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Salinity Preferences and Nursery Habitat Considerations for Blue Crab (*Callinectes sapidus*), Bull Shark (*Carcharhinus leucas*), and Smalltooth Sawfish (*Pristis pectinata*) in the Caloosahatchee Estuary

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Section 1. Objective

Recent studies have documented the use of the Caloosahatchee Estuary as nursery habitat and provide new insight on salinity preferences and habitat considerations for juvenile blue crab (*Callinectes sapidus*), bull shark (*Carcharhinus leucas*), and smalltooth sawfish (*Pristis pectinata)*. Such information may be useful in quantifying beneficial freshwater inflow and developing technical criteria associated with inflow management rules such as water reservations or minimum flows and levels. This document provides a review and synthesis of relevant technical information for these three species in the context of habitat characteristics, salinity preferences, and spatial considerations within the Caloosahatchee Estuary.

Section 2. Background

Caloosahatchee Estuary

The Caloosahatchee River, its estuary, and associated watershed are located on the lower west coast of Florida (**Figure 1**). The Caloosahatchee River (C-43 canal) runs 70 kilometers (km) from Lake Okeechobee (S-77 structure) to the Franklin Lock and Dam (S-79 structure). Separating fresh and brackish water, the Franklin Lock demarcates the existing head of the Caloosahatchee Estuary, which extends 42 km downstream to Shell Point, where it empties into San Carlos Bay in the southern portion of the greater Charlotte Harbor system. The width of the estuary is irregular, ranging from 160 meters (m) in the upper portion to 2500 m near its mouth (Scarlatos 1988). The narrow section between the Franklin Lock and Beautiful Island has a mean depth of about 6 m, while the area downstream has an average depth of 1.5 m (Scarlatos 1988). The surface area of the estuary is about 65 square km).

The Caloosahatchee River and Estuary has been highly altered from its natural state by human intervention and engineering. Historically, the Caloosahatchee River was a sinuous watercourse originating near Lake Flirt, approximately 3.2 km east of La Belle at Fort Thompson (Flaig and Capece 1998) (**Figure 1**). Beginning in the 1880s, the river was straightened and deepened, losing 76 river bends and 13.2 km of river length as a consequence (Antonini et al. 2002). The river has also been connected to Lake Okeechobee and three water control structures have been added. The first structures, S-77 and S-78, were completed in the 1930s. The last structure, S-79, was completed in 1966 to prevent saltwater intrusion and assure a freshwater supply for Lee County (Antonini et al. 2002). The river is no longer free-flowing and is operated as two pools: one at an elevation of about 3.3 m between the S-77 and S-78 structures, and the other between the S-78 and S-79 structures at an elevation of about 0.9 m. The tidally influenced Caloosahatchee Estuary has also been significantly altered (Chamberlain and Doering 1998a). Early descriptions of the tidally influenced sections of the Caloosahatchee Estuary characterize it as barely navigable, owing to extensive shoals and oyster bars (Sackett 1988). A navigation channel has been dredged and a causeway was built across the mouth of San Carlos Bay in the 1960s. Historic oyster bars upstream of Shell Point have been mined and used in the construction of roads. Currently, seven bridges and one railroad trestle connect the northern and southern shores of the Caloosahatchee Estuary.

The Caloosahatchee River is now part of the Okeechobee Waterway, allowing boat traffic between Fort Myers on the west coast and Stuart on the east coast of Florida. It provides irrigation water, drainage and potable water, as well as conveyance of regulatory releases of water from Lake Okeechobee to tide. Modifications to the Caloosahatchee River allowed development in the watershed. A network of secondary and tertiary canals now overlays the Caloosahatchee River watershed. This network provides

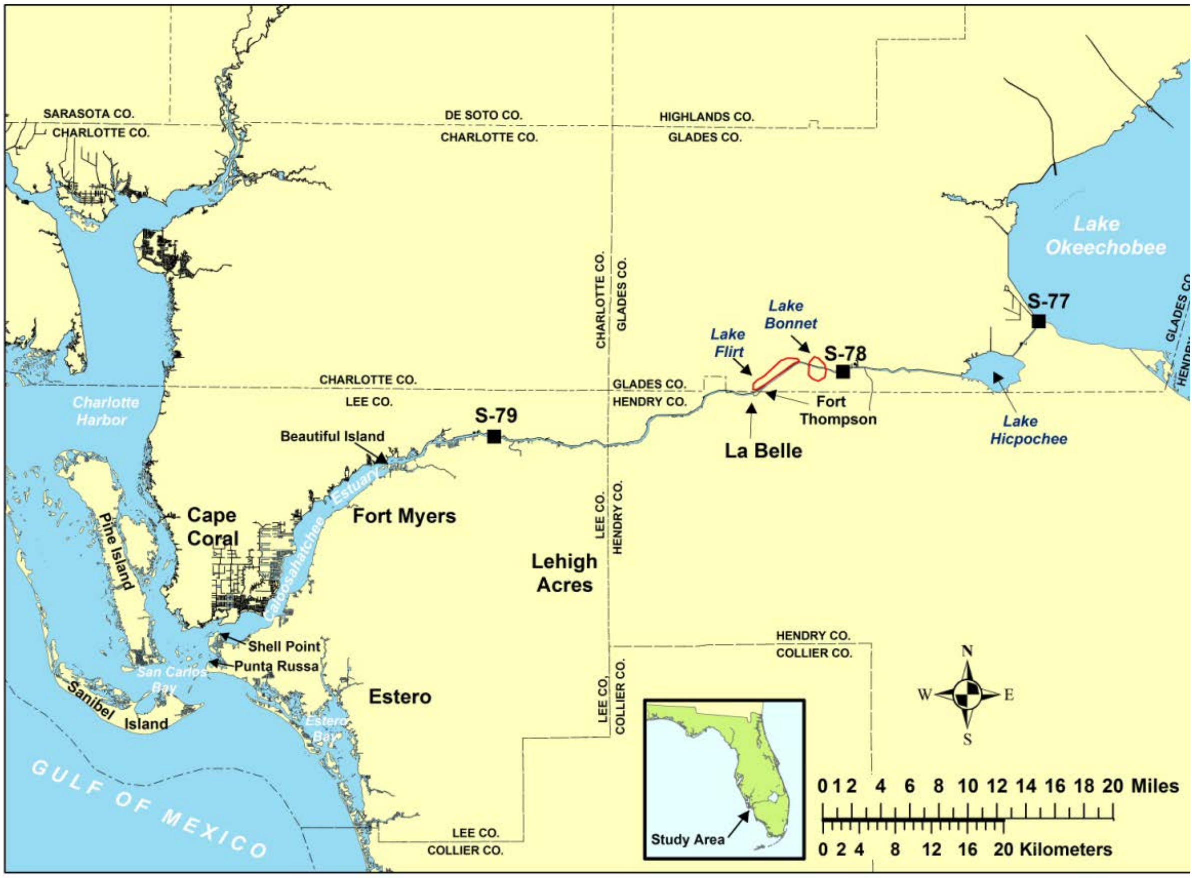

Figure 1. Caloosahatchee River and Estuary showing water control structures, connection to Lake Okeechobee, and historical headwaters at Lake Flirt and Lake Bonnet.

conveyance for both drainage, and irrigation to accommodate citrus groves, sugarcane, cattle grazing, and urban development.

The changes to the Caloosahatchee River watershed, combined with population growth, have had major effects on the Caloosahatchee Estuary. First, the delivery of freshwater downstream of the S-79 structure has been altered both by regulatory discharges from Lake Okeechobee and from alterations within the watershed. As might be expected for a watershed characterized by extensive drainage features (see Hopkinson and Vallino 1995), runoff is variable, often with very high wet season discharges and very low dry season discharges. Large volume releases of fresh water during the wet season can flush all salt water from the tidally influenced sections of the water body. By contrast, freshwater inflow at the S-79 structure can stop entirely during the dry season. Salt water intrudes to the S-79 structure, sometimes reaching a salinity of 20 (Chamberlain and Doering 1998a, 1998b). Fluctuations of this magnitude at the head and mouth of the tidally influenced portion of the system cause mortality of organisms at both ends of the salinity gradient (Doering et al. 2002).

While changes to the watershed and structural alterations along the river have altered the delivery of fresh water, other changes at the seaward end of the system such as the building of the Sanibel Causeway, which crosses the mouth of San Carlos Bay at Punta Rassa, have also influenced the system. The United States Fish and Wildlife Service predicted that this barrier would restrict exchange with the gulf, retain fresh water, and lower the salinity in Southern Charlotte Harbor (USFWS 1960). Reductions in salinity were predicted to adversely affect a flourishing bay scallop fishery, which, in fact, collapsed after the construction of the causeway. Twenty years later, the Florida Department of Natural Resources reported a significant decline in seagrass cover in deeper areas and attributed this, in part, to an increased amount of fresh water (Harris et al. 1983).

Basis for Determining Freshwater Inflow Needs in South Florida's Coastal Systems

Freshwater inflow defines the structure and function of estuarine and coastal systems. Natural variation in freshwater flow can directly impact fisheries production by regulating environmental factors that determine habitat availability for fish and invertebrates (Gillson 2011). Additionally, freshwater inflows can help prevent stratification, and carry nutrients that stimulate phytoplankton and zooplankton, enhancing the recruitment, growth, and survival of fish and invertebrates (Kostecki et al. 2010, Hoffman et al. 2007, Quinones and Montes 2001 Fisher et al. 1988). Other factors associated with freshwater inflow are also important for maintaining populations of estuarine organisms in particular fishes, which include salinity and larval/juvenile transport (Stevens et al. 2008). However, despite multiple lines of evidence describing linkages between freshwater flow and the production of estuarine and coastal fisheries, the underlying mechanisms remain poorly understood (Gillson 2011) often making it difficult to quantify or link inflow-biotic response to water management strategies that strive to maintain or provide measurable benefits to fish and wildlife.

The South Florida Water Management District has applied a combination of the valued ecosystem component (VEC) approach (USEPA 1995) and the habitat overlap approach (Browder and Moore 1981) to determine minimum freshwater inflow requirements and water reservations in coastal systems throughout South Florida (Hunt et al. 2005, SFWMD 2009a, 2009b, 2006, 2003, 2002a, 2002b, 2000). These efforts require that a link between water resource values (i.e., protection of fish and wildlife) and flow or water level be identified and quantified. The VEC approach was developed by the United States Environmental Protection Agency (USEPA 1995) as part of its National Estuary Program. A VEC can be any part of the environment that is considered important. The approach has been modified for application in coastal systems to focus on providing critical estuarine habitat. In many instances, that habitat is biological and typified by one or more prominent species. In other cases the habitat may be physical, such as an open water oligohaline zone or shallow water depth. Enhancing and maintaining the biological and physical habitats should lead to a generally healthy and diverse ecosystem. Determining appropriate freshwater inflows or describing effects related to specific quantities of freshwater inflows on the entire estuarine system is best accomplished by examining several VECs occupying different salinity zones or ranges, in combination with biota that may have other requirements (e.g., related to stationary habitats). In addition, environmental variables that vary with freshwater inflow, such as temperature and light conditions, may also be important to consider when using estuarine habitat as a VEC or indicator of estuarine condition (Hunt and Doering 2005).

The concept of static and dynamic habitat overlap (Browder and Moore 1981) is based on the ideas of Gunter (1961) that (1) estuaries serve a nursery function and (2) salinity determines the distribution of species and/or different life stages of a species within an estuary. In addition, the concept recognizes the importance of appropriate physical or static habitat to the nursery function and ability of the estuary to support diverse and abundant faunal populations. Freshwater inflow positions favorable salinities relative to important stationary habitat factors such as shoreline, water depth, and bottom type (Browder and Moore 1981). Because different organisms occupy different positions along the estuarine salinity gradient (e.g., Bulger et al. 1993), changes to the salinity gradient, such as compression or truncation resulting from structural alterations, may impact nursery function and result in reduction in diversity and abundance of fish and wildlife.

In the Caloosahatchee Estuary, static habitat-forming species found throughout the length of the estuary include tape grass (*Vallisneria americana*) in the upper, low salinity region of the estuary, eastern oysters (*Crassostrea virginica*) in the lower, mesohaline region of the estuary, and seagrasses—turtle grass (*Thalassia testudinum*) and shoal grass (*Halodule wrightii*)—in the more marine portion of the system in San Carlos Bay. This spatial distribution along the longitudinal axis is driven largely by salinity tolerances associated with each species. The salinity tolerance of tape grass is used to identify minimum freshwater inflows that will maintain grass bed habitat and ensure a low salinity region in the upper estuary (SFWMD 2003, 2000). In addition to these biotic habitat-forming species, biogenic shoreline or island features (e.g., mangroves) and a variety of important physical habitat features such as shallow water depths, small creeks, and canal systems can also be found along the length of the estuary. The physical habitat becomes limited in the uppermost part of the estuary near the S-79 structure where the system is deep and narrow.

Utilization of Estuaries as Nursery Habitat

Many organisms depend on estuaries during part of their life cycle (Day et al. 1989, Gunter 1961). One of the key ecological or resource functions attributed to estuaries is their role as nursery areas for larval and juvenile stages of many marine species including commercially important fish and shellfish (Rozas and Hackney 1984, 1983, Gunter 1961). As much as 90 percent of the annual fisheries value for the Gulf of Mexico fisheries can be attributed to estuarine-dependent species (Seaman 1988).

Observations and research often link nursery area utilization in coastal ecosystems to salinity ranges or zones. Fauna using the estuary are thought to recruit to their preferred salinity (or habitat) zones. Motile animals may move position with their preferred salinity zones in response to freshwater inflows and tidal influences. All organisms within an estuary must find areas with acceptable combinations of both salinity and habitat type. Studies worldwide indicate that the oligohaline and mesohaline zones of estuaries (i.e., with salinities in the range 0–17) are utilized by larvae and juveniles of estuarine dependent species (Day et al. 1989). Areas with low salinities are considered critical to the life histories of many organisms (Holmes et al. 2000, Hughes et al. 2000) and offer habitat to a wide variety of adult and juvenile freshwater, estuarine, and marine fishes (Peterson and Ross 1991, Odum et al. 1988, Rozas and Hackney 1983). Some species require low salinity to complete their development. For example, larvae of the inland silverside *(Menidia beryllina)* do not survive past the yolk-sac stage at salinity of 17 but show no adverse effects at salinity of 8 (Patillo et al. 1995). Areas of high productivity are often associated with low salinity areas within partially mixed estuaries (see discussion in SFWMD 2009b) and have been used to establish the basis for a water reservation in the St. Lucie River, Florida (SFWMD 2009b).

There are a number of factors along with salinity conditions that contribute to the utilization of estuaries as nursery areas. For example, estuaries are thought to be good nurseries because they provide an increased food supply and lower predation pressure. The latter is thought to arise both from higher turbidity, inhibiting predators that hunt by sight, and low salinities that predators cannot tolerate (Drinkwater and Frank 1994). Suitable habitat is also an important variable and may be especially important for some species as it can offer protection, thereby decreasing predation risk. Habitat can be both biotic (e.g., submerged aquatic vegetation [SAV] and oyster) and physical (e.g., shallow depth, structural features, and geomorphological features). In tidal rivers, river backwaters (e.g., oxbows, embayments, and smaller tributaries) may also provide habitat for different species than those that utilize the main stem of the river. Numerous abiotic (e.g., salinity, water depth, and tidal regime), biotic (e.g., larval supply, food availability, and predation) or landscape-level factors (e.g., spatial patterns and relative location to other habitat) can create site specific variation and influence the nursery value of habitats for a species (Beck et al. 2001). In estuarine environments, salinity is often cited as a key or integrating factor influencing habitat utilization. For example, the densities of many species within marshes are highly dependent on salinity (Minello 1999). Salinity can further affect animals that utilize the habitat through loss or modification of critical habitat (e.g., fragmentation or decreased bed size of SAV) that results in higher mortality from predation, lower recruitment, and a decline in number of species (Patillo et al. 1995).

Recent research efforts have been undertaken to document and gain a better understanding of utilization of the Caloosahatchee Estuary by juveniles of different species. There are several species known to utilize this system as a nursery area including blue crab, bull sharks and the federally listed endangered small tooth sawfish. For the sawfish, the Caloosahatchee Estuary up to the S-79 structure is designated as critical habitat as part of the Endangered Species Act (NMFS 2009a).

Section 3. Salinity Preferences and Nursery Habitat Characteristics

Blue Crab

The blue crab is an estuarine-dependent macroinvertebrate that supports valuable recreational and commercial fisheries along the Atlantic and Gulf coasts (Guillory 2000, Mazzotti et al. 2006). Blue crab is common in the crab trap fishery in the Caloosahatchee Estuary, historically has had large and consistent landings within the estuary (Mazotti et al. 2006), and is classified as “highly abundant” based on the National Oceanic and Atmospheric Administration’s Estuarine Living Marine Resources Program (Nelson 1992).

The life history of the blue crab involves a complex cycle of planktonic, nektonic, and benthic stages that occur throughout both estuarine and nearshore marine habitats (Perry and McIlwain 1986, Mazotti et. al. 2006). Movements of blue crab within estuaries are related to life cycle stages, seasons, and environmental conditions. Because the blue crab occupies habitats throughout the coastal ecosystem during different parts of its life cycle, maintenance of the entire estuarine system in a condition suitable for continued production is deemed important (Perry and McIlwain 1986). Factors affecting distribution and survival include bottom type, food availability, available shelter, water temperature, and salinity. Both young and adult blue crabs occur in estuarine waters throughout the year and serve as an important prey species for a variety of birds as well as spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), croaker, gars, sheepshead (*Archosargus probatecephalus*), and catfish. Blue crabs feed on a variety of crustaceans, mollusks, fish, detritus, and other blue crabs.

A positive link between river discharge and blue crab recruitment and/or commercial harvest has been identified in several areas including Louisiana, Texas, and Florida (More 1969, Wilber 1994, Guillory 2000) suggesting that lower salinities may be beneficial to the blue crab. There is a differential distribution of adult male and female crabs in relation to salinity. Females are migratory and move alongshore, offshore, and to the upper estuary in association with mating, gonadal maturation, and spawning. Mating occurs in brackish areas of the upper estuary and, in Florida, peaks from May through October when water temperatures exceed 22 degrees Celsius (Mazzotti et al. 2006). While females typically return to higher salinity waters of the lower estuary and adjacent marine areas after mating, adult males tend to remain in the low salinity waters (Perry and McIlwain 1986 and references contained within, Mazzotti et al. 2006). The greatest number of molting males can be found at temperatures between 16 and 20 degrees Celsius in the salinity range 11–15 (Mazzotti et al. 2006). In South Florida coastal waters, this would suggest maintaining suitable estuarine areas with this relatively low salinity range during the winter dry season would be beneficial to the blue crab.

Although juvenile crabs occur over a broad range of salinities, they are most abundant in low to intermediate salinities characteristic of middle and upper estuarine waters (Perry and McIlwain 1986). In the Caloosahatchee Estuary, peak recruitment of juvenile crabs (40 millimeter carapace width) occurs during the dry season from November to April. Highest catches of these crabs occurred at salinities in the 0.5–5 range (Stevens et al. 2008).

Beds of SAV are important nursery habitat in some areas, providing refuge from predation and the potential for higher growth rates (Posey et al. 2005). In low salinity areas of Mobile Bay, Alabama, Heck et al. (2001) recorded juvenile blue crab in tape grass beds believed to have a significant nursery function. Similarly, tape grass beds within the shoals of the St. Johns River, Florida are also reported to be an important habitat for juvenile blue crabs (Tagatz 1968). Rozas and Minello (2006) examined the pattern and size distribution for blue crabs within Barataria Bay, Louisiana among habitat types, which included tape grass beds, emergent vegetation and nonvegetated sites. The blue crabs were 8 and 10 times more abundant at tape grass sites than nonvegetated sites in the spring and fall, respectively. The largest blue crabs were found at emergent sites, intermediate size crabs at tape grass sites, and smallest crabs at nonvegetated sites. The authors indicate this size distribution among the habitat types is consistent with initial settlement in tape grass as small juveniles and later emergent vegetation as larger juveniles. Separate position in the estuary of smaller crabs and larger juveniles is also apparent in relation to salinity. In Louisiana estuaries, Daud (1979) found that at the 5–10 millimeter stage, juvenile blue crabs were more abundant in the brackish to saline areas and Guillory (2000) noted that larger juvenile blue crabs seem to prefer low to intermediate salinities characteristic of middle and upper estuarine waters. Posey et al. (2005) also notes that small juveniles may be more abundant in oligohaline to upper mesohaline areas with unstructured habitat. Since blue crab are known to prey on each other (Perry and McIlwain 1986), estuaries that allow for both spatial distribution of different size classes and provide a variety of suitable and productive habitats (e.g., SAV, emergent vegetation, and oysters with ample available food sources) are important aspects for protection of suitable nursery function and continued production for blue crab fisheries.

Bull Shark

Bull sharks are cartilaginous fish in the subclass Elasmobranchii, which includes sharks, rays, and skates. The bull shark is one of the most common large shark species in Florida's coastal waters (Wiley and Simpfendorfer 2007) and considered a top-level or apex predator**.** Bull sharks are found worldwide in shallow subtropical and tropical coastal marine, estuarine, and some fresh waters. Estuarine environments are believed to provide young bull sharks protection from predation and abundant food sources that promote high survival rates and rapid growth (see references contained in Simfendorfer et al. 2005).

Several studies have documented that the Caloosahatchee Estuary is utilized as bull shark nursery area (Ortega et al. 2009, Heupel and Simpfendorfer 2008, Simpfendorfer et al. 2005). A population survey was conducted from 2001 to 2003 in the Charlotte Harbor ecosystem including the Caloosahatchee

Estuary, San Carlos Bay, and Pine Island Sound. Simpfendorfer et al. (2005) found that neonates and young of the year (less than I year old, 68–127 centimeters total length) utilize the Caloosahatchee Estuary as a nursery, while larger age classes were found in nearby San Carlos Bay (1–3 years old, 89–112 centimeters total length) and Pine Island Sound (1–10 years old, 91–189 centimeters total length). The highest utilization within the Caloosahatchee Estuary was found in the first year of life (Simpfendorfer et al. 2005).

Studies have confirmed that salinity was an important physical driver in determining the movement and distribution of young bull sharks (less than 1 year) in the Caloosahatchee Estuary, with preferred salinity conditions ranging from 7 to 17 (Ortega et al. 2009, Heupel and Simpfendorfer 2008, Simpfendorfer et al. 2005). Significant correlations between bull shark presence and salinity have been reported in the Caloosahatchee Estuary (Ortega et al. 2009, Heupel and Simpfendorfer 2008, Simpfendorfer et al. 2005). Simpfendorfer et al. (2005) showed that while bull sharks are tolerant of a wide range of environmental conditions, they had a preference for specific salinity and temperature conditions. Neonates and juveniles (2 year olds) were found to be especially prevalent in the Caloosahatchee Estuary. High catch rates for the youngest individuals (less than 1 year old) were significantly correlated with temperatures and salinity, preferring warm temperatures (greater than 29 degrees Celsius) and salinities in the range 7–17.5. Additional studies showed that juveniles (2 year olds) remained in salinities 7–20, and avoided areas with salinities outside this range (Heupel and Simpfendorfer 2008). Although not tested, Simpfendorfer et al. (2005) speculated that one reason the young bull sharks stay in the Caloosahatchee Estuary is to minimize energy costs associated with osmoregulation due to their small size and large surface-to-volume ratio relative to adult bull sharks that can tolerate salinities ranging from marine to fresh water. Thus in addition to protection from predators, estuarine waters also may provide an environment that favors metabolic efficiency for young sharks while growing to the next age class.

In recent years, studies have utilized acoustic tagging and telemetry to better understand the movement of young bull sharks in the Caloosahatchee Estuary (Heupel et al. 2010, Ortega et al. 2009, Heupel and Simpfendorfer 2008). These studies further support the earlier work that salinity was a key factor in determining movement of bull sharks in the Caloosahatchee Estuary. Neonates and young of the year (less than 1 year old) were found to utilize the entire 27 km of the lower Caloosahatchee Estuary from the S-79 structure to the mouth (Heupel et al. 2010). The mean monthly home ranges were found to be 0.9–5.6 km, indicating that sharks were mobile within the estuarine waters, seeking out preferred physical, chemical, and biological conditions. They moved upstream during the dry season and downstream during the wet season indicating a movement related to freshwater flow and estuarine salinity (Heupel et al. 2010).

Although identified as a key physical variable, the movement of bull sharks in the Caloosahatchee Estuary is not solely determined by salinity (Heupel et al. 2010, Ortega et al. 2009, Heupel and Simpfendorfer 2008, Simpfendorfer et al. 2005). The availability of prey species for bull sharks may also be an important secondary consideration (Huepel and Simpfendorfer 2008). The estuary size class partitioning within the Charlotte Harbor ecosystem (i.e., placing the youngest individuals in the estuary) noted by Simpfendorfer et al. (2005) may be driven by the availability of food and suitable habitats to hide from predators, some of which may be older bull sharks. Juveniles have been reported to cannibalize young of the year in the Indian River Lagoon (Nelson et al. 1984 as cited in Simpfendorfer et al. 2005). Simpfendorfer et al. (2005) observed distinct habitat partitioning within Southwest Florida waters with neonate and young of the year individuals occupying different habitats from older juveniles. In this study, salinity was an important factor, with younger sharks occupying mesohaline regions and older juveniles utilizing the more saline polyhaline regions. Estuaries possessing gentle salinity gradients that change gradually over space may minimize overlap of the two size classes and facilitate habitat partitioning. Thus, estuaries with an adequate spatial expanse of the salinity gradient may promote higher survival of younger juveniles and increase bull shark nursery function. Additionally, the presence of small tributaries (e.g., creeks or canals) or areas with abundant structured habitat where the smaller size class may hide with limited access to larger predators would also be beneficial.

Smalltooth Sawfish

Smalltooth sawfish are cartilaginous fish in the subclass Elasmobranchii. Historically, sawfish were common in Florida's coastal waters. However, populations diminished during the second half of the twentieth century due to fishing pressure and habitat loss (Simfendorfer 2006). The smalltooth sawfish was listed as endangered by the National Marine Fisheries Service in 2003 and is protected by the Endangered Species Act (NMFS 2003). The South Florida Water Management District completed a biological assessment for the Comprehensive Everglades Restoration Plan Caloosahatchee River (C-43) West Basin Reservoir Project (see http://www.evergladesplan.org/pm/projects) as part of the requirements of the Endangered Species Act, which states that the sawfish could "benefit from indirect project impacts which include salinity regime improvements to the downstream Caloosahatchee Estuary" (Scheda Ecological Associates 2006). In January 2009, the National Marine Fisheries Service issued the Smalltooth Sawfish Recovery Plan under Section 4 of the Endangered Species Act. It describes actions to reduce threats, restore habitats, and generally increase abundance of the smalltooth sawfish (NMFS 2009b). In addition, the recovery plan provides delisting guidelines and identifies critical habitat areas. One of the objectives of the recovery plan is the protection and/or restoration of habitats for the juveniles occurring in estuarine and nearshore coastal waters. Later that year, the National Marine Fisheries Service designated 840,000 acres of coastal and estuarine waters as critical habitat for the smalltooth sawfish, which includes the Charlotte Harbor Estuary, the Caloosahatchee up to the S-79 structure, the Ten Thousand Islands area, and Florida Bay (NMFS 2009a).

Population surveys have been conducted in the Caloosahatchee Estuary since 2000 using a variety of sampling gear (i.e., haul seine, long line, and gill net), acoustic surveys, and angler reporting. The Mote Marine Laboratory and the Florida Fish and Wildlife Conservation Commission perform monitoring and research on the smalltooth sawfish in Florida, and have recently compiled a summary of data on abundance and distribution (Poulakis et al. 2010). Monitoring and tracking efforts in combination with by-catch data indicate that the smalltooth sawfish have used the Caloosahatchee Estuary as a nursery area for more than 20 years (Poulakis et al. 2010, Seitz and Poulakis 2002) and remain within estuarine areas of the Caloosahatchee for most or all of the first several years of life (Simfendorfer et at. 2011). The relatively long juvenile stage and high site fidelity (they stay within the Caloosahatchee River) associated with the sawfish make existing nursery areas particularly valuable (NMFS 2009a). While adults and older juvenile smalltooth sawfish (5–10 years old) tolerate marine conditions, juveniles less than 5 years old prefer shallow water (depth less than 1 meter) and estuarine conditions to avoid marine predators such as sharks (Simpfendorfer et al. 2008). The S-79 structure serves as an upstream barrier for the smalltooth sawfish in the Caloosahatchee Estuary.

Several studies have been initiated within the Charlotte Harbor system including the Caloosahatchee Estuary, which incorporated the review of documented encounters and tracking combined with in situ environmental measurements. In one study, 40 juvenile fish, collected as part of the 2004–2009 population surveys, were fitted with acoustic tags and tracked for up to 473 days (Poulakis et al. 2010). Tagged fish followed a pattern related to salinity and time of day. Sawfish in the Caloosahatchee Estuary spent 61 percent of the time in canals, moving into canal systems during the day and then returned to the river at night, a behavior possibly associated with reducing the likelihood of encountering predators. In addition, climate extremes for two wet years (2005 and 2006) and one dry year (2007) provided evidence of the movement of juvenile fish with freshwater flow with juvenile sawfish movement up and down the estuary reported with different inflows—moving upstream during dry periods and moving downstream during wet periods.

The preference for a specific salinity range in the Caloosahatchee Estuary has also been recently examined statistically (Simpfendorfer et al. 2011). The locations of tagged fish were regressed with temperature and salinity data collected at the Fort Myers Bridge and with freshwater flow data collected at the S-79 structure. This evaluation shows that juvenile sawfish had an affinity for salinities between 18 and 24. Interestingly, separate investigations within the Caloosahatchee Estuary determined that bull sharks had an affinity for salinities between 7 and 20 (Heupal and Simpfendorfer 2008, Simfendorfer et al. 2005). Simfendorfer et al. (2011) suggests that this difference in salinity range between the two species may reduce predation on juvenile sawfish by facilitating a spatial separation. In the Caloosahatchee Estuary, response to changes in salinity was found to differ among individuals of different ages for sawfish (Simpfendorfer et al. 2011). Individuals approaching 1 year (100–140 centimeters) were most mobile, and moved upriver to the lowest salinity levels. The exact reason for this sensitivity was not specifically determined in this study, but is believed to be related to the energetic costs of osmoregulation or movement of preferred prey in response to salinity change. The youngest, more vulnerable individuals (neonates) did not demonstrate this level of sensitivity, which may have been due to an increased energetic cost of osmoregulation. Fine-scale acoustic tracking has demonstrated that the neonates occupy small activity spaces in very shallow habitats, likely to avoid predation, thus employing a different survival strategy (Simfendorfer et al. 2011). For juvenile sawfish, estuarine areas containing very shallow depths (less than 1 m) may be a critical survival factor due to the protection provided from large predators, with ontogenetic changes in habitat use indicated (Simfendorfer et al. 2011).

Section 4. Summary of Nursery Habitat Considerations

Habitat Availability

The availability of estuarine habitats that provide young and juvenile organisms with food sources and/or refuge from predation are widely recognized as valuable and contributing factors to successful nursery function. In combination with the presence of suitable habitat providing these features, suitable overlapping salinity conditions are often indicated. Both biotic and physical habitat provide functional nursery conditions within the Caloosahatchee Estuary for blue crabs, bull sharks, and sawfish. For example, several studies have shown that tape grass beds serve as habitat for young blue crab (Rozas and Minello 2006, Heck et al. 2001, Tagatz 1968). Further, the highest catches of juvenile blue crab in the Caloosahatchee Estuary are indicated at salinities in the 0.5–5 range, with peak recruitment from November–April (Stevens et al. 2008). Thus, freshwater inflows that provide year-round salinity conditions supporting sustainable tape grass beds in the upper Caloosahatchee Estuary (salinities in the range 0–10), would also benefit the blue crab by providing tape grass as nursery habitat. Another example illustrating the importance of a specific habitat use is suggested for the youngest juvenile sawfish (neonates), which occupy small activity spaces in very shallow habitats (Simfendorfer et al. 2011). Interestingly, while larger individuals approaching 1 year indicated movement in response to salinity changes in the estuary, the neonates that typically occupied very shallow spaces did not show the same response, apparently preferring to stay in the same area. Thus for juvenile sawfish, estuarine areas containing very shallow depths (less than 1 m) may be a critical survival factor, possibly due to the protection offered from large predators that cannot access the shallow habitat (Simfendorfer et al. 2011). Within the Caloosahatchee Estuary, low flow resulting in salinity conditions that lead to occurrence of the older juvenile sawfish in the upper estuary, where the river narrows and shallow habitat is very limited, may increase exposure and risk of predation (Simfendorfer et al. 2011).

Habitat Partitioning

In addition to availability of nursery habitat, evidence supports the need to have space or area containing estuarine conditions that provide adequate spatial separation or partitioning between different biota. This may include spatial separation between species (i.e., predator and prey) or within different age classes of the same species. Examples of the latter include the bull shark and blue crab as described in Section 3. Variation in salinity conditions in response to natural seasonal variation in freshwater inflow is expected in estuarine systems. Thus, many mobile species that utilize estuaries as nursery areas can tolerate some degree of salinity variability within a tolerance range, often associated with duration and frequency of exposure. Mobile species may also move within the estuary in response to freshwater inflow to seek preferred salinity ranges and/or habitat types. However, when the position of specific salinity conditions is altered to the extent that stationary habitat becomes limited, competition for space and available habitat may result.

In structurally modified systems such as the Caloosahatchee Estuary, changes in salinity patterns can result from altered flow patterns that impact the timing, frequency, magnitude, and/or duration of normal flows. During the dry season, the combination of limited rainfall, lack of water storage in the basin, and withdrawals to meet human demands for irrigation and potable water often results in periods of no freshwater discharge to the Caloosahatchee Estuary. The S-79 structure was built in part to act as a salinity barrier to prevent saltwater intrusion and protect freshwater supplies. As anticipated in the design and operation of this structure, salt water may intrude all the way up to the existing head of the estuary at the S-79 structure during the dry season, eliminating low salinity ranges and threatening species that require low salinity to complete their life cycle (SFWMD 2003, Doering et al. 2002, Chamberlain and Doering 1998a, 1998b). The resultant salinity gradient is truncated and the estuarine area compressed. Unable to move upstream, many nursery residents, including planktonic forms (see Tolley et al. 2010) may become impinged at the S-79 structure and subjected to increased competition for food, increased predation, and stress induced by high salinity and limited space. The risk to the organisms that rely on the estuary as a nursery area and resultant loss of nursery function for the larger coastal ecosystem increases as the frequency and magnitude of such changes increase.

In the Caloosahatchee Estuary, both the location of the S-79 structure, and the funnel shape of the estuary itself, can result in habitat compression. Movement of biota upstream into the narrow and deeper portion of the upper estuary in response to salinity intrusion may result in leaving areas containing preferred stationary habitats. In addition, competition with other organisms for limited upstream habitat as well as food sources is likely. The overall reduction in available estuarine area or movement to a more compressed space within the estuary may also make some species more vulnerable to predation by other, larger nursery residents.

As presented in preceding sections, bull shark and small tooth sawfish represent specific examples of juvenile apex predators that reside in and utilize the Caloosahatchee Estuary as a nursery and illustrate habitat partitioning. Research on juvenile bull sharks indicates an affinity for salinities between 7 and 20 within the Caloosahatchee Estuary (Heupel and Simpfendorfer 2008, Simfendorfer et al. 2005), while juvenile sawfish prefer slightly higher salinity conditions between 18 and 24 (Simfendorfer et al. 2011).

This difference in salinity range may reduce predation on the endangered juvenile sawfish by the bull shark in the Caloosahatchee Estuary system by facilitating a separation between these two species (Simfendorfer et al. 2011). Thus, for the sawfish, maintaining a year-round estuarine gradient containing suitable shallow area that allows some partition from the larger juvenile bull shark would benefit the survival and recovery of this endangered species.

Partitioning of estuarine nursery areas is also important for different age classes of the same species. Examples include blue crabs and bull sharks, which are known to cannibalize younger individuals of their own species when occupying the same space. Several lines of research indicate size class separation based on both habitat and salinity for juvenile blue crab (Rozasa and Minello 2006, Posey et al. 2005, Guillory 2000, Daud 1979). Providing both an array of salinities and a variety of suitable and productive habitats (e.g., SAV, emergent vegetation, and oysters with ample available food sources) are important for protection of suitable blue crab nursery and sustainable crab fisheries. Similarly for the bull shark, research indicates spatial partitioning between the age classes based on salinity (Simfendorfer et al. 2005). Providing year-round flows that support salinities within the Caloosahatchee Estuary in the preferred range (7–20) for young bull sharks (less than 1 year old) would maintain the spatial separation from older individuals utilizing San Carlos Bay and the Pine Island Sound area and protect the bull shark nursery in the Caloosahatchee Estuary.

Section 5. Conclusions and Recommendations

Research documenting the use of estuaries as nursery habitat provides new insights highlighting both the importance of these areas and need for consideration of both available habitat and habitat partitioning. This information is relevant to coastal ecosystem management and may be used to aid in establishing and quantifying freshwater inflow needs in coastal systems. The review presented in Section 3 demonstrates that the Caloosahatchee Estuary is used as a nursery area for blue crab, bull sharks, and the smalltooth sawfish. The compilation of this information helps provide key information linking nursery area utilization with salinity conditions, as well as spatial and habitat requirements for these species. The information could be used within the existing framework of the VEC and habitat overlap approaches used by the South Florida Water Management District to develop inflow requirements within its minimum flows and levels and water reservation programs and for restoration targets within the Caloosahatchee Estuary as well as other coastal systems.

Key findings within this context for each species are highlighted below.

Blue Crab

- The Caloosahatchee Estuary is utilized as a nursery area for blue crab.
- Juveniles recruit during the dry season and highest catches are in low salinity (0.5–5) (Stevens et al. 2008). Studies have shown that tape grass beds serve as habitat for young blue crab (Rozas and Minello 2006, Heck et al. 2001, Tagatz 1968). Thus, freshwater inflows that provide salinity conditions supportive of sustainable tape grass beds in the upper estuary (0–10) would also be beneficial to the blue crab.
- Because adult male and juvenile blue crab stay within estuarine habitat, maintaining adequate areas year-round within the Caloosahatchee Estuary that provide for a range of estuarine salinity conditions is needed to maintain productive blue crab population.

- At relatively low temperatures, characteristic of the winter dry season months in the Caloosahatchee Estuary, maintaining a salinity range between 11 and 15 is also indicated to support adult male molting (Mazzotti et al. 2006).
- Salinity conditions that allow size class separation and spatial separation between the small and large juvenile blue crab is indicated to avoid cannibalism throughout the year.
- Salinity conditions that allow spatial separation between adult males and juveniles is indicated to provide for adequate prey sources (i.e., food availability) throughout the year.
- Because blue crab can occupy a variety of habitats within the coastal ecosystem, maintenance of the entire estuarine system in a condition suitable for continued production is deemed important (Perry and McIlwain 1986).

Bull Shark

- The Caloosahatchee Estuary is utilized as a nursery area for bull sharks.
- In order to continue to serve as nursery habitat, maintaining year-round areas containing salinities between 7 and 20 for young and juveniles is indicated. Because bull shark stay in the Caloosahatchee Estuary during the first few years of life, maintaining adequate areas year-round that provide for this full range of salinity conditions was recommended in several references (Heupel et al. 2010, Heupel and Simpfendorfer 2008, Ortega et al. 2009, Simpfendorfer et al. 2005).
- Maintaining suitable conditions that provide both ample prey sources (i.e., food availability) and a salinity gradient sufficient for young and juvenile size class separation is also indicated to ensure adequate survival rates for all young and juvenile class sizes.

Smalltooth Sawfish

- The Caloosahatchee Estuary up to the S-79 structure is designated critical nursery area for the endangered smalltooth sawfish (NMFS 2009a).
- The relatively long juvenile stage (lasting several years), coupled with the high site fidelity—they stay in the same nursery area throughout their juvenile years—make existing nursery areas particularly valuable (NMFS 2009b).
- Neonates and juveniles (less than 3 years old) are highly mobile within the Caloosahatchee Estuary (Simpfendorfer et al. 2011), enabling them to seek preferred salinity and habitat.
- In the Caloosahatchee Estuary, maintaining suitable nursery habitat throughout the year will benefit the survival and help provide protection of this species.
- The combination of key conditions needed for nursery function throughout the year include maintaining areas of salinities in the preferred range that overlap with shallow areas and other physical habitat that provides refuge from predation.
- In addition to maintaining a year-round estuarine salinity gradient encompassing suitable habitat, maintaining adequate space that does not overlap with areas containing larger predators such as bull sharks is also indicated to allow adequate habitat partitioning and reduce the risk of predation (i.e., promotes low mortality rates of the young sawfish).

Some additional steps to apply this information in the development of inflow targets are recommended. Future analyses utilizing a geographic information system-based evaluation that contained the following information if available could be applied:

- Physical habitat along the length of the estuary, such as water depth, creeks, canal inputs, and other known geomorphological and physical features (RECOVER 2013)
- Location of shoreline and backwater habitats
- Biotic habitat information such as SAV and oyster beds (RECOVER 2013)
- Salinity-flow information (observational data or modeling)
- Locations of known utilization (i.e., sightings or reports) for each species
- Additional spatial information such as location or distribution of food sources

Evaluations could be made for multiple species that allow testing of different flows or ranges of flows combined with overlays of the above information for determinations of (1) amount of potential nursery area available under different flows and (2) locations of habitat with respect to salinity requirements. Area that overlaps with predators, amount of suitable stationary habitat available, food sources and other factors could be evaluated and compared under different flow scenarios. Flows that compress estuarine area and impact size class separation could be tested and evaluated. Preferred flow envelopes or thresholds could be developed using this multi-species approach and used in combination with existing habitat-based VEC information such as SAV and oysters.

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