# A REVIEW OF THE EFFECTS OF ALTERED HYDROLOGY AND SALINITY ON VERTEBRATE FAUNA AND THEIR HABITATS IN NORTHEASTERN FLORIDA BAY

Jerome J. Lorenz

Audubon Florida Tavernier Science Center, 115 Indian Mound Trail, Tavernier FL, 33070; email: jlorenz@audubon.org; phone: 305-852-5092

## ABSTRACT

Estuarine productivity is highly dependent on the freshwater sources of the estuary. In Florida Bay, Taylor Slough was historically the main source of fresh water. Beginning in about 1960, and culminating with the completion of the South Dade Conveyance System in 1984, water management practice began to change the quantity and distribution of flow from Taylor Slough into Northeastern Florida Bay. These practices altered salinity and hydrologic parameters that had measurable negative impacts on vertebrate fauna and their habitats. Here, I review those impacts from published and unpublished literature and anecdotal observations. Almost all vertebrates covered in this review have shown some form of population decline since 1984; most of the studies implicate declines in food resources as the main stressor on their populations. My conclusion is that the diversion of fresh water resulted in an ecological cascade starting with hydrologic stresses on primary then secondary producers culminating in population declines at the top of the food web.

Key Words: Florida Bay, Everglades, Taylor Slough, water management, population declines

## INTRODUCTION

Anthropogenic alterations in the quantity, timing and distribution of freshwater to estuaries have had calamitous ecological consequences to these important habitats on a global scale (Day et al. 1989). Declines in productivity at all trophic levels have been well documented. Although some of these changes occur as cataclysmic events, incremental deviations in the freshwater source tend to be more common (Day et al. 1989). These incremental changes result in more subtle ecological changes through time that can go unobserved by the casual observer, and rarely are there rigorous data to support scientific claims of ecological decline (Day et al. 1989). In south Florida, the Florida Bay estuary has been relatively well studied and the chronological sequence of water diversions from its main freshwater source, Taylor Slough, have been well documented (Fourqurean and Robblee 1999). These provide for the possibility of a thorough review of the impacts on higher trophic levels that occurred through time as a result of this water diversion.

Florida Bay is divided into basins by numerous anastomosing carbonate mud banks (Fourqurean and Robblee 1999). Lorenz (2000) grouped these basins into 4 distinct sub-regions based on a variety of physical and biological data. The Western and Southern sub-regions were largely defined by diurnal tidal influences of the Gulf of Mexico and the Atlantic Ocean, respectively. The Central sub-region was characterized by low influence of diurnal tides and low freshwater input from the Everglades. The last sub-region was defined as a large basin in the northeastern corner of Florida Bay (Northeastern Basin) and several smaller sounds adjacent to this basin. Collectively, these basins are referred to as the Northeastern Florida Bay sub-region (NEFB; Fig1).

The hydrology and salinity of NEFB are heavily influenced by inflows of fresh water from Taylor Slough (Light and Deneen 1994, McIvor et al 1994, Kotun and Renshaw this issue). Beginning in 1960, and culminating with the completion of the South Dade Conveyance System (SDCS) in 1984, water management practices began to heavily influence flows through Taylor Slough into NEFB (Kotun and Renshaw this issue). The multiple canals, levees, pumps and control structures that comprise the water management system of southern Florida dramatically altered the quantity, timing and distribution of freshwater flows from the Everglades, through Taylor Slough and into NEFB (Kotun and Renshaw, this issue). The goal of this review is to outline the physical changes that have occurred in the NEFB, followed by a detailed account of changes in habitats, populations and assemblages of multiple vertebrate species (summarized in Table 1).

## REVIEW

### Changes in Salinity and Hydrology

Kotun and Renshaw (this issue) demonstrated that a series of infrastructure changes to the canal system and concurrent changes in water management practices (Kotun and Renshaw this issue) resulted in sequential decrease in flow through Taylor Slough into the Northeastern Basin. The overall result of these actions was that water that once flowed through Taylor Slough and into the Northeastern Basin was diverted to the L-31N/C-111 canal complex (Fig1) and was discharged into the small sounds that make up the eastern extreme of NEFB and Manatee Bay to the northeast (Barrata and Fennema 1989, Kotun and Renshaw; this issue). Kotun and Renshaw (this issue) describe how, historically, the long residence time of fresh water in the Northeastern Basin acted as a buffer against increases in salinity during the dry season (December to May) when inflows from Taylor Slough were relatively modest compared to wet season (June - November) inflows. The majority of the discharge from the C-111 occurred in proximity to US Highway 1 (US-1; Fig1), flowing southward into Long Sound (Fig1; Barrata and Fennema 1989). From there, fresh water cascaded through Little Blackwater Sound, Blackwater Sound, and Buttonwood Sound, thereby bypassing the Northeastern Basin (Barrata and Fennema 1989, Kotun and Renshaw; this issue) and greatly reducing the salinity buffering capacity of the Basin by keeping salinities low. The end result was increased salinization throughout NEFB.

Although there are no historical salinity records dating back to the pre-drainage era, several studies used physical models and paleoecological techniques to reconstruct historical salinity patterns. McIvor et al. (1994) combined several physical models to reconstruct salinity from 1965 - 1981 at a location in the Northeastern Basin near the Taylor Slough outfall. They concluded that if Taylor Slough had remained in an unaltered state, salinity would have been 20 to 30 psu lower than in its current state.

Several paleoecological studies of sediment core samples from Florida Bay indicate that the Florida Bay in general had lower salinity than occurs today (Halley et al. 1994, Brewster-Wingard and Ishman 1999, Halley and Roulier 1999, Swart et al. 1999). Molluskan skeletal remains found in those cores were from species with lower salinity tolerance than those that occur at the same locations today. More specific to NEFB, Meeder et al. (1996) quantified the rate of saltwater encroachment into the wetlands between Florida Bay and the C-111 canal using paleoecological techniques. They concluded that the rate of saline intrusion was several times that indicated by sea level rise alone and demonstrated that the rate of saline intrusion was correlated with canal operation.

Marshall et al. (2008) combined the use of physical models with paleoecological techniques. They used long-term hydrological and climatological empirical data with paleoecological data to produce statistical models that could hindcast hydrologic patterns in Taylor Slough, freshwater flows from Taylor Slough and salinity in Florida Bay. These models indicate that flow from Taylor Slough was almost 4 times greater than current values and that salinity in NEFB is currently 12 -15 psu higher than would have occurred under the greater freshwater flow regime.

Marshall et al. (2008) also indicated that water levels in Taylor Slough were about 15 cm higher and that hydroperiods were 4 times greater. Johnson and Fennema (1989) indicated that prior to water management impacts, the mean difference between wet season maximum and dry season minimum water levels was about 1 m. By 1988, they found the average difference to about 0.25 m due to lower wet season maximums and higher dry season minimums. Kotun and Renshaw (this issue) present some data that indicate more recent water management practices have ameliorated some of this difference, however, it is still quite different than the pre-drainage system. Kotun and Renshaw (this issue) also provide a detailed account of the changes in hydrology since 1950 that indicate significant changes in water levels and hydroperiods in Taylor Slough.

Biological evidence also indicates that the salinity regime has changed dramatically in NEFB. Vegetation surveys of the area between Florida Bay and the C-111 canal indicate a steady landward increase in the width of the dwarf red mangrove

(*Rhizophora mangle*) zone into areas that were historically fresh water herbaceous marshes (Egler 1952, Tabb et al. 1967, Ross et al. 2002). Ross et al. (2002) compared the results of their survey to a 1948 survey performed by Egler (1952). The comparisons indicated that the mangrove dominated area had expanded inland by as much as 3.3 km since the 1948 study, supplanting the pre-existing freshwater marshes. Ross et al. (1996) stated that this rate of mangrove intrusion was greater than could be attributed to sea level rise alone. Aerial surveys were used to confirm the observed changes in the plant community of the ecotone region (Ross et al. 2002). Apparently, the canal system reduced the pressure of the fresh water head resulting in more frequent and sustained salt water intrusion into this area, which would eliminate saline sensitive herbaceous plants and favor the expansion of the mangrove zone.

From 1993 to 2012, I collected monthly measurements of salinity along several upstream-downstream transect lines in the wetlands north of NEFB. Coincidentally, during a 1905 sailing cruise from Miami to Key West Florida (recounted in Gilpen-Johnson et al. 2000), fresh water was found at one of these transect locations in late March. Using measurements made closest to the same calendar date as that of the 1905 record (all were within 3 weeks of that date), I estimated the mean salinity at this location for the late March-early April time period to be 18.5 (±2.4se) psu for the period 1993-2012. The National Oceanic and Atmospheric Administration (NOAA) operated five rainfall gages in southern Florida that were active in both 1905 and from the period 1993-2005 (data after May 2005 were unavailable). Data from these rainfall gages indicated that the 1905 hydrologic year (June-May) was a drought year. Non-Metric Multidimensional Scaling of monthly rainfall from the NOAA gages indicated that there were 2 modern hydrologic years with spatially and temporally similar rainfall patterns to those of 1905: 1997 and 2001. In late March-early April of those two years salinity was 24 and 26 psu, respectively. These data suggest that regional rainfall patterns that historically resulted in freshwater conditions on these wetlands well into the dry season currently result in salinities that approach marine conditions.

Collectively, the studies cited above provide substantive evidence that the ecotonal wetlands north of Florida Bay have experienced higher salinities, longer periods of saline intrusion and shorter hydroperiods due to anthropogenic manipulation of water resources. Anecdotal evidence to support these conclusions can be garnered from testimonials from residents of the region prior to Everglades' drainage. Simmons and Ogden (1998) document an eyewitness account of conditions along the northeastern mainland coast of Florida Bay during the 1920's and 1930's. They reported that the mangrove zone only extended about 100 m north from the bay in the vicinity of Long Sound and Joe Bay, beyond which were freshwater glades. Dwarf mangrove forests currently extend several kilometers inland at these locations (Ross et al. 2002). Simmons and Ogden (1998) also report that many creeks that delivered fresh water to the Northeastern Basin and southern Biscayne Bay are now filled in from lack of flow. As part of the planning process for the creation of Everglades National Park (ENP), Beard (1938) performed a wildlife reconnaissance within the proposed park boundary. He identified the region between Florida City and Key Largo, east of US Highway 1, as seasonal farmland. Currently, this area is dominated by dwarf mangroves (Ross et al 2002). Former farmland can be readily identified because the individual mangroves grow in straight lines along the old furrows (Pers. Obs.). Water salinity is currently brackish to marine, which would result in soil salinity levels that would prohibit successful farming today. Will (1984) provided an account of the construction of the Homestead Canal to Cape Sable in 1922. His photographs clearly show freshwater plant species (e.g. sawgrass, (*Cladium jamaicense*); royal palm, (*Roystonea regia*); Paurotis palm, (*Paurotis wrighti*) in areas that are currently dominated by mangrove forests. Water salinity in these areas currently ranges from about 10 to 50 psu (Pers. Obs.). Other reminiscences from residents of the area indicate a decline in the spatial extent of freshwater wetlands bordering Florida and Biscayne bays (Anonymous 1987). Furthermore, large freshwater upwellings occurred from Marco Island to Virginia Key (Tebeau 1955, Audubon 1960, Craighead 1971, Anonymous 1987) including several in Florida Bay that were active as late as the 1970's (McIvor et al. 1994, Gulick 1995). Tebeau (1955) presented a photograph of an artesian spring on Chockoloskee Island. That such upwellings no longer exist indicates that the freshwater head pressure from the Everglades has declined significantly.

Coastal Mangrove Prey Base Fishes

Historically there were large numbers of wading birds that nested in NEFB during the dry season (Powell et al. 1989, Lorenz et al. 2002). The coastal mangrove habitats (Fig 1) of Taylor Slough and the C-111 are critical foraging habitat for these wading birds during the dry season nesting cycle (Powell et al. 1989, Lorenz et al. 2002). These habitats may have historically been important nursery habitats for juvenile game fish species (Lewis et al. 1988, Rutherford et al. 1986) and they are currently important foraging habitats for game fish (Odum et al. 1982, Ley et al. 1989, Ley 1992, Faunce et al. 2002) especially during low water periods of the dry season. Following the completion of the SDCS in 1984 (Kotun and Renshaw, this issue), roseate spoonbills, (*Platelea ajaja*) nest numbers in NEFB began to steadily decline (discussed below). Powell (1986) speculated that the reason for the decline was due to changes in food resources related to water management practices. This hypothesis led to an extensive multilevel ecological study of the relationship between hydrology and salinity in the coastal mangrove habitats where these birds feed. Among the findings was that relatively high salinity and highly variable salinity adversely affected primary production (Frezza et al. 2007). These authors concluded that such declines in primary production would adversely affect higher trophic levels. Lorenz (1999) demonstrated that prey fish productivity was a function of complex interactions between water level, hydroperiod and salinity. It was also found that lower, more stable salinity led to assemblages of fish species that were more productive than at higher and more variable salinity (Lorenz and Serafy 2006). Prey base fishes were also found to expand throughout ephemeral mangrove habitat and increase their numbers throughout the wet season (Lorenz 2000) and that high water levels and longer hydroperiods led to greater fish abundance at the end of the wet season (Lorenz 1999, Lorenz 2000). During low water periods of the dry season these fish become highly available to predators when the ephemeral wetlands dry and fish become concentrated in the remaining deeper water habitats (Lorenz 2000, Lorenz this issue). Fish were found to begin aggregating in the refuges when water levels on the ephemeral wetlands dropped below 13 cm (Lorenz this issue) and that spoonbill nesting success was dependent on water levels lower than 13 cm throughout their nesting cycle (Lorenz this issue). Pulse discharges from the C-111 (for flood control purposes) during the nesting cycle raised water levels above 13 cm, dispersed the prey base and resulted in nest abandonment (Lorenz 2000, Lorenz this issue). These findings indicate that the demonstrated operational effects of the upstream canal system include lowered water levels, shortened hydroperiods, and increased salinity (Marshall et al 2008, Kotun and Renshaw this issue); thus, it is clear that these operations also impacted productivity, abundance and availability of prey fishes in the coastal mangrove wetlands of Florida Bay.

## Fisheries Species

Fisheries stocks in estuaries have been positively related to freshwater inflow (Day et al. 1989a, Longley 1994). Likewise, diversion of flow from estuaries results in a decline in fisheries stocks (Browder and Moore 1981, Day et al. 1989a). Although freshwater inflows impact estuaries on multiple levels (Snedaker et al. 1977, Day et al. 1989b), anthropogenic changes in salinity regime in estuaries has been linked to a decline in fisheries stocks (Flanagan and Hendrickson 1976, Browder and Moore 1981, Longley 1994). A commonly cited impact of increased salinity is disruption of nursery function in estuarine systems (Snedaker et al. 1977, Browder and Moore 1981, Bradley et al. 1990, Ley et al. 1999). Temporally and spatially extensive surveys of fish assemblages in the wetlands north of NEFB reveal little indication that this habitat is currently a nursery for fishery species (Ley et al. 1999, Lorenz 1999, Lorenz and Serafy 2006).

Rutherford et al. (1989) correlated spotted seatrout (*Cynoscion nebulosus*) harvest in Florida Bay with rainfall in the southern Everglades two years earlier. Tilmant et al. (1989a) found that red drum (*Sciaenops ocellatus*) recruitment into Florida Bay's fishery increased following years with increased runoff from the Everglades. Tilmant et al. (1989b) indicated that larval recruitment and juvenile survival of common snook (*Centropomus undecimalis*) in Florida Bay were enhanced in years with high fresh water flows from the Everglades. These three studies were based on surveys taken by ENP between 1958 and 1987. A common prey item of game fish as well as supporting its own fishery, pink shrimp (*Farfantepenaeus duorarum*) harvested in Dry Tortugas fishery use central and western Florida Bay as a nursery area (Browder, 1985). In an examination of 14 years of combined harvest by quarter year, pink shrimp harvest was correlated with Everglades water levels from the previous quarter (Browder 1985). Browder et al. (1999) indicated that relatively high water temperature and low salinity regimes play a role in whether basins in central Florida Bay contribute recruits to the fishery. Although these studies examined fishery stocks for all of Florida Bay (not just the Northeastern Basin), they indicate that increased runoff into Florida Bay created more favorable conditions for recruitment of fishery species. Therefore, the escalating diversion of fresh water away from Florida Bay starting in 1960 probably resulted in less robust fishery stocks than had occurred prior to water management in the southern Everglades. Reports from fishers corroborate this conclusion (Zieman et al. 1989, Gulick 1995).

The association between fish communities and submerged aquatic vegetation (SAV) has been well documented since the late 1950's (Serafy 1992). In Florida Bay, Rutherford et al. (1986) linked various game fish species to SAV type. Thayer et al. (1987) and Ley (1992) characterized the fish community associated with mangrove shorelines. Thayer and Chester (1989) and Sogard et al. (1989b) characterized fish communities associated with various seagrass species in basin and mud bank habitats respectively. Massive seagrass die-offs occurred throughout Florida Bay during the late 1980's and early 1990's (Robblee et al. 1991). As an example of the link between fish community structure and SAV type, Matheson et al. (1999) repeated the techniques of Sogard et al. (1989) at bank sites impacted by the seagrass die-off and found dramatically different community types. Likewise, Thayer et al. (1999) repeated the techniques of Thayer and Chester (1989) and documented both a decline in seagrass abundance and changes in the fish community in basin and channel habitats within the bay.

Zieman et al. (1989) suggested that the northern half of the Northeastern Basin was dominated by the seagrass shoal grass (*Halodule wrightii*) in the late 1950's. Shoal grass is a pioneering species that is capable of tolerating fluctuations in salinity (Zieman et al. 1989). Between 1960 and 1983, shoal grass was gradually replaced by turtle grass (*Thalassia testudinum*; Zieman et al. 1989), a species of seagrass that generally displaces shoal grass under stenohaline conditions, but can not tolerate salinity fluctuations to the same degree as shoal grass. Zieman et al. (1989) attributes this change to consistently higher salinity in NEFB as a result of water diversion away from the coastal wetlands. Zieman et al. (1989) related that, beginning in the late 1970's, fishers reported fewer mullet in the Northeastern Basin because thick turtle grass beds were not as useful as feeding areas as shoal grass beds.

Rutherford et al. (1986) sampled juvenile game fish throughout Florida Bay. More than 80% of the juvenile snook collected were found in low salinity (mean 8.9 psu) SAV environs dominated by *Chara spp.* and *Utricularia spp.* Juvenile spotted seatrout were mostly (>80%) collected from grass and shoal grass beds with a mean salinity of 17.2 psu. Gilmore et al. (1983) found that snook depend on coastal fresh water and low salinity environments for their early life history stages. Wakeman and Wohlslag (1977; in Longley 1994) reported optimum metabolic salinity for juvenile spotted seatrout was 20 to 25 psu. Longley et al. (1994) reported that spotted seatrout density over vegetation increased with salinity but decreased above 30 psu. Catch rates for snook in NEFB declined from 1972 to 1984 while catch rates for spotted seatrout increased over the same period (Rutherford et al. 1989). These changes may be the result of changes in dominant SAV (Rutherford et al. 1986). These findings all suggest that salinity increases in the Northeastern Basin due to water management have resulted in broad ecological changes.

With the completion of the SDCS in 1984, dry season flood control for agricultural lands required out-of-season pulses of water to be delivered to the C-111 basin (Van Lent et al. 1993). These pulses resulted in temporary increases in water level and salinity decreases in NEFB (Baratta and Fennema 1994). As a result, salinity variability increased in NEFB after 1983. Serafy et al. (1997) demonstrated that water management in southern Florida can result in lethally extreme salinity fluctuations for many common fish species. Montague and Ley (1993) periodically sampled NEFB macrophytes and benthic crustaceans in conjunction with a variety of physicochemical parameters and found that high variation in salinity had a negative impact on the flora and fauna examined. Ley (1992) also found that the standard deviation of mean salinity was negatively correlated with fish biomass. Finally, Ley et al. (1994) concluded that the diets of fishes in areas of high salinity variation were inferior to those of more stable salinity environments. The authors speculated that higher variance in ambient salinity resulted in reduced productivity in benthic plants and crustaceans resulting in lower quality prey and lower biomass in fishes (Ley et al. 1994). Stable salinities had the opposite effect. These results indicate that the salinity pulses caused by water management practices would be detrimental to plant, invertebrate and fish communities in the Northeastern Basin.

Reptiles

Florida Bay is unique in this hemisphere in that it has three sympatric reptiles adapted to estuarine conditions; the American crocodile (*Crocodylus acutus*), the diamondback terrapin (*Malaclemys terrapin*) and the mangrove water snake (*Nerodia clarkii compressicauda*), all of which live and reproduce in the Northeastern Basin (Dunson and Mazzotti 1989). The south Florida population of American crocodiles was never large (estimated to be between 1000 and 2000) but by 1970 it had declined to between 200 to 400 individuals (Ogden 1978). In the 1930's, the nesting range of Florida Bay's crocodile population included all of the NEFB and beyond to other regions of Florida Bay (Ogden 1978). By 1970, the majority of nesting occurred in the mainland coastal wetlands in the Northeastern Basin (Mazzotti 1999). Since then, the number of nests and nest success rates in NEFB have remained almost constant (Mazzotti 1999). Mazzotti (1999) indicated that decreased fresh water flow from upland sources to the Northeastern Basin might have altered the salinity regime such that many historical nesting sites became unsuitable based on the physiological needs of hatchlings (see below). Interestingly, crocodiles have expanded their range and numbers within ENP over the last 30 years but rather than expanding southward to historical nest locations, Cape Sable (northwestern Florida Bay) has now become the population center (Mazzotti.

This further reinforces that conditions in the Northeastern Basin has become unsuitable for nesting crocodiles.

Mazzotti and Dunson (1984) found that different salinity regimes resulted in different growth rates in hatchling crocodiles. Optimum growth was found to occur at 9 psu salinity (Dunson and Mazzotti 1989). Hatchling crocodiles failed to grow at 35 psu even when provided ample food (Mazzotti and Dunson 1984) and mortality ensued under these conditions (Dunson 1982). Once young crocodiles reached 200 g body weight, they were tolerant of marine conditions (Mazzotti and Dunson 1984). Cumulatively, these studies show that low salinity environments are conducive to hatchling growth while marine conditions inhibit growth and crocodiles are physiologically unable to osmoregulate until they are about 200 g (Dunson and Mazzotti 1989). Moler (1991) found that when young-of-the-year crocodiles reach 200 g prior to the seasonal increase in salinity (December), average survival through the dry season was almost 30% while it was only 10% for those individuals less than 200 g. These results indicate that increased salinity in the Northeastern Basin as a result of water management would reduce survival in hatchling crocodiles (Mazzotti 1999).

Operation of the SDCS may have impacted crocodile nesting in another way. Since 1984, the SDCS has operated in flood control mode (Van Lent et al. 1999). Following above average rainfall events, water is pumped southward so that upstream urban and agricultural lands are drained quickly. These pulse releases temporarily result in higher water levels along the creek habitats in Taylor Slough and south of the C-111 canal (Baratta and Fennema 1994), thereby flooding nests and making eggs inviable (Mazzotti 1999). Nesting sites along these creeks are desirable for crocodiles because they have lower salinity and are more protected from wind and wave action than other sites (Mazzotti 1989). The percentage of total nests found along creeks declined from 28% in the 1970's to 12% in the 1980's and 7% in the 1990's (Mazzotti 1999).

Population dynamics of the diamondback terrapin in Florida Bay have not been well studied. The lower Florida Keys sub-species of terrapin, known as the mangrove terrapin (*Malaclemys terrapin rhizophorarum*), is currently classified as rare by the state of Florida (Wood 1997). The sub-species of Florida's west coast (*Malaclemys terrapin macrospilata*) is also very limited in range and abundance (Milsap et al. 1990). In Florida Bay terrapins nest and forage on and around mangrove islands. Similar to crocodiles, hatchling mangrove terrapins provided with ample food exhibit optimum growth at 9 psu salinity and fail to grow at 21 psu and higher if not provided some fresh drinking water (Dunson and Mazzotti 1989). Hatchlings in Florida Bay can acquire enough drinking water from rainfall to survive, however, increasing salinity does result in physiological stress (Dunson and Mazzotti 1989). The water management projects of the last four decades have increased the salinity in the Northeastern Basin and the terrapin population may have been adversely affected as a result.

The mangrove water snake is highly resistant to dehydration due to low uptake of salts while feeding and probably satisfies its fresh water intake by drinking rainwater (Dunson and Mazzotti 1989). As a result, this species is well adapted to highly saline environments (Dunson and Mazzotti 1989). There is no indication of adverse impacts on the population as a result of water management.

## Marine Mammals

The Florida manatee (*Trichechus manatus latirostris*) is a federally listed endangered species (O'Shea and Ludlow 1992) that feeds prodigiously on SAV, consuming about 4% to 9% of it's body weight (20-45 kg) in about five hours of feeding time each day (Bengston 1983). Manatees feed heavily on seagrasses but other SAV, bank grasses, overhanging mangroves, and floating plant species are also major components of their diet (O'Shea and Ludlow 1992). Movements and aggregations can be correlated to some degree with the distribution of SAV (Hartman 1974). Although manatees are common in marine habitats and tolerate hypersaline conditions, they are most frequently encountered in brackish and fresh water environments (O'Shae and Ludlow 1992). Worthy (1998) suggests that manatees may require regular access to fresh or brackish water to meet osmoregulatory needs. In the 1930's, the Northeastern Basin and associated fresh water creeks were believed to be the most important area for manatees within the proposed boundary of ENP (Beard 1938). In subsequent years, the low number of manatees within Florida Bay were attributed to lower fresh water inflows (Hartman 1974, Odell 1979). Although the impact of water diversion away from Florida Bay on the manatee population was probably minimal, the impact of the loss of such prodigious grazers to the ecology of the Northeastern Basin may have been profound. Changes in SAV communities in the Northeastern Basin may have occurred, in part, to a reduction in grazing pressure by manatees.

Although there are no records available for the historic use of the Northeastern Basin as a foraging ground for bottlenose dolphin (*Tursiops truncatus*), recent surveys revealed very little activity in this region (Torres 2009). Given the decline of common prey items (as identified by Torres 2009) of dolphin in the Northeastern Basin, this paucity of dolphin use may be a consequence of lack of prey items potentially associated with the operation of the SDCS (see fishery species section).

## Birds

The Florida Committee on Rare and Endangered Plants and Animals lists 16 species of bird that nest in Florida Bay (Rodgers et al. 1996). Most of these birds (11 species) are wading birds (order Ciconiiformes) and most are highly opportunistic nesters. Wading birds nest in various locations throughout the Everglades system in both estuarine and freshwater areas. Furthermore, birds that nest in the Everglades region may nest in other locations throughout the southeastern United States (Bancroft et al. 1994) and possibly other international locations. Although these birds may be very good indicators of overall conditions of the entire Everglades landscape (Frederick and Collopy 1989, Bancroft et al. 1994, Ogden 1994), their transient and intermittent use of Florida Bay nesting sites, compounded with their frequent use of nearby fresh water regions of the landscape complicates the evaluation of Florida Bay health using population statistics for these species. There are, however, five species of birds listed by the state of Florida as rare or endangered (2 are wading birds) that have distinct Florida Bay populations and have been relatively well studied, thereby allowing for an evaluation of recent environmental changes.

Several research projects have examined the population of nesting roseate spoonbills in Florida Bay. This species was nearly extirpated in the early 1900's but, once afforded protection from hunting, the population recovered. The number of spoonbills nesting in Florida Bay increased exponentially from the 1950's though the mid 1970's, reaching a peak of 1259 nests in 1978. Following the completion of the SDCS in 1984, nest numbers steadily declined to approximately 600-800 nests in the 1980's, 400-500 in the 2000's (Bay-wide nest counts were discontinued in 1992 - 1999) and less than 350 since 2008 (Lorenz et al. 2002, Stone and Lorenz 2012). In NEFB, the decline was even more pronounced dropping from 688 nests in 1978 to 20 nests in 2011 (Lorenz et al. 2002, Stone and Lorenz 2012). Lorenz et al. (2002) demonstrated that degradation of foraging grounds is the most likely explanation for this decline. Lorenz et al. (2002) also showed that nesting success production was 1.4 chicks per nest (c/n) prior to the SDCS and 0.7 c/n following its completion (most wading bird studies consider a production rate of <1.0 c/n as a failing population). Studies of prey base fishes on their primary foraging grounds in NEFB indicate a reduction in habitat productivity, prey abundance and prey availability concurrent with the decline in nesting success and nest numbers and that water management practices have caused abandonment of nests in NEFB (detailed above under prey base fishes). Recent results from a banding and tracking study found that spoonbills have a high degree of fidelity to their natal habitat when they reach breeding age and that they can breed at least until 19 years of age with an estimated life expectancy of 25 to 30 years (JJL, unpublished data). That the NEFB nesting population is largely closed to immigration or emigration, and that they are not reproducing at a high enough production rate to maintain numbers enough to keep up with mortality explains the steady decline in NEFB. The root cause is that water management practices have reduced prey parameters such that nesting spoonbills can not access enough prey to meet the energetic demands of their chicks (Lorenz et al. 2009). Lorenz et al. (2009)

demonstrated that spoonbills are an umbrella indicator for Florida Bay suggesting that other piscivorous species are likely having the same difficulties.

The vast majority of the US great white heron population (*Ardea herodias occidentalis*) is located in southern Florida with 65% of the population nesting in Florida Bay (Powell and Bjork 1996). Great white herons are considered an estuarine species that feeds almost exclusively on fish (Powell and Bjork 1996). In 1959, the number of great white herons in Florida Bay was estimated to be between 800 and 900 individuals (Powell et al. 1989). Intermittent surveys between 1959 and 1984 indicated that the population remained fairly constant at about 900 individuals (Powell et al. 1989). Hurricanes resulted in large-scale mortality in this species but the population was found to be resilient and recovered quickly (Powell et al. 1989). Complete surveys have not been performed since 1984, however, a three-year study of great white herons in the early 1980's indicated that nest production was much lower than similar records collected in 1923 (Powell and Powell 1986). Powell and Powell (1986) also found that birds that received supplemental food from humans had similar production rates to those of 1923 while those that were not supplemented had much lower production. They concluded that foraging habitat quality had been reduced. Powell et al. (1989) speculated that water diversion upstream from Florida Bay had negatively impacted the prey base thereby explaining the reduced nesting success in herons.

The populations of eastern brown pelican (*Pelecanus occidentalis carolinensis*) was delisted from the endangered species list due recovery across its range. This was not the case in Florida Bay. Prior to 1976, the number of pelican nests in the state was approximately 6000 (Nesbitt 1996), with about 850 in Florida Bay (Kushlan and Frohring

1985). Statewide nest numbers increased steadily from that point; in 1989 there were 12,310 nesting pairs (Nesbitt 1996). Over this same period the number of nests in Florida Bay steadily declined (Kushlan and Frohring 1985). Ogden (1993) counted 350 nests in a 1993 survey. Prior to the completion of the SDCS, pelicans commonly nested in the Northeastern Basin (Ogden 1993, JC Ogden, Pers. Comm.), however surveys of nesting colonies in this region from 1995 to 2012 revealed little pelican nesting activity (Pers. Obs., L. Oberhofer, ENP, Pers. Comm). Furthermore, nesting throughout Florida Bay has become a rarity with multi-year gaps between nesting activity (Pers. Obs.) and nesting activity isolated to the extreme western portion of the bay (Pers. Obs.). Pelicans feed exclusively on fish (Nesbitt 1996) and Kushlan and Frohring (1985) hypothesized that the reason for the decline in nesting in Florida Bay was a reduction in prey availability. Although the pelican prey base was not investigated, changes in fish community structure as a result of water diversion may support their hypothesis.

Ospreys (*Pandion haliaetus*) are large raptors that prey almost exclusively on fish. Most North American osprey populations seriously declined in the 1950's and 1960's as a result of pesticide contaminants in the environment, however, the Florida Bay population remained largely unaffected (Ogden 1977). While most other osprey populations recovered during the 1970's and 1980's (due largely to legislation that restricted environmentally damaging pesticides), the Florida Bay population declined (Poole 1989). In the late 1960's and early 1970's there were about 200 pairs of nesting osprey in Florida Bay (Ogden 1993). Intermittent nesting surveys taken in the 1970's indicated a steady decline in nest numbers and, by 1993, there were only 70 nests in Florida Bay; a 58% decline from 20 years earlier (Ogden 1993). Much of the loss occurred in NEFB (Pers

Obs, J. Ogden, Pers Comm). Over the same time period, nest success per attempt also declined (Ogden 1993). These declines in number of nests and nesting success coincide with major changes in water delivery to the Bay. During the 1986-87 nesting season, Bowman et al. (1989) compared success of ospreys that nested on the main line Florida Keys with those of Florida Bay. They found that nesting ospreys that foraged exclusively in Florida Bay had significantly lower nest production than those that nested along the Keys. By observing nests that allowed for foraging in both the Bay and the Atlantic Ocean, Bowman et al. (1989) demonstrated that foraging flights toward the ocean were more frequently successful than flights toward the bay. The authors concluded that Florida Bay ospreys experienced decreased reproductive success due to an inadequate food supply.

Similar to the osprey, the southern bald eagle (*Haliaetus leucocephalus leucocephalus*) was federally listed as a result of environmental contaminants, but the Florida Bay population was largely unaffected (Curnutt 1996, Baldwin et al. 2012). Surveys of Florida Bay's nesting population of bald eagles began in 1958 (Curnutt 1991). An analysis of the territoriality of eagles in Florida Bay from 1958 to the mid-1980's indicated that the Bay is largely saturated and number of territories remained remarkably constant (Curnutt 1991, Robertson 1993). Up to 30 territories were documented with 80-100% occupancy during the period (Baldwin et al. 2012). Beginning in the mid-1980's (coinciding with the completion of the SDCS) the number of occupied territories began to decline reaching a low of just 50% occupancy in 2003 and 2004 (Baldwin et al. 2012). Most of the abandoned territories were in NEFB; currently only one of the seven historic territories in NEFB is active (ENP data, L. Oberhofer Pers. Comm.). Nests in other regions of the Bay continue to be highly productive compared to other eagle population around North America (Baldwin et al. 2012). Although bald eagles principally feed on fish, they are opportunistic feeders (Curnutt 1996). In Florida Bay, eagles supplement their diet with terrapins, a variety of birds, and carrion (Robertson 1993). Also, bald eagles are well known for thieving meals from ospreys through harassment (kleptoparasitism). The plasticity of the eagles diet and the opportunistic nature of foraging makes the observed decline particularly alarming given that this consummate generalist apparently can not successfully raise young in NEFB.

## Conclusions

Faunal studies in Florida Bay strongly suggest that water management practices (starting in 1960 but culminating in 1984 with the completion and operation of the SDCS) have had a profound impact on many animal populations. Many investigations demonstrated a decline in reproductive success coincident with the physical and ecological changes in the coastal wetlands. Most of the investigations implicated food stresses as a cause for the observed changes in higher trophic levels. Collectively, the studies reviewed imply declining success of vertebrate species in the Northeastern Basin through an ecological cascade set in motion by upstream water management practices. The cascade began with the increasing diversion of water away from its natural course over the last several decades (Kotun and Renshaw this issue). The resulting alteration in hydrology and salinity of NEFB altered the plant communities within the basin and adjacent coastal wetlands. Plant and fish communities changed in response to the altered dynamic environment and in response to each other. The result was a lowering of the quality of the forage base for vertebrate species, culminating in their inability to acquire enough food in the region to maintain their populations.

## ACKNOWLEDGEMENTS

The author would like to thank John Kipp, Lori Oberhofer, Sonny Bass and especially the late John C. Ogden for their contributions to my understanding of the subject matter. This publication was produced as part of a special issue devoted to investigating the ecological response of over 20 years of hydrologic restoration and active management in the Taylor Slough drainage of Everglades National Park. Support for this special issue was provided by; the Everglades National Park, the Southeast Environmental Research Center, the Florida Coastal Everglades Long-Term Ecological Research program (National Science Foundation cooperative agreement #DBI-0620409), the Everglades Foundation and the South Florida Water Management District.

## LITERATURE CITED

Anonymous (1987) Along the Florida Reef:1871. In: Tales of Old Florida. Castle, Seacaucus, pp 265-309.

Audubon JJ (1960) Audubon and his journals, Vol 2. Dover Publications, New York.

Baldwin JD, Bosley JW, Oberhofer L, Bass OL, Mealey BK (2012) Long term changes, 1958-2010, in the reproduction of bald eagles of Florida Bay, southern coastal Everglades. Journal of Raptor Research 46:336-348.

Bancroft G, Strong AM, Sawicki RJ, Hoffman W, Jewell SD (1994) Relationships among wading bird forage patterns, colony locations, and hydrology in the Everglades In:

Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration. St. Lucie press, Delray Beach, pp 615-658.

Baratta AM, Fennema RJ (1994) The effects of wind, rain, and water releases on the water depth and salinity of northeast Florida Bay. Bulletin of Marine Science 54:1072.

Beard DB (1938) Everglades National Park project wildlife reconnaissance. United States Department of the Interior, National Park Service, Everglades National Park, Homestead.

Bengston JL (1983) Estimating food consumption of free-ranging manatees in Florida. Journal of Wildlife Management. 47:1186-1192.

Bowman RG, Powell GVN, Hovis JA, Kline NC, Wilmers T (1989) Variations in reproductive success between subpopulations of the osprey (Pandion haliaetus) in south Florida. Bulletin of Marine Science 44:245-250.

Bradley PM, Kjerfve B, Morris JT (1990) Re-diversion salinity change in the Cooper River, South Carolina: ecological implications. Estuaries 13:373-379.

Brewster-Wingard GL, Ishman SE (1999) Historical trends in salinity and substrate in cental Florida Bay: a palioecological reconstruction using modern analogue data. Estuaries 22:269-383.

Browder JA, Moore D (1981) A new approach to determining the quantitative relationship between fishery production and the flow of fresh water to estuaries. Proceedings on the national symposium on fresh water inflow to estuaries. Vol 1. U.S. Fish and wildlife service, Office of biological services. FWS/OBS-81/04:403-430.

Browder JA, (1985) Relationship between pink shrimp production on the Tortugas fishing grounds and water flow patterns in the Florida Everglades. Bulletin of Marine Science 37:839-856.

Browder JA, Gleason PJ, and Swift DR (1994) Periphyton in the Everglades: spatial variation, environmental correlates and ecological implications. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration. St. Lucie press, Delray Beach, Florida, pp 379-418.

Browder JA, Restrepo VR, Rice JK, Robblee MB, Zein-Eldin Z (1999) Environmental influences on potential recruitment of pink shrimp, Farfantepenaeus duorarum, from Florida Bay nursery grounds. Estuaries 22:484-499.

Craighead FC (1971) The trees of south Florida. University of Miami Press, Miami.

Curnutt JL (1996) Southern bald eagle. In: Rodgers JA, Kale HW, Smith HT (eds) Rare and endangered biota of Florida, volume 5: birds. University of Florida Press, Gainesville, pp 179-187.

Day JW, Hall CAS, Kemp WM Yanez-Arencibia A (1989a) Estuarine Fisheries. In: Day JW, Hall CAS, Kemp WM, Yanez-Arencibia A (eds) Estuarine ecology. John Wiley & Sons, New York, pp 479-511.

Day JW, Hall CAS, Kemp WM and Yanez-Arancibia A (eds). (1989b) Estuarine ecology. John Wiley and Sons, New York.

DeAngelis DL, Loftus WF, Texler JC Ulanowicz RE (1997) Modeling fish dynamics and effects of stress in a hydrologically pulsed ecosystem. Journal of Aquatic Ecosystem Stress and Recovery 6:1-13.

Dunson WA (1982) Salinity relations of crocodiles in Florida Bay. Copeia 1982:374-385.

Dunson WA, Mazzotti FJ (1989) Salinity as a limiting factor in the distribution of reptiles in Florida Bay: a theory for the estuarine origin of marine snakes and turtles. Bulletin of Marine Science 44:229-244.

Egler FE (1952) Southeast saline Everglades vegetation. Vegetatio 3:213-265.

Eisler R (1987) Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85.

Faunce CH, Lorenz JJ, Ley JA, Serafy JE (2002) Size structure of grey snapper (Lutjanus griseus) within a mangrove "no-take" estuary. Bulletin of Marine Science 70:2011-2016.

Frederick PC, Collopy MW (1989a) Nesting success of five ciconiiform species in relation to water conditions in the Florida Everglades. Auk 106:625-634.

Frederick PC, Collopy MW (1989b) The role of predation in determining reproductive success of colonially nesting wading birds in the Florida Everglades. Condor 91:860-867.

Frederick PC, Loftus WF (1993) Responses of marsh fishes and breeding wading birds to low temperatures: a possible behavioral link between predator and prey. Estuaries 16:198-215.

Frezza PE, Canedo LC, Lorenz JJ (2007) Relationships between submerged aquatic vegetation abundance and salinity variability within the coastal mangrove zone of northeastern Florida Bay. Estuarine Research Federation Biennial meeting, Providence RI, USA.

Gilmore RG, Donohoe CJ, Cooke DW (1983) Observations on the distribution and biology of east-central Florida populations of the common snook, Centropomus undecimalis. Florida Scientist Special Suppliment 45:313-336.

Halley RB, Swart PK, Dodge RE, Hudson JH (1994) Decade-scale trend in sea water salinity revealed $^{18}$O analysis of Montastraea annularis annual growth bands. Bulletin of Marine Science 54:670-678.

Halley RB, Roulier LM (1999) Reconstructing the history of eastern and central Florida Bay using mollusk-shell isotope records. Estuaries 22:358-368.

Hartman DS (1974) Distribution, status, and conservation of the manatee in the United States. National Technological Information Service PB81-140725, Springfield, Virginia.

Johnson RA, Fennema RA (1989) Conflicts over flood control and wetland preservation in the Taylor Slough and eastern panhandle basins of Everglades National Park. Wetlands: Concerns and Successes. American Water Resources Association, pp 451-462.

Kotun and Renshaw, this issue of Welands. Taylor Slough hydrology: 50 years of water management, 1960-2010.

Kushlan JA, Frohring PC (1985) Decreases in the brown pelican population in southern Florida. Colonial Waterbirds 8:83-95.

Lewis RR, Gilmore RG, Crewz DW, Odum WE (1988) Mangrove habitat and fishery resources of Florida. In: Florida Aquatic Habitat and Fishery Resources, Florida Chapter of the American Fisheries Society, Eustis, pp 281-336.

Ley JA (1992) Influence of freshwater flow on the use of mangrove prop-root habitat by fishes. Dissertation, University of Florida.

Ley JA, McIvor CC, Montague CL (1999) Fishes in mangrove prop-root habitats of northeastern Florida Bay: distinct assemblages across and estuarine gradient. Estuarine, Coastal and Shelf Science 48:701-723.

Ley JA, Montague CL, McIvor CC (1994) Food habits of mangrove fishes: a comparison along estuarine gradients in northeastern Florida Bay. Bulletin of Marine Science 54:881-889.

Light SS, Dineen JW (1994) Water control in the Everglades: a historical perspective. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach pp 47-84.

Loftus WF, Eklund AM (1994) Long-term dynamics of an Everglades small-fish assemblage. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach, pp 461-483.

Longley WL (ed) (1994) Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin.

Lorenz JJ (1999) The response of fishes to physicochemical changes in the mangroves of northeast Florida Bay. Estuaries 22:500-517.

Lorenz JJ (2000) Impacts of water management on roseate spoonbills and their piscine prey in the coastal wetlands of Florida Bay. Dissertation, University of Miami.

Lorenz JJ, Ogden JC, Bjork RD, Powell GVN (2002) Nesting patterns of roseate spoonbills in Florida Bay 1935-1999: implications of landscape scale anthropogenic impacts. In: Poter JW, Porter KG (eds) The Everglades, Florida Bay and the coral reefs of the Florida Keys: An ecosystem sourcebook, CRC Press, Boca Raton, pp. 555-598,

Lorenz, JJ, Serafy JE (2006) Changes in the demersal fish community in response to altered salinity patterns in an estuarine coastal wetland: implications for Everglades and Florida Bay restoration efforts. Hydrobiologia 569:401-422.

Lorenz, JJ, Langan-Mulrooney B, Frezza PE, Harvey RG, Mazzotti FJ (2009) Roseate spoonbill reproduction as an indicator for restoration of the Everglades and the Everglades estuaries. Ecological Indicators 9S:S96-S107.

Lorenz this issue. The relationship between water levels, prey availability and reproductive success in roseate spoonbills utilizing a seasonally flooded wetland as a forage area while nesting in Florida Bay

Marshall FE, Wingard GL, Pitts P (2008) A simulation of historic hydrology and salinity in Everglades National Park: coupling paleoecologic assemblage data with regression models. Estuaries and Coasts DOI 10.1007/s12237-008-9120-1.

Mazzotti FJ, Dunson WA (1984) Adaptations of Crocodylus acutus and Alligator mississippians for life in saline water. Comparative Biochemistry and Physiology 79A:641-646.

Mazzotti FJ (1999) The American crocodile in Florida Bay. Estuaries 22:552-561.

McIvor CC, Ley JA, Bjork RD (1994) Changes in freshwater inflow from the Everglades to Florida Bay including effects on the biota and biotic processes: a review. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach, pp 117-146.

Meeder JF, Ross MS, Telesnicki G, Ruiz PL (1996) Vegetation analysis in the C-111/Taylor Slough basin. Final Report to the South Florida Water Management District (Contract C-4244), West Palm Beach.

Milsap BA, Gore JA, Runde DE, Cerulean SI (1990) Setting priorities for the conservation of fish and wildlife species in Florida. Wildlife Monograph No. 111.

Moller PE (1991) American crocodile population dynamics. Final report for study number 7532, Bureau of Wildlife Research, Florida Game and Freshwater Fish Commission, Tallahassee.

Montague CL, Ley JA (1993) A possible effect of salinity fluctuation on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 16:703-717.

Nesbitt SA (1996) Eastern brown pelican. In: Rodgers JA, Kale HW, Smith HT (eds) Rare and endangered biota of Florida, volume 5: birds. University of Florida Press, Gainesville, pp 144-155.

Odell DK (1979) Distribution and abundance of marine mammals in the waters of Everglades National Park. In: Proceedings of the Conference on Science and Research, volume 5(1) of National Park Service Series. New Orleans pp 673-678.

Odum WC, McIvor CC, Smith TJ (1982) The ecology of mangroves of south Florida: a community profile. U.S. Fish Wildlife Service Office of Biological Services FES/OBS-81-24.

Ogden JC (ed) (1977) Transactions of the North American Osprey Research Conference. Transaction and Proceeding of the Service No. 2, U.S. National Park Service, pp 143-151.

Ogden JC (1978) Status and nesting biology of the American crocodile, Crocodylus acutus, (Reptilia, Crocodilidae) in Florida. Journal of Herpetology 12:183-196.

Ogden JC (1993) Florida Bay vertebrates: status reports for osprey, roseate spoonbill, brown pelican and northwestern wading bird colonies. Everglades National Park, Homestead.

Ogden JC (1994) A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem condition in the southern Everglades. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration. St. Lucie press, Delray Beach, pp 533-570.

O'Shea TJ, Ludlow ME (1992) Florida Manatee. In: S. R. Humphrey (ed.) Rare and Endangered Biota of Florida Vol I. Mammals. University Press of Florida, Gainesville, pp 190-200.

Poole AF (1989) Ospreys: a natural and unnatural history. Cambridge, New York.

Powell GVN, Powell AH (1986) Reproduction by great white herons Ardea herodias in Florida Bay as an indicator of habitat quality. Biological Conservation 36:101-113.

Powell GVN (1987) Habitat use by wading birds in a subtropical estuary: implications of hydrography. Auk 104:740-749.

Powell GVN, Bjork RD, Ogden JC, Paul RT, Powell AH, Robertson WB (1989) Population trends in some Florida Bay wading birds. Wilson Bulletin 101:436-457.

Powell GVN, Bjork RD (1996) Great white heron. In: Rodgers JA, Kale HW, Smith HT (eds) Rare and endangered biota of Florida, volume 5: birds. University of Florida Press, Gainesville, pp388-403.

Robertson WB (1993) Florida bay vertebrates -- status reports for great white heron, reddish egret and bald eagle. Everglades National Park, Homestead, Florida.

Robblee MB, Barber TB, Carlson PR, Durako MJ, Fourqurean JW, Muehlstein LK, Porter D, Yarbro LA, Zieman RT, Zieman JC. (1991) Mass mortality of the tropical seagrass Thalassia testudinum in Florida Bay (USA). Marine Ecology Progress Series 71:297-299.

Rodgers JA, Kale HW, Smith HT (eds) (1996) Rare and endangered biota of Florida, volume 5: birds. University of Florida Press, Gainesville.

Ross MS, Meeder JF, Sah JP, Ruiz PL, Telesnicki G (1996) The southeast saline Everglades revisited: a half-century of coastal vegetation change. Vegetation Analysis in the C-111/Taylor Slough Basin. Final Report to the South Florida Water Management District (Contract C-4244), West Palm Beach, Florida.

Ross MS. Meeder JF, Sah JP, Ruiz PL, Telesnicki G (2002) The southeast saline Everglades revisited: a half-century of coastal vegetation change. Journal of Vegetation Science

Rutherford, ES, Schmidt TW, Tilmant JT (1986) The early life history of spotted seatrout, red drum, gray snapper, and snook in Everglades National Park, Florida. Report SFRC-86/07, South Florida Research Center, Everglades National Park, Homestead, Florida.

Rutherford, E. S. Tilmant JT, Thue EB, Schmidt TW (1989) Fishery harvest and population dynamics of spotted seatrout, Cynoscion nebulosus, in Florida Bay and adjacent waters. Bulletin of Marine Science 44:108-125.

Serafy JE (1992) Fish assemblages and macrophytes: quantitative investigations in tidal freshwater Chesapeake Bay. Dissertation, University of Maryland.

Serafy JE, Lindeman KC, Hopkins TE, Ault JS (1997) Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observations. Marine Ecology Progress Series 160:161-172.

Snedaker S, de Sylva D, Cottrell D (1977) A review of the role of fresh water in the estuarine ecosystem. Southwest Florida Water Management District, Brooksville, Florida.

Sogard SM, Powell GVN, Holmquist JG (1989a) Spatial distribution and trends in abundance of fishes residing in seagrass meadows on Florida Bay mud banks. Bulletin of Marine Science 44:179-199.

Sogard SM, Powell GVN, Holmquist JG (1989b) Utilization by fishes of shallow, seagrass-covered banks in Florida Bay: 1. Species composition and spatial heterogeneity. Environmental Biology of Fishes 24:53-65.

Stone M, Lorenz JJ (2012) Roseate spoonbills in Florida Bay. South Florida Annual Wading Bird Report 12:?-?

Swart PK, Healy G, Greer L, Lutz M, Saied A, Anderegg D, Dodge RE, Rudnick D (1999) The use of proxy chemical records in coral skeletons to ascertain past environmental conditions in Florida Bay. Estuaries 22:384-398.

Tabb DC, Alexander TR, Thomas TM, Maynard N (1967) The physical, biological, and geological character of the area south of the C-111 Canal in extreme southeastern Everglades National Park, Florida; Report to the U.S. National Park Service (contract NPS 14-10-1-160-11). Everglades National Park, Homestead.

Tebeau CW (1955) The story of the Chokoloskee Bay country, with the reminiscences of pioneer C.S. "Ted" Smallwood. Banyan Books, Miami.

Thayer GW, Chester AJ (1989) Distribution and abundance of fishes among basin and channel habitats in Florida Bay. Bulletin of Marine Science, 44:200-219.

Thayer GW, Colby DR, Hettler WF (1987) Utilization of the red mangrove prop root habitat by fishes in south Florida. Marine Ecology Progress Series 35:25-38.

Thayer GW, Powell AB, Hoss DE (1999) Composition of larval, juvenile, and small adult fishes relative to changes in environmental conditions in Florida Bay. Estuaries 22:518-533.

Tilmant JT, Rutherford ES, Thue EB (1989a) Fishery harvest and population dynamics of red drum (Sciaenops ocellatus) from Florida Bay and adjacent waters. Bulletin of Marine Science 44:126-138.

Tilmant JT, Rutherford ES, Thue EB (1989b) Fishery harvest and population dynamics of common snook (Centropomus undecimalis) from Florida Bay and adjacent waters. Bulletin of Marine Science. 44:523-524.

Torres LG (2009) A kaleidoscope of mammal, bird and fish: habitat use patterns of top predators and their prey in Florida Bay. Marine Ecology Progress Series, 375:289-304.

Van Lent TJ, Johnson R, Fennema R (1993) Water management in Taylor Slough and the effects on Florida Bay. Report to South Florida Research Center, Everglades National Park, Homestead.

Van Lent TJ, Snow RW, James FE (1999) An examination of the modified water deliveries project, the C-111 project and the experimental water deliveries project:

hydrologic analysis and effects on endangered species. South Florida Natural Resources Center, Everglades National Park, Homestead.

Wakeman JM, Wohlschlag DE (1977) Salinity stress and swimming performance of spotted seatrout. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 31:357-361.

Will LE (1984) A dredgeman of Cape Sable. The Glades Historical Society, Belle Glade.

Wood DA (1997) Official lists of endangered and potentially endangered fauna and flora in Florida. Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

Worth GAJ (1998) Physiological constraints on the ecology of the West Indian manatee: Potential ramifications for the release of long-term captive manatees. Florida Marine Research Institute, St. Petersburg.

Zieman JC, Fourqurean JW, Iverson RL (1989) Distribution, abundance and productivity of seagrasses and macroalgae in Florida Bay. Bulletin of Marine Science 44:292-311.

811 Table 1 Summary of documented and inferred changes to vertebrate populations in Northeastern Florida Bay (NEFB).

| Species/Group | References | Type of evidence | Inferred change from historical | Documented change through time |
|---|---|---|---|---|
| Prey base fishes | Lorenz 1999, Lorenz 2000, Lorenz and Serafy 2006, Lorenz 2012 | Inferred from field studies | Much lower productivity due to salinity stress, habitat change and reduced hydroperiod | Freshwater periods are more productive than periods with saline influence |
| Spotted seatrout | Rutherford et al. 1989 | Inferred from field studies | Perhaps increased in number due to a more compatible higher salinity | Increased catch rates from 1972 to 1984 |
| Red drum | Tilmont et al 1989a, Rutherford et al. 1989 | Inferred from field studies | Decreased due to less freshwater runoff | |
| Common snook | Tilmont 1989b, Rutherford et al. 1989 | Inferred from field studies | Decreased due to less freshwater runoff | Declined catch rates from 1972 to 1984 |
| Mud bank fish community structure | Sogard et al 1989, Matheson et al. 1999 | Qualitative | | Changed from benthic to pelagic dominated spp from 1984-86 to 1994-96 |
| Seagrass fish community structure | Thayer and Chester 1989, Thayer et al. 1999 | Qualitative | | Changed from benthic to pelagic dominated spp from 1984-85 to 1994-96 |
| Mangrove shoreline fish productivity | Ley 1992, Montegue and Ley 1993, Ley et al. 1994 | Inferred from field studies | Lowered productivity compared to historic condition | |
| American crocodile range | Ogden 1978, Mazzotti 1999, Mazzotti et al. 2009 | Quantitative | Much more abundant and widespread historically | Nesting range shrank from all of NEFB in 1930's to just the coastal mangrove by 1999; population center in ENP shifted from NEFB to Cape Sable beginning in the early 2000's |
| American crocodile abundance | Ogden 1978, Mazzotti and Dunson 1984, Moler 1991, Mazzotti 1999 | Quantitative, inferred from field studies | Salinity stress reduced growth rate and survival of hatchlings and juveniles resulting in population decline since 1984 | Declined from up to 2000 historically to less than 400 by 1970. Modest increases in nest number since but recovery not as fast as expected under a more historic flow regime |
| Mangrove terrapin | Dunson and Mazzotti 1989 | Inferred from experimental results | Hatchling survival reduced from historical due to salinity stress | |
| West Indian manatee | Beard 1938, Hartman 1974, Odell 1979, Worthy 1998 | Quantitative, inferred from field studies | Less use of NEFB due to salinity stress and salinity induced habitat changes | Declined from high use in 1938 to rare in 1990's relative to overall population numbers |

| | | | | |
|---|---|---|---|---|
| Bottlenose dolphin | Torres 2009 | Inferred from field studies | Reduction of preferred prey (see fish) species may explain minimal use of the Northeastern Basin | |
| Roseate spoonbills | Lorenz 2000, Lorenz et al. 2002, Lorenz et al. 2009 | Quantitative, inferred from field studies | Lower nesting success due to salinity induced declines in prey number | Decline in the number of nests from 1259 in 1979 to less than 350 currently |
| Great white heron | Powell and Powell 1986, Powell et al 1989 | Quantitative, inferred from field studies | Lowered nest productivity due to reduced prey base | Significant decline in nesting success in the mid-1980's compared to early 1920's |
| Eastern brown pelican | Kushlan and Frohring 1985, Ogden 1993 | Quantitative, qualitative | Were common nesters in NEFB in 1980's but have only nested twice since 1991 | Baywide nest numbers declined from 850 in 1976 to 350 in 1993. |
| Ospreys | Ogden 1987, Poole 1989, Ogden 1993, Bowman et al. 1989 | Quantitative, inferred from field studies | Reduced nest numbers and nesting success due to low prey productivity | Baywide decline from 200 nests in the 1970's to 70 nests; disproportionately larger declines in NEFB. |
| Bald eagle | Curnutt 1996, Baldwin et al. 2012 | Quantitative | | Consistently about 30 territories baywide from 1958 to mid 1980's then declined to 50% occupancy in 2003, Territories in NEFB declined from 7 to 1 since mid-1980's. |

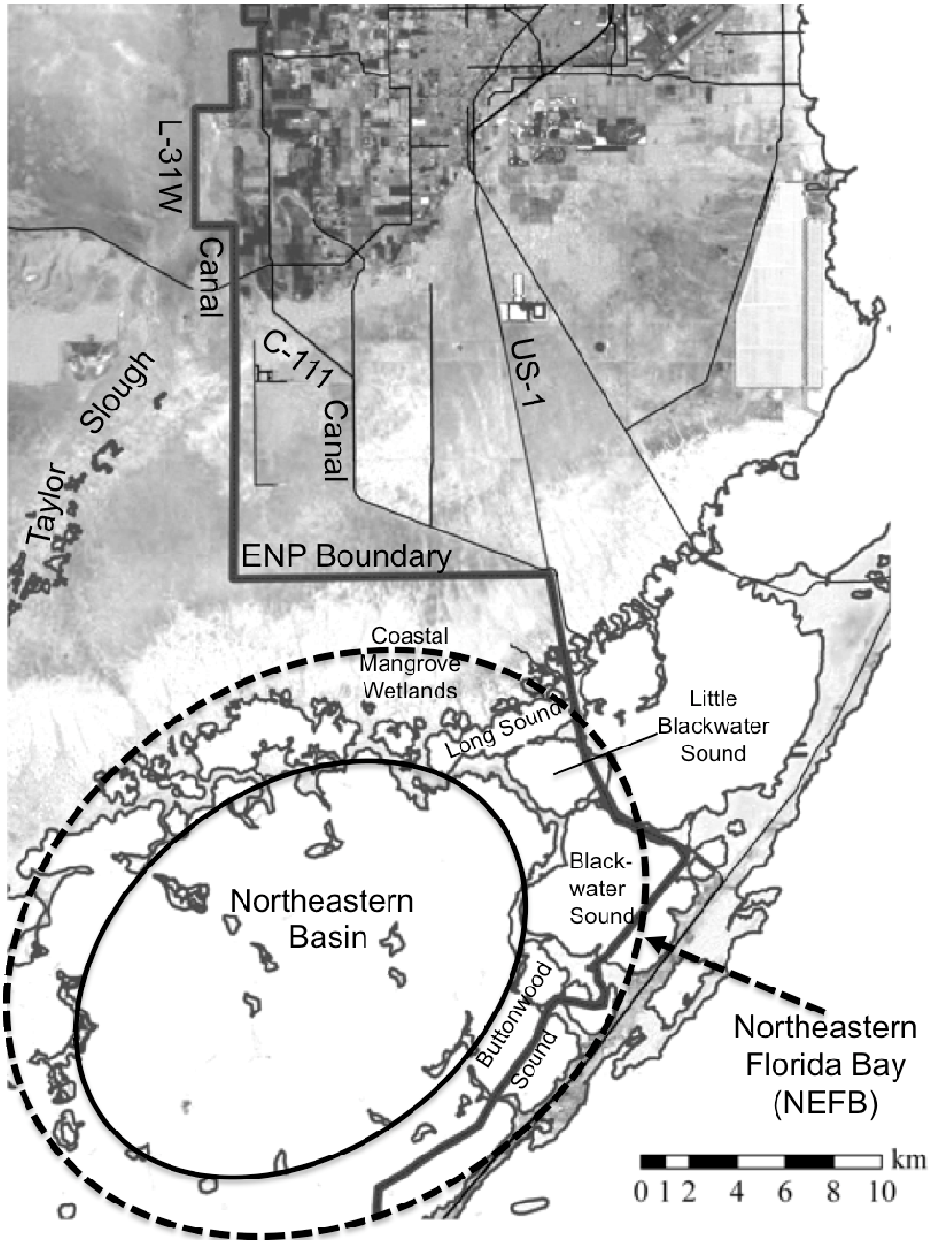

Fig 1. Map of northeastern Florida Bay and adjacent Everglades wetlands. The solid line defines the Northeastern Basin and the dashed line defines the Northeastern Florida Bay sub-region (NEFB; as defined by Lorenz 2000).