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A Review of the Effects of Altered Hydrology and Salinity on Vertebrate Fauna and Their Habitats in Northeastern Florida Bay

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1 **A REVIEW OF THE EFFECTS OF ALTERED HYDROLOGY AND SALINITY**
2 **ON VERTEBRATE FAUNA AND THEIR HABITATS IN NORTHEASTERN**
3 **FLORIDA BAY**

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7

8 **ABSTRACT**

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 Here, I review those impacts from published and unpublished literature and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

22

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

24 declines

25 INTRODUCTION

26 Anthropogenic alterations in the quantity, timing and distribution of freshwater to
27 estuaries have had calamitous ecological consequences to these important habitats on a
28 global scale (Day et al. 1989). Declines in productivity at all trophic levels have been
29 well documented. Although some of these changes occur as cataclysmic events,
30 incremental deviations in the freshwater source tend to be more common (Day et al.
31 1989). These incremental changes result in more subtle ecological changes through time
32 that can go unobserved by the casual observer, and rarely are there rigorous data to
33 support scientific claims of ecological decline (Day et al. 1989). In south Florida, the
34 Florida Bay estuary has been relatively well studied and the chronological sequence of
35 water diversions from its main freshwater source, Taylor Slough, have been well
36 documented (Fourqurean and Robblee 1999). These provide for the possibility of a
37 thorough review of the impacts on higher trophic levels that occurred through time as a
38 result of this water diversion.

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

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

60

61 REVIEW

62 Changes in Salinity and Hydrology

63 Kotun and Renshaw (this issue) demonstrated that a series of infrastructure
64 changes to the canal system and concurrent changes in water management practices
65 (Kotun and Renshaw this issue) resulted in sequential decrease in flow through Taylor
66 Slough into the Northeastern Basin. The overall result of these actions was that water
67 that once flowed through Taylor Slough and into the Northeastern Basin was diverted to
68 the L-31N/C-111 canal complex (Fig1) and was discharged into the small sounds that
69 make up the eastern extreme of NEFB and Manatee Bay to the northeast (Barrata and
70 Fennema 1989, Kotun and Renshaw; this issue). Kotun and Renshaw (this issue)

71 describe how, historically, the long residence time of fresh water in the Northeastern
72 Basin acted as a buffer against increases in salinity during the dry season (December to
73 May) when inflows from Taylor Slough were relatively modest compared to wet season
74 (June - November) inflows. The majority of the discharge from the C-111 occurred in
75 proximity to US Highway 1 (US-1; Fig1), flowing southward into Long Sound (Fig1;
76 Barrata and Fennema 1989). From there, fresh water cascaded through Little Blackwater
77 Sound, Blackwater Sound, and Buttonwood Sound, thereby bypassing the Northeastern
78 Basin (Barrata and Fennema 1989, Kotun and Renshaw; this issue) and greatly reducing
79 the salinity buffering capacity of the Basin by keeping salinities low. The end result was
80 increased salinization throughout NEFB.

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

87 Several paleoecological studies of sediment core samples from Florida Bay
88 indicate that the Florida Bay in general had lower salinity than occurs today (Halley et al.
89 1994, Brewster-Wingard and Ishman 1999, Halley and Roulier 1999, Swart et al. 1999).
90 Molluskan skeletal remains found in those cores were from species with lower salinity
91 tolerance than those that occur at the same locations today. More specific to NEFB,
92 Meeder et al. (1996) quantified the rate of saltwater encroachment into the wetlands
93 between Florida Bay and the C-111 canal using paleoecological techniques. They

94 concluded that the rate of saline intrusion was several times that indicated by sea level
95 rise alone and demonstrated that the rate of saline intrusion was correlated with canal
96 operation.

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

104 Marshall et al. (2008) also indicated that water levels in Taylor Slough were about
105 15 cm higher and that hydroperiods were 4 times greater. Johnson and Fennema (1989)
106 indicated that prior to water management impacts, the mean difference between wet
107 season maximum and dry season minimum water levels was about 1 m. By 1988, they
108 found the average difference to about 0.25 m due to lower wet season maximums and
109 higher dry season minimums. Kotun and Renshaw (this issue) present some data that
110 indicate more recent water management practices have ameliorated some of this
111 difference, however, it is still quite different than the pre-drainage system. Kotun and
112 Renshaw (this issue) also provide a detailed account of the changes in hydrology since
113 1950 that indicate significant changes in water levels and hydroperiods in Taylor Slough.

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

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

128 From 1993 to 2012, I collected monthly measurements of salinity along several
129 upstream-downstream transect lines in the wetlands north of NEFB. Coincidentally,
130 during a 1905 sailing cruise from Miami to Key West Florida (recounted in Gilpen-
131 Johnson et al. 2000), fresh water was found at one of these transect locations in late
132 March. Using measurements made closest to the same calendar date as that of the 1905
133 record (all were within 3 weeks of that date), I estimated the mean salinity at this location
134 for the late March-early April time period to be 18.5 (± 2.4 se) psu for the period 1993-
135 2012. The National Oceanic and Atmospheric Administration (NOAA) operated five
136 rainfall gages in southern Florida that were active in both 1905 and from the period 1993-
137 2005 (data after May 2005 were unavailable). Data from these rainfall gages indicated
138 that the 1905 hydrologic year (June-May) was a drought year. Non-Metric
139 Multidimensional Scaling of monthly rainfall from the NOAA gages indicated that there

140 were 2 modern hydrologic years with spatially and temporally similar rainfall patterns to
141 those of 1905: 1997 and 2001. In late March-early April of those two years salinity was
142 24 and 26 psu, respectively. These data suggest that regional rainfall patterns that
143 historically resulted in freshwater conditions on these wetlands well into the dry season
144 currently result in salinities that approach marine conditions.

145 Collectively, the studies cited above provide substantive evidence that the
146 ecotonal wetlands north of Florida Bay have experienced higher salinities, longer periods
147 of saline intrusion and shorter hydroperiods due to anthropogenic manipulation of water
148 resources. Anecdotal evidence to support these conclusions can be garnered from
149 testimonials from residents of the region prior to Everglades' drainage. Simmons and
150 Ogden (1998) document an eyewitness account of conditions along the northeastern
151 mainland coast of Florida Bay during the 1920's and 1930's. They reported that the
152 mangrove zone only extended about 100 m north from the bay in the vicinity of Long
153 Sound and Joe Bay, beyond which were freshwater glades. Dwarf mangrove forests
154 currently extend several kilometers inland at these locations (Ross et al. 2002). Simmons
155 and Ogden (1998) also report that many creeks that delivered fresh water to the
156 Northeastern Basin and southern Biscayne Bay are now filled in from lack of flow. As
157 part of the planning process for the creation of Everglades National Park (ENP), Beard
158 (1938) performed a wildlife reconnaissance within the proposed park boundary. He
159 identified the region between Florida City and Key Largo, east of US Highway 1, as
160 seasonal farmland. Currently, this area is dominated by dwarf mangroves (Ross et al
161 2002). Former farmland can be readily identified because the individual mangroves grow
162 in straight lines along the old furrows (Pers. Obs.). Water salinity is currently brackish to

163 marine, which would result in soil salinity levels that would prohibit successful farming
164 today. Will (1984) provided an account of the construction of the Homestead Canal to
165 Cape Sable in 1922. His photographs clearly show freshwater plant species (e.g.
166 sawgrass, (*Cladium jamaicense*); royal palm, (*Roystonea regia*); Paurotis palm, (*Paurotis*
167 *wrightii*) in areas that are currently dominated by mangrove forests. Water salinity in
168 these areas currently ranges from about 10 to 50 psu (Pers. Obs.). Other reminiscences
169 from residents of the area indicate a decline in the spatial extent of freshwater wetlands
170 bordering Florida and Biscayne bays (Anonymous 1987). Furthermore, large freshwater
171 upwellings occurred from Marco Island to Virginia Key (Tebeau 1955, Audubon 1960,
172 Craighead 1971, Anonymous 1987) including several in Florida Bay that were active as
173 late as the 1970's (McIvor et al. 1994, Gulick 1995). Tebeau (1955) presented a
174 photograph of an artesian spring on Chockoloskee Island. That such upwellings no
175 longer exist indicates that the freshwater head pressure from the Everglades has declined
176 significantly.

177

178 Coastal Mangrove Prey Base Fishes

179 Historically there were large numbers of wading birds that nested in NEFB during
180 the dry season (Powell et al. 1989, Lorenz et al. 2002). The coastal mangrove habitats
181 (Fig 1) of Taylor Slough and the C-111 are critical foraging habitat for these wading
182 birds during the dry season nesting cycle (Powell et al. 1989, Lorenz et al. 2002). These
183 habitats may have historically been important nursery habitats for juvenile game fish
184 species (Lewis et al. 1988, Rutherford et al. 1986) and they are currently important
185 foraging habitats for game fish (Odum et al. 1982, Ley et al. 1989, Ley 1992, Faunce et

186 al. 2002) especially during low water periods of the dry season. Following the
187 completion of the SDCS in 1984 (Kotun and Renshaw, this issue), roseate spoonbills,
188 (*Platylea ajaja*) nest numbers in NEFB began to steadily decline (discussed below).
189 Powell (1986) speculated that the reason for the decline was due to changes in food
190 resources related to water management practices. This hypothesis led to an extensive
191 multilevel ecological study of the relationship between hydrology and salinity in the
192 coastal mangrove habitats where these birds feed. Among the findings was that relatively
193 high salinity and highly variable salinity adversely affected primary production (Frezza et
194 al. 2007). These authors concluded that such declines in primary production would
195 adversely affect higher trophic levels. Lorenz (1999) demonstrated that prey fish
196 productivity was a function of complex interactions between water level, hydroperiod and
197 salinity. It was also found that lower, more stable salinity led to assemblages of fish
198 species that were more productive than at higher and more variable salinity (Lorenz and
199 Serafy 2006). Prey base fishes were also found to expand throughout ephemeral
200 mangrove habitat and increase their numbers throughout the wet season (Lorenz 2000)
201 and that high water levels and longer hydroperiods led to greater fish abundance at the
202 end of the wet season (Lorenz 1999, Lorenz 2000). During low water periods of the dry
203 season these fish become highly available to predators when the ephemeral wetlands dry
204 and fish become concentrated in the remaining deeper water habitats (Lorenz 2000,
205 Lorenz this issue). Fish were found to begin aggregating in the refuges when water levels
206 on the ephemeral wetlands dropped below 13 cm (Lorenz this issue) and that spoonbill
207 nesting success was dependent on water levels lower than 13 cm throughout their nesting
208 cycle (Lorenz this issue). Pulse discharges from the C-111 (for flood control purposes)

209 during the nesting cycle raised water levels above 13 cm, dispersed the prey base and
210 resulted in nest abandonment (Lorenz 2000, Lorenz this issue). These findings indicate
211 that the demonstrated operational effects of the upstream canal system include lowered
212 water levels, shortened hydroperiods, and increased salinity (Marshall et al 2008, Kotun
213 and Renshaw this issue); thus, it is clear that these operations also impacted productivity,
214 abundance and availability of prey fishes in the coastal mangrove wetlands of Florida
215 Bay.

216

217 Fisheries Species

218 Fisheries stocks in estuaries have been positively related to freshwater inflow
219 (Day et al. 1989a, Longley 1994). Likewise, diversion of flow from estuaries results in a
220 decline in fisheries stocks (Browder and Moore 1981, Day et al. 1989a). Although
221 freshwater inflows impact estuaries on multiple levels (Snedaker et al. 1977, Day et al.
222 1989b), anthropogenic changes in salinity regime in estuaries has been linked to a decline
223 in fisheries stocks (Flanagan and Hendrickson 1976, Browder and Moore 1981, Longley
224 1994). A commonly cited impact of increased salinity is disruption of nursery function in
225 estuarine systems (Snedaker et al. 1977, Browder and Moore 1981, Bradley et al. 1990,
226 Ley et al. 1999). Temporally and spatially extensive surveys of fish assemblages in the
227 wetlands north of NEFB reveal little indication that this habitat is currently a nursery for
228 fishery species (Ley et al. 1999, Lorenz 1999, Lorenz and Serafy 2006).

229 Rutherford et al. (1989) correlated spotted seatrout (*Cynoscion nebulosus*) harvest
230 in Florida Bay with rainfall in the southern Everglades two years earlier. Tilmant et al.
231 (1989a) found that red drum (*Sciaenops ocellatus*) recruitment into Florida Bay's fishery

232 increased following years with increased runoff from the Everglades. Tilmant et al.
233 (1989b) indicated that larval recruitment and juvenile survival of common snook
234 (*Centropomus undecimalis*) in Florida Bay were enhanced in years with high fresh water
235 flows from the Everglades. These three studies were based on surveys taken by ENP
236 between 1958 and 1987. A common prey item of game fish as well as supporting its own
237 fishery, pink shrimp (*Farfantepenaeus duorarum*) harvested in Dry Tortugas fishery use
238 central and western Florida Bay as a nursery area (Browder, 1985). In an examination of
239 14 years of combined harvest by quarter year, pink shrimp harvest was correlated with
240 Everglades water levels from the previous quarter (Browder 1985). Browder et al. (1999)
241 indicated that relatively high water temperature and low salinity regimes play a role in
242 whether basins in central Florida Bay contribute recruits to the fishery. Although these
243 studies examined fishery stocks for all of Florida Bay (not just the Northeastern Basin),
244 they indicate that increased runoff into Florida Bay created more favorable conditions for
245 recruitment of fishery species. Therefore, the escalating diversion of fresh water away
246 from Florida Bay starting in 1960 probably resulted in less robust fishery stocks than had
247 occurred prior to water management in the southern Everglades. Reports from fishers
248 corroborate this conclusion (Zieman et al. 1989, Gulick 1995).

249 The association between fish communities and submerged aquatic vegetation
250 (SAV) has been well documented since the late 1950's (Serafy 1992). In Florida Bay,
251 Rutherford et al. (1986) linked various game fish species to SAV type. Thayer et al.
252 (1987) and Ley (1992) characterized the fish community associated with mangrove
253 shorelines. Thayer and Chester (1989) and Sogard et al. (1989b) characterized fish
254 communities associated with various seagrass species in basin and mud bank habitats

255 respectively. Massive seagrass die-offs occurred throughout Florida Bay during the late
256 1980's and early 1990's (Robblee et al. 1991). As an example of the link between fish
257 community structure and SAV type, Matheson et al. (1999) repeated the techniques of
258 Sogard et al. (1989) at bank sites impacted by the seagrass die-off and found dramatically
259 different community types. Likewise, Thayer et al. (1999) repeated the techniques of
260 Thayer and Chester (1989) and documented both a decline in seagrass abundance and
261 changes in the fish community in basin and channel habitats within the bay.

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

273 Rutherford et al. (1986) sampled juvenile game fish throughout Florida Bay.
274 More than 80% of the juvenile snook collected were found in low salinity (mean 8.9 psu)
275 SAV environs dominated by *Chara spp.* and *Utricularia spp.* Juvenile spotted seatrout
276 were mostly (>80%) collected from grass and shoal grass beds with a mean salinity of
277 17.2 psu. Gilmore et al. (1983) found that snook depend on coastal fresh water and low

278 salinity environments for their early life history stages. Wakeman and Wohlslag (1977;
279 in Longley 1994) reported optimum metabolic salinity for juvenile spotted seatrout was
280 20 to 25 psu. Longley et al. (1994) reported that spotted seatrout density over vegetation
281 increased with salinity but decreased above 30 psu. Catch rates for snook in NEFB
282 declined from 1972 to 1984 while catch rates for spotted seatrout increased over the same
283 period (Rutherford et al. 1989). These changes may be the result of changes in dominant
284 SAV (Rutherford et al. 1986). These findings all suggest that salinity increases in the
285 Northeastern Basin due to water management have resulted in broad ecological changes.

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

301 opposite effect. These results indicate that the salinity pulses caused by water
302 management practices would be detrimental to plant, invertebrate and fish communities
303 in the Northeastern Basin.

304

305 Reptiles

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

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

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

339 Operation of the SDCS may have impacted crocodile nesting in another way.
340 Since 1984, the SDCS has operated in flood control mode (Van Lent et al. 1999).
341 Following above average rainfall events, water is pumped southward so that upstream
342 urban and agricultural lands are drained quickly. These pulse releases temporarily result
343 in higher water levels along the creek habitats in Taylor Slough and south of the C-111
344 canal (Baratta and Fennema 1994), thereby flooding nests and making eggs inviable
345 (Mazzotti 1999). Nesting sites along these creeks are desirable for crocodiles because

346 they have lower salinity and are more protected from wind and wave action than other
347 sites (Mazzotti 1989). The percentage of total nests found along creeks declined from
348 28% in the 1970's to 12% in the 1980's and 7% in the 1990's (Mazzotti 1999).

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

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

367

368 Marine Mammals

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

388 Although there are no records available for the historic use of the Northeastern
389 Basin as a foraging ground for bottlenose dolphin (*Tursiops truncatus*), recent surveys
390 revealed very little activity in this region (Torres 2009). Given the decline of common

391 prey items (as identified by Torres 2009) of dolphin in the Northeastern Basin, this
392 paucity of dolphin use may be a consequence of lack of prey items potentially associated
393 with the operation of the SDCS (see fishery species section).

394

395 Birds

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

411 Several research projects have examined the population of nesting roseate
412 spoonbills in Florida Bay. This species was nearly extirpated in the early 1900's but,
413 once afforded protection from hunting, the population recovered. The number of

414 spoonbills nesting in Florida Bay increased exponentially from the 1950's through the mid
415 1970's, reaching a peak of 1259 nests in 1978. Following the completion of the SDCS in
416 1984, nest numbers steadily declined to approximately 600-800 nests in the 1980's, 400-
417 500 in the 2000's (Bay-wide nest counts were discontinued in 1992 - 1999) and less than
418 350 since 2008 (Lorenz et al. 2002, Stone and Lorenz 2012). In NEFB, the decline was
419 even more pronounced dropping from 688 nests in 1978 to 20 nests in 2011 (Lorenz et al.
420 2002, Stone and Lorenz 2012). Lorenz et al. (2002) demonstrated that degradation of
421 foraging grounds is the most likely explanation for this decline. Lorenz et al. (2002) also
422 showed that nesting success production was 1.4 chicks per nest (c/n) prior to the SDCS
423 and 0.7 c/n following its completion (most wading bird studies consider a production rate
424 of <1.0 c/n as a failing population). Studies of prey base fishes on their primary foraging
425 grounds in NEFB indicate a reduction in habitat productivity, prey abundance and prey
426 availability concurrent with the decline in nesting success and nest numbers and that
427 water management practices have caused abandonment of nests in NEFB (detailed above
428 under prey base fishes). Recent results from a banding and tracking study found that
429 spoonbills have a high degree of fidelity to their natal habitat when they reach breeding
430 age and that they can breed at least until 19 years of age with an estimated life
431 expectancy of 25 to 30 years (JJL, unpublished data). That the NEFB nesting population
432 is largely closed to immigration or emigration, and that they are not reproducing at a high
433 enough production rate to maintain numbers enough to keep up with mortality explains
434 the steady decline in NEFB. The root cause is that water management practices have
435 reduced prey parameters such that nesting spoonbills can not access enough prey to meet
436 the energetic demands of their chicks (Lorenz et al. 2009). Lorenz et al. (2009)

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

439 The vast majority of the US great white heron population (*Ardea herodias*
440 *occidentalis*) is located in southern Florida with 65% of the population nesting in Florida
441 Bay (Powell and Bjork 1996). Great white herons are considered an estuarine species
442 that feeds almost exclusively on fish (Powell and Bjork 1996). In 1959, the number of
443 great white herons in Florida Bay was estimated to be between 800 and 900 individuals
444 (Powell et al. 1989). Intermittent surveys between 1959 and 1984 indicated that the
445 population remained fairly constant at about 900 individuals (Powell et al. 1989).
446 Hurricanes resulted in large-scale mortality in this species but the population was found
447 to be resilient and recovered quickly (Powell et al. 1989). Complete surveys have not
448 been performed since 1984, however, a three-year study of great white herons in the early
449 1980's indicated that nest production was much lower than similar records collected in
450 1923 (Powell and Powell 1986). Powell and Powell (1986) also found that birds that
451 received supplemental food from humans had similar production rates to those of 1923
452 while those that were not supplemented had much lower production. They concluded
453 that foraging habitat quality had been reduced. Powell et al. (1989) speculated that water
454 diversion upstream from Florida Bay had negatively impacted the prey base thereby
455 explaining the reduced nesting success in herons.

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

460 1985). Statewide nest numbers increased steadily from that point; in 1989 there were
461 12,310 nesting pairs (Nesbitt 1996). Over this same period the number of nests in Florida
462 Bay steadily declined (Kushlan and Frohring 1985). Ogden (1993) counted 350 nests in
463 a 1993 survey. Prior to the completion of the SDCS, pelicans commonly nested in the
464 Northeastern Basin (Ogden 1993, JC Ogden, Pers. Comm.), however surveys of nesting
465 colonies in this region from 1995 to 2012 revealed little pelican nesting activity (Pers.
466 Obs., L. Oberhofer, ENP, Pers. Comm). Furthermore, nesting throughout Florida Bay
467 has become a rarity with multi-year gaps between nesting activity (Pers. Obs.) and
468 nesting activity isolated to the extreme western portion of the bay (Pers. Obs.). Pelicans
469 feed exclusively on fish (Nesbitt 1996) and Kushlan and Frohring (1985) hypothesized
470 that the reason for the decline in nesting in Florida Bay was a reduction in prey
471 availability. Although the pelican prey base was not investigated, changes in fish
472 community structure as a result of water diversion may support their hypothesis.

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

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

494 Similar to the osprey, the southern bald eagle (*Haliaeetus leucocephalus*
495 *leucocephalus*) was federally listed as a result of environmental contaminants, but the
496 Florida Bay population was largely unaffected (Curnutt 1996, Baldwin et al. 2012).
497 Surveys of Florida Bay's nesting population of bald eagles began in 1958 (Curnutt 1991).
498 An analysis of the territoriality of eagles in Florida Bay from 1958 to the mid-1980's
499 indicated that the Bay is largely saturated and number of territories remained remarkably
500 constant (Curnutt 1991, Robertson 1993). Up to 30 territories were documented with 80-
501 100% occupancy during the period (Baldwin et al. 2012). Beginning in the mid-1980's
502 (coinciding with the completion of the SDCS) the number of occupied territories began to
503 decline reaching a low of just 50% occupancy in 2003 and 2004 (Baldwin et al. 2012).
504 Most of the abandoned territories were in NEFB; currently only one of the seven historic
505 territories in NEFB is active (ENP data, L. Oberhofer Pers. Comm.). Nests in other

506 regions of the Bay continue to be highly productive compared to other eagle population
507 around North America (Baldwin et al. 2012). Although bald eagles principally feed on
508 fish, they are opportunistic feeders (Curnutt 1996). In Florida Bay, eagles supplement
509 their diet with terrapins, a variety of birds, and carrion (Robertson 1993). Also, bald
510 eagles are well known for thieving meals from ospreys through harassment
511 (kleptoparasitism). The plasticity of the eagles diet and the opportunistic nature of
512 foraging makes the observed decline particularly alarming given that this consummate
513 generalist apparently can not successfully raise young in NEFB.

514

515 Conclusions

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

529 quality of the forage base for vertebrate species, culminating in their inability to acquire
530 enough food in the region to maintain their populations.

531

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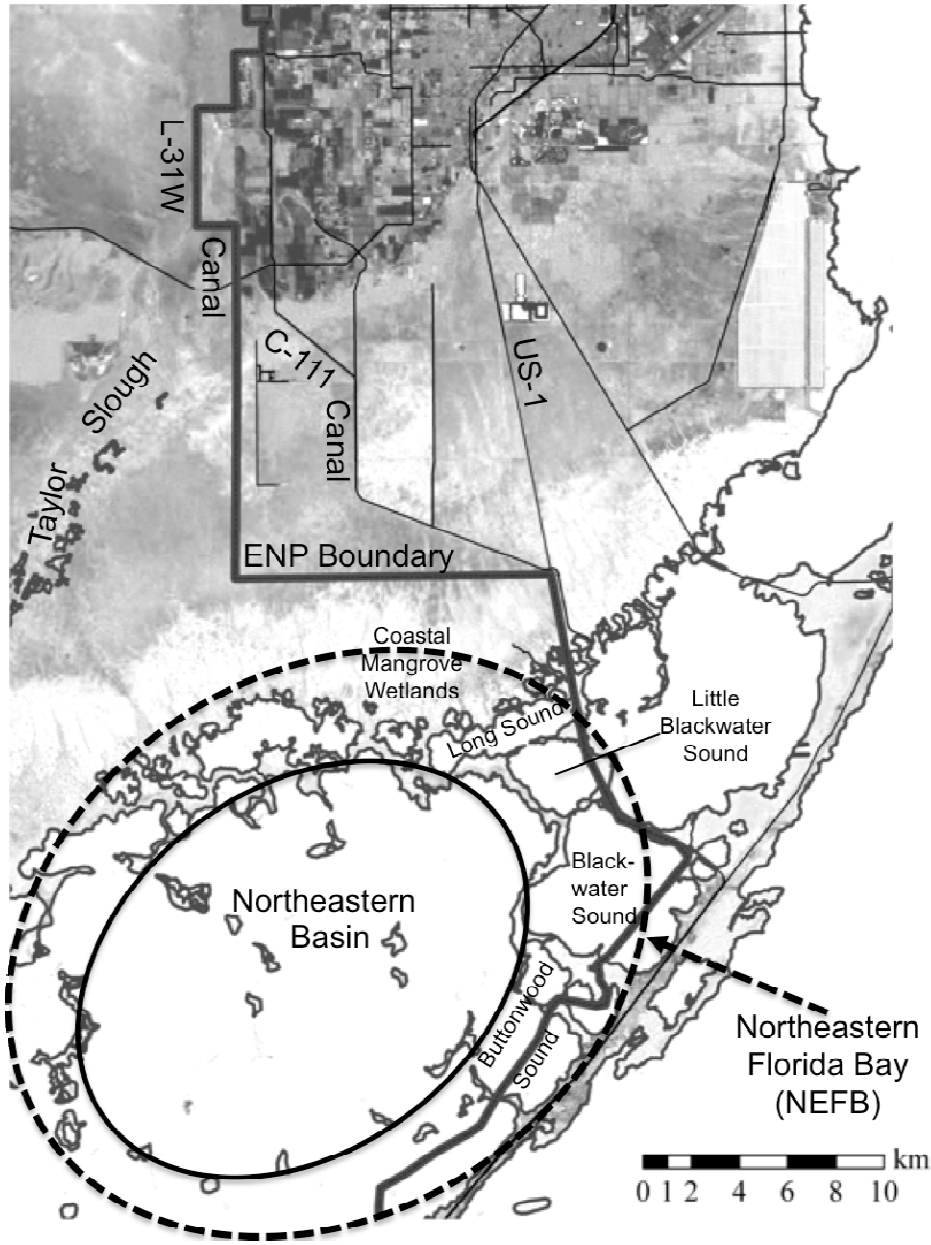
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811 Table 1 Summary of documented and inferred changes to vertebrate populations in Northeastern Florida Bay (NEFB).

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, Montague 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.



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816 Fig 1. Map of northeastern Florida Bay and adjacent Everglades wetlands. The solid line

817 defines the Northeastern Basin and the dashed line defines the Northeastern Florida Bay

818 sub-region (NEFB; as defined by Lorenz 2000).

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