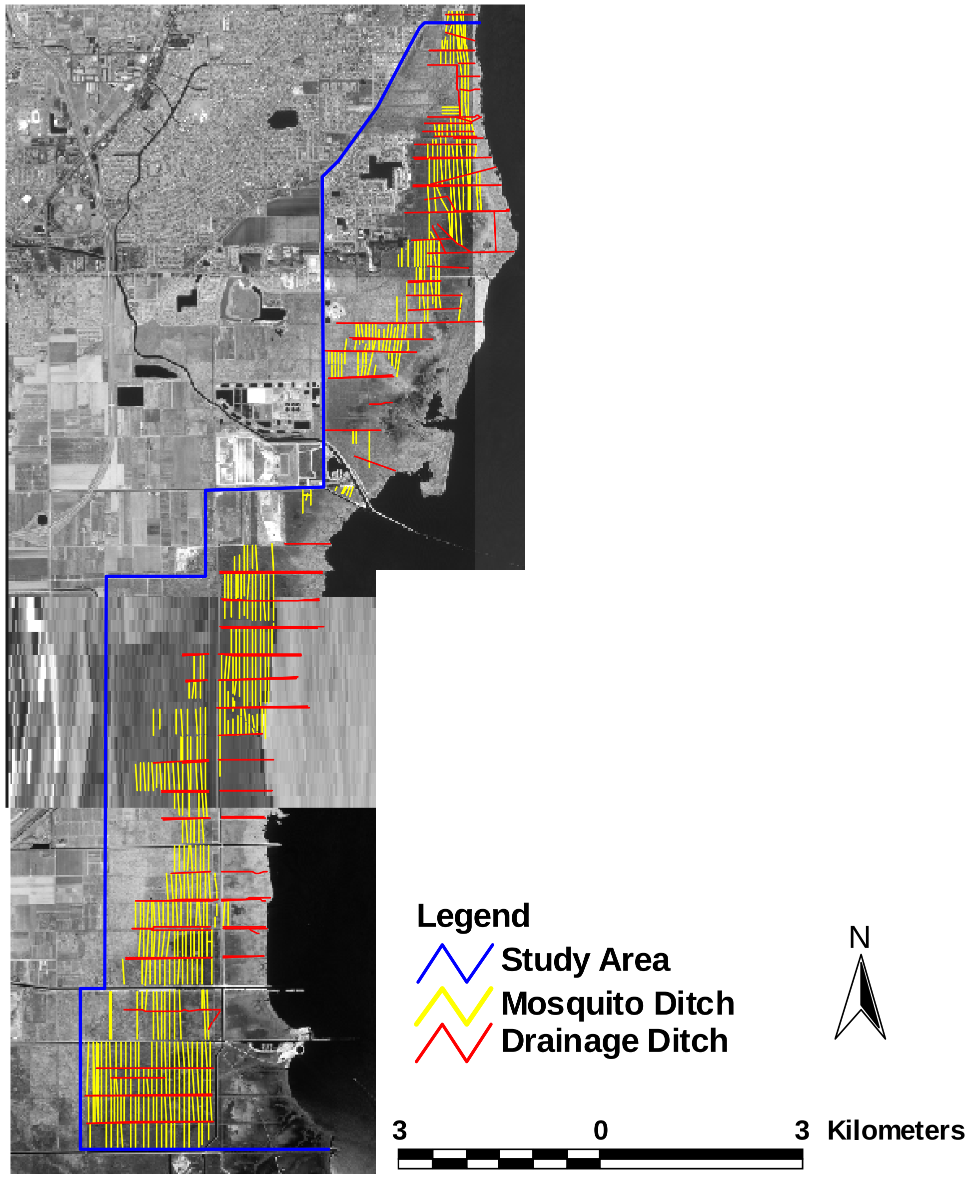

Figure 2: Distribution of ditches within the Biscayne Bay Coastal Wetland study area.

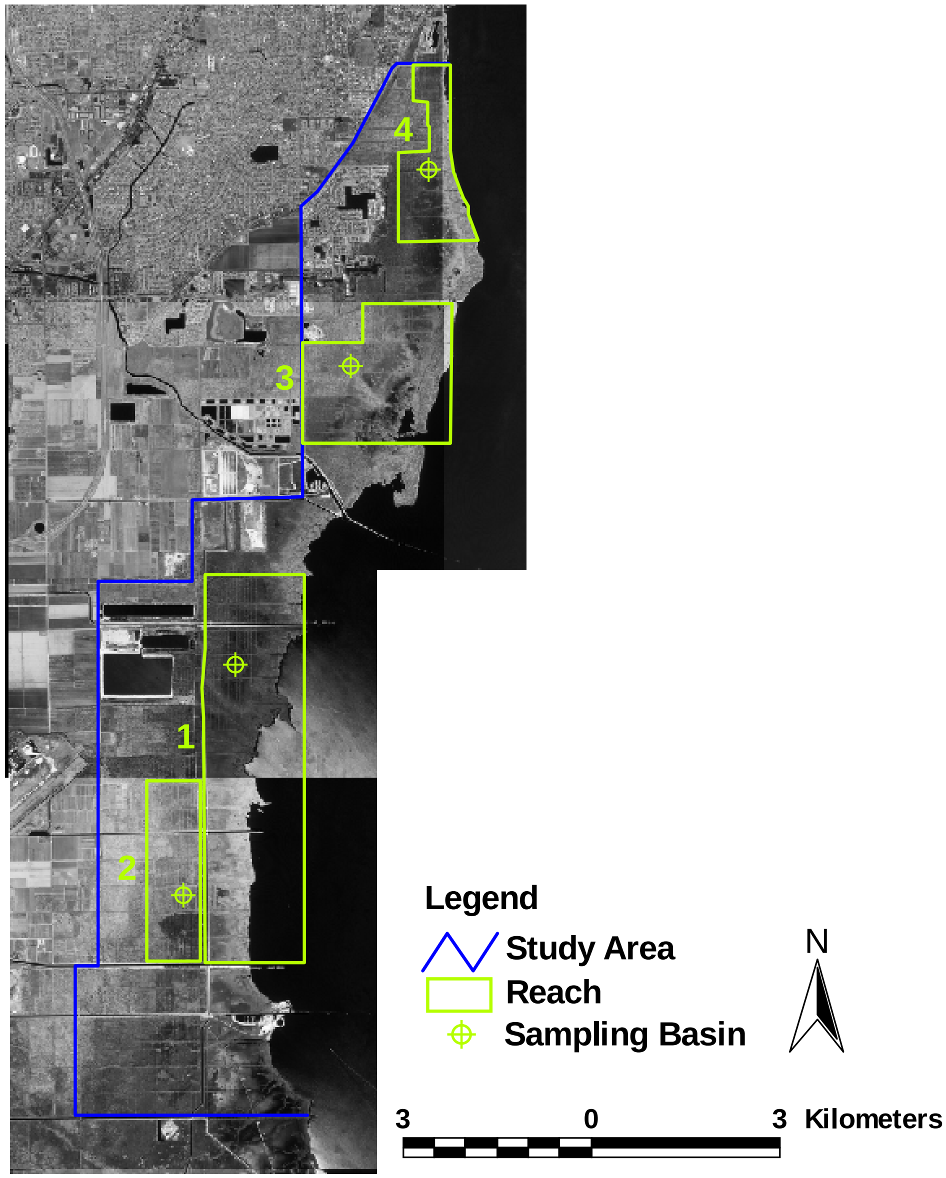

Figure 3: The location of each Reach and sampling basin within the Biscayne Coastal Wetlnad Complex.

Figure 4a: Mosquito ditch silted-in and hydrologically inert.

Figure 4b: Mosquito ditch not fully silted-in but hydrologically inert.

Figure 4c: Mosquito ditch partially silted-in but hydrologically active.

Figure 5: Typical spoil mound found adjacent to most mosquito ditches within the Biscayne Bay Coastal Wetland complex.

Figure 6: Vegetation growth along the bank of a typical mosquito ditch in Reach 1.

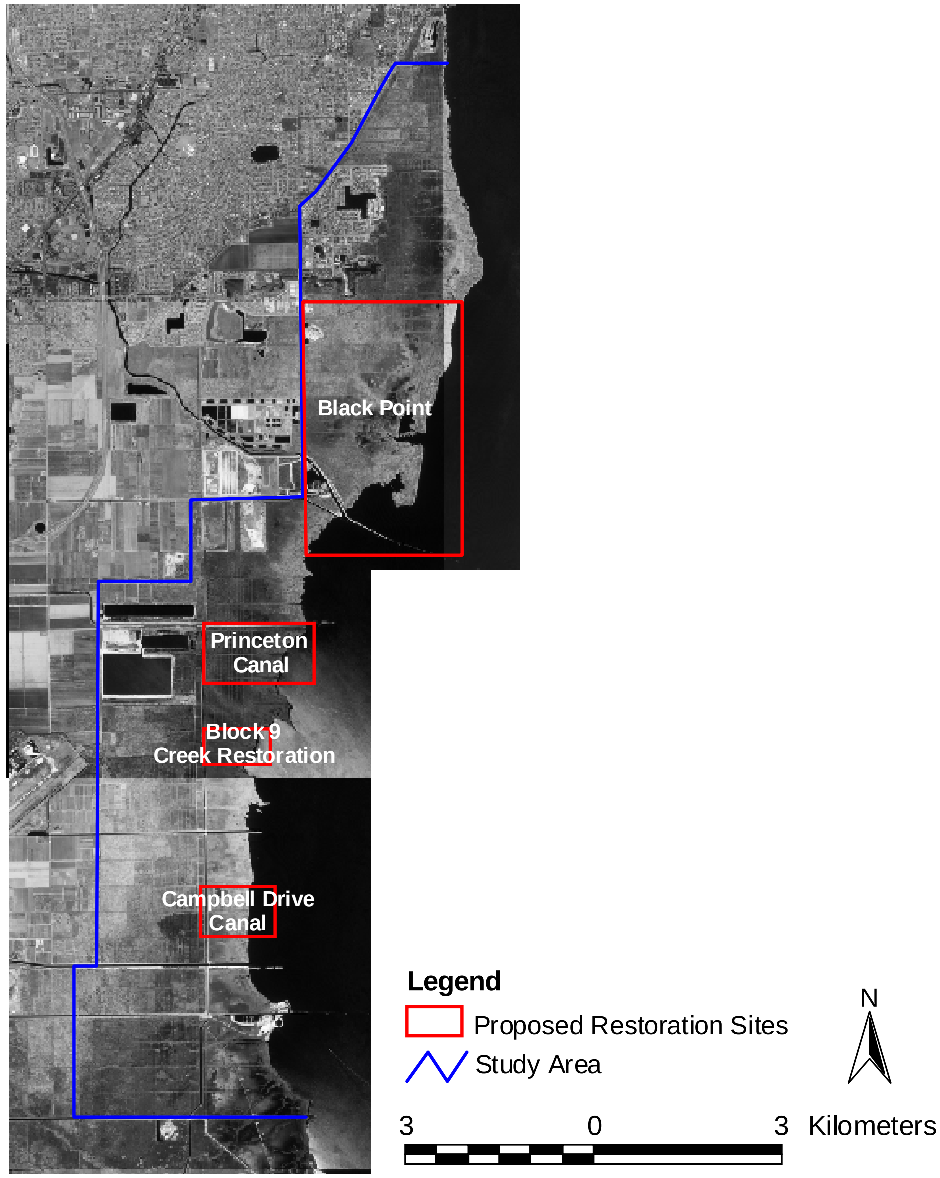

Figure 7: Location of proposed restoration sites within the Biscayne Coastal Wetlnad Complex.

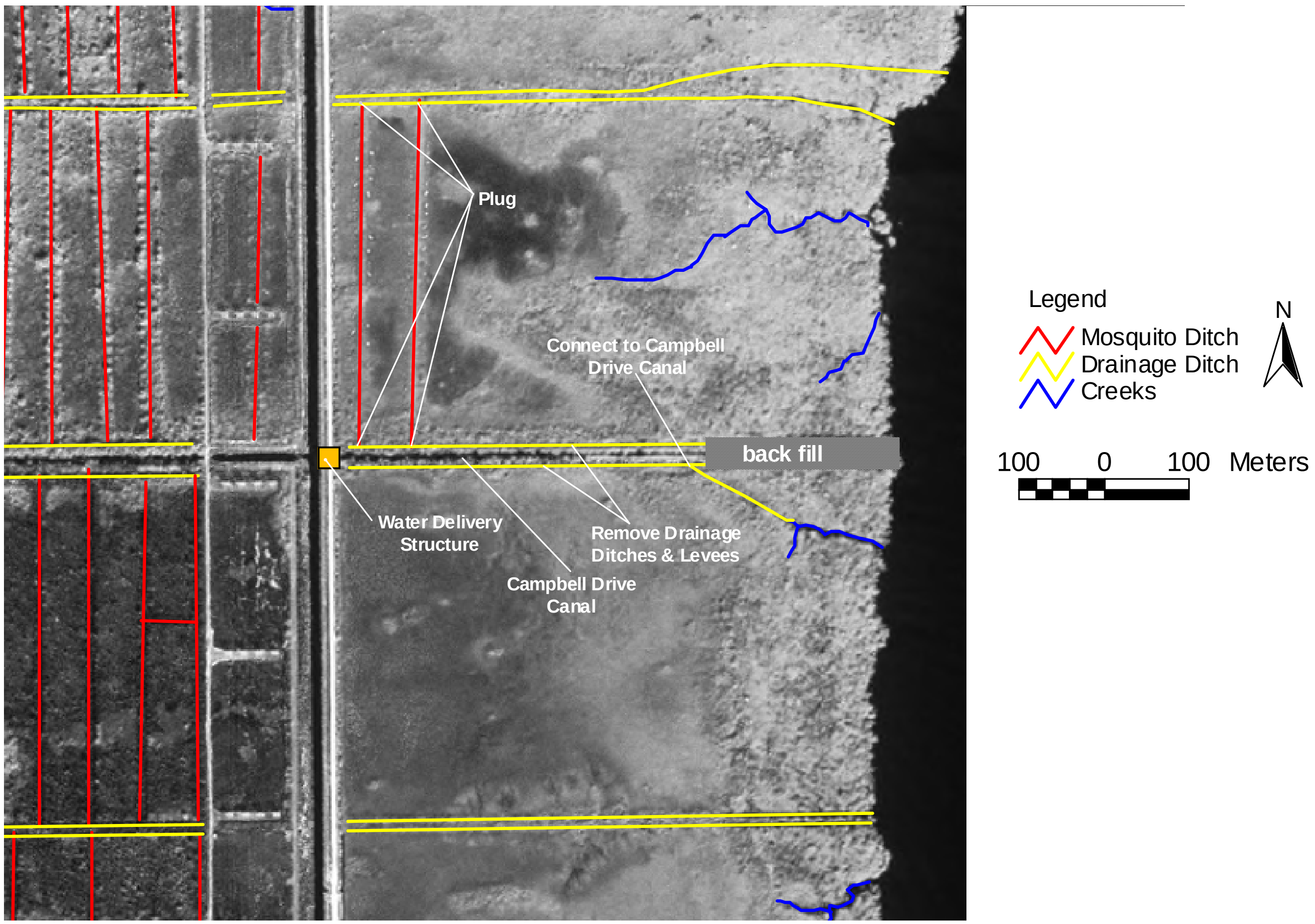

Figure 8: Campbell Drive canal restoration site with proposed restoration activities.

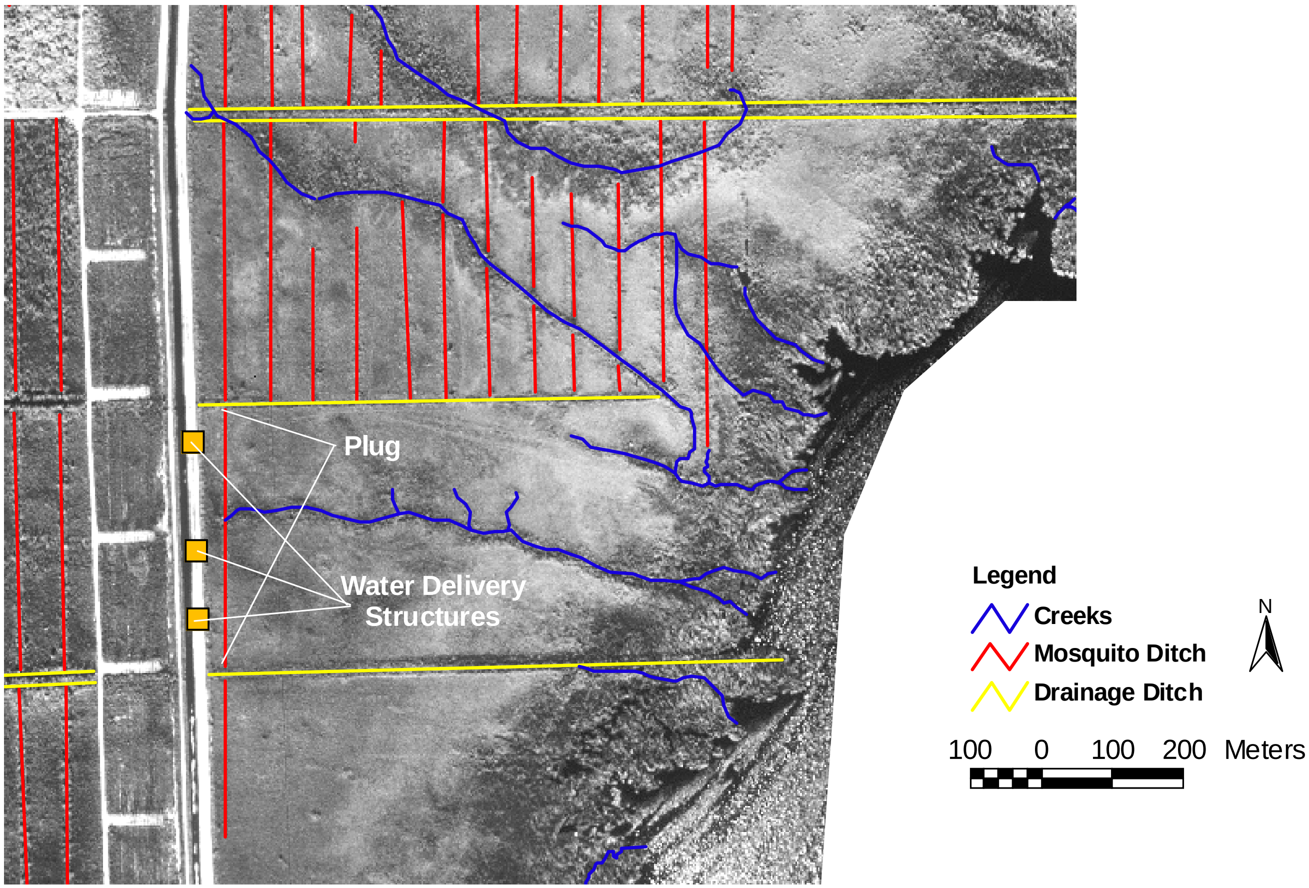

Figure 9: Block 9 - Creek restoration site with proposed restoration activities.

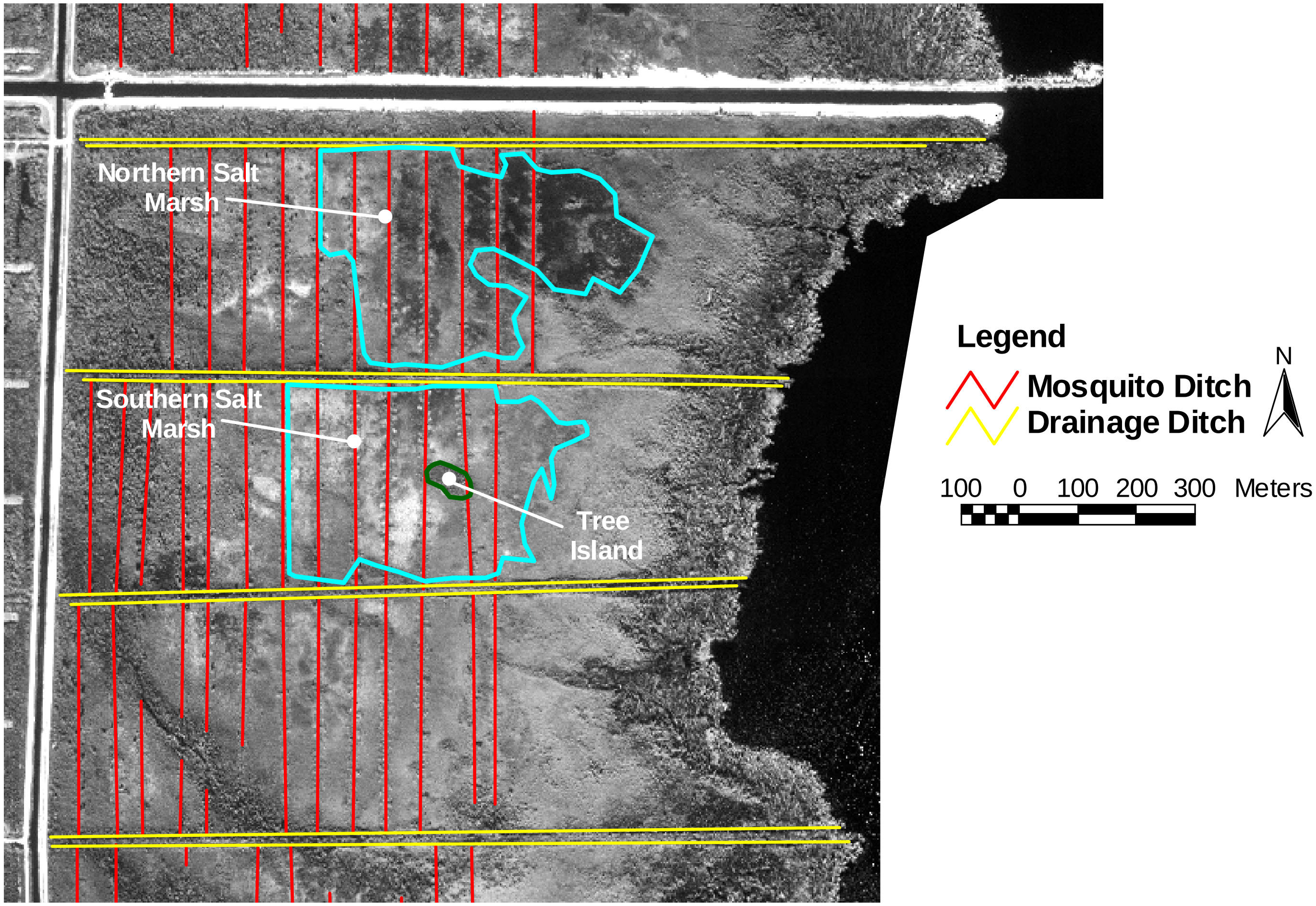

Figure 10: Princeton Canal restoration site with the location of the two relic salt marshes and tree island.