Development of a Decision Support Tool to Prioritize Estuarine and Marine Habitats for Restoration and Enhancement

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Abstract: Marine and estuarine habitats of Florida are biologically productive and economically valuable. They provide a diversity of species with spawning grounds, nurseries, shelter, and food, augmenting fisheries production and supporting a vibrant natural resources-based economy. Additionally, these habitats shelter coastal areas from storm damage, maintain water quality, produce oxygen, and sequester carbon. Although substantial conservation efforts have been implemented to conserve estuarine and marine habitats, these resources continue to be threatened by shoreline development, altered hydrology, pollution, dredging, mosquito-control impoundments, and climate change. Because of rapid human population expansion, economic growth, and related development pressures, Florida faces the challenge of balancing human requirements with those of natural resource conservation. To inform conservation of these resources, a geographic-information-system-based process was used to develop a multi-criteria decision analysis tool and prioritize those resources for actions related to habitat restoration and enhancement. Estuarine and marine habitats were identified, mapped, and quantified based on a suite of parameters representing their socioeconomic, fish, and wildlife values, and the need, feasibility, and potential for habitat restoration. A total of 283 sub-watersheds (National Hydrology Dataset HUC 12) containing 1,061,864 ha of estuarine habitat and 9244 5-km^2 gridded cells of marine habitat were prioritized for conservation. This prioritization process provided scientifically based regional and statewide maps directing conservation efforts for estuarine and marine habitat into the foreseeable future. The spatial products from this evaluation can be combined with those for freshwater habitats in Florida to allow for landscape-scale management of aquatic resources across ecosystems while sequencing and connecting upstream and downstream projects to achieve optimal desired outcomes.

Key words: habitat, landscape conservation, conservation prioritization

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Marine and estuarine environments contain some of the most biologically productive and economically valuable fish and wildlife habitats in Florida (Kautz et al. 1998, Granek et al. 2010, Whitney et al. 2015), including complex intertidal habitats, extensive soft-bottom (e.g., bare sediments, algae beds, and seagrass beds), and hardbottom systems (e.g., annelid reefs, coral reefs, rocky outcroppings, and sponge and octocoral covered rock). Estuaries serve as spawning grounds and nursery areas for commercially valuable fish and invertebrate species. They also support a diversity of finfish, shellfish, birds, and marine mammals, and provide a litany of ecosystem services, including protection from flooding and storm damage, enhanced water quality, carbon storage, oxygen generation, and the sequestration of contaminants (Kautz et al. 1998, Pendleton 2009, Granek et al. 2010, Jerath et al. 2016). More than half of commercially harvested fish in the United States depends on estuaries and nearby coastal waters at some stage in their life cycle. The abundance and health of adult stocks of commercially harvested shrimp, crabs, oysters, and other invertebrate species are directly related to the quality and quantity of estuarine habitats (Stedman and Hanson 2000, Stedman and Dahl 2008). Further, these habitats support the resting, feeding, and breeding of 85% waterfowl and other migratory birds in the United States; nearly 45% of the nation's endangered and threatened species are also dependent on coastal habitats (Steadman and Dahl 2008). Marine and estuarine habitats contribute significantly to Florida's US$58.6 billion outdoor recreation industry (Outdoor Industry Association 2017) by providing opportunities for hunting, boating/paddling, fishing, birding, and photography. A thriving $9.0 billion recreational and commercial fishing industry supporting more than 200,000 jobs statewide also depends on Florida's marine and estuarine habitats (National Marine Fisheries Service 2018).

Historically, Florida contained an estimated 8.2 million ha of wetlands. Over time, approximately 45% of these habitats were converted, altered, or destroyed, the most wetland area of any state (Estevez et al. 1984, Dahl 1990, 2005). Between 1950 and 1970, Florida lost approximately 30,350 ha of estuarine habitat, primarily due to dredging and filling associated with urban development and navigation (Hefner 1986). Extensive mangrove and saltmarsh systems were ditched and diked for mosquito-source control resulting in isolation from adjacent estuaries and a loss of resiliency to sea level rise (Smith et al. 2007). Freshwater and estuarine wetland losses have slowed significantly due to the passage of several federal and state environmental statutes and substantial governmental land purchases for the purpose of conservation and recreation. However, the remaining estuarine wetlands face impacts from shoreline development, altered hydrology, pollution, dredging, and impoundments for mosquito control (Frayer and Hefner 1991, Dahl 2005, Jud et al. 2011).

Conserving, protecting, and restoring natural systems, while ensuring an adequate water supply, remains one of Florida's greatest challenges (Purdum et al. 2002). The 2018 human population estimate in Florida exceeded 21.3 million (U.S. Census Bureau 2018) and is expected to increase to 27.3 million by 2045 (Rayer and Wang 2015). In the future, Florida faces the challenge of balancing economic growth and rapid population expansion against conservation of limited natural resources (Frayer and Hefner 1991, Dahl 2005). Natural resource managers must effectively identify suitable sites for restoration and protection of marine and estuarine habitats. Restoration projects can suffer from poor cost-to-benefit ratios due to improper placement, inadequate planning, or failure to incorporate the values and perspectives of local stakeholders (Roni and Quimby 2005). A restoration prioritization system implemented across broad geographic areas can maximize ecological, sociological, and fish and wildlife benefits while minimizing costs (Darwiche-Criado et al. 2017, Lovette et al. 2018).

In 2009, the Florida Fish and Wildlife Conservation Commission (FWC) began using the Aquatic Restoration Prioritization and Evaluation Tool (ARPET), a freshwater lake decision support tool that synthesizes existing socioeconomic, ecological, and environmental data within a geographic-information-system (GIS) platform to identify and prioritize public freshwater lakes for potential restoration. The ARPET provides an expedient, cost-effective, and science-driven decision framework for lake restoration (FWC 2012a). Because of its demonstrated effectiveness, FWC followed a similar protocol in 2015 to prioritize other freshwater resources (i.e., streams, freshwater forested wetlands, and freshwater non-forested wetlands), resulting in the development of a freshwater aquatic management guiding document, Florida's freshwater priority resources: a guide for future management (FWC 2017) described by Bock et al. (2018). The FWC decided to evaluate Florida's marine and estuarine resources in a similar manner, to be combined with the Florida's freshwater priority resources with the objective of creating a tool to provide an expedient and cost-effective decision framework for integrated aquatic habitat restoration across watersheds, while improving the scientific rigor and removing subjectivity from the process of selecting aquatic resources for restoration. This comprehensive tool, A GIS Assessment of Florida's Aquatic Resources: A Framework for Restoration and Management 2020 (FWC 2020), independently prioritizes six aquatic resource types (forested wetlands, non-forested wetlands, lakes, streams, estuaries and marine) within each of the five FWC management regions (i.e., administrative boundaries determined by county lines; Bock et al. 2018). Herein, we describe development and potential applications of this tool specific to informing the conservation of estuarine and marine habitats.

Methods

All geospatial analyses were conducted in ArcMap 10.4.1. A variety of spatial data layers were used in the analysis (Appendix 1; described further in FWC [2020]).

Identification of Estuarine and Marine Resources

Florida's statutory authorization allows state investments in habitat restoration and enhancement projects only on public lands, so this assessment of estuarine and marine habitats was confined to public-trust resources. All estuarine and marine habitats were considered to be sovereign submerged lands, and therefore publicly accessible for the purposes of this assessment. Because estuarine habitats lacked names and defined borders outside of those delineated by confined estuaries, these resources were consolidated by sub-watersheds using the Hydrologic Unit Code 12 (HUC 12) boundaries in the National Hydrologic Dataset (Appendix 1). Estuaries were mapped by aggregating the relevant land cover classes from the 10-m resolution Cooperative Land Cover Map (Appendix 1) and clipping them to boundaries of sub-watersheds (Figure 1). Although marine habitat had no clearly defined boundaries, the

Appendix 1. Spatial data sources for the estuarine and marine resource prioritization analysis in Florida (NHD = National Hydrological Dataset, USGS = U.S. Geological Survey, FDEP = Florida Department of Environmental Protection, FWC = Florida Fish and Wildlife Conservation Commission, FNAI = Florida Natural Areas Inventory, NOAA = National Oceanic and Atmospheric Administration, USFWS = U.S. Fish and Wildlife Service, BTT = Bonefish and Tarpon Trust, FL MNH = Florida Museum of Natural History.

Category	Data	Source	Agency
	HUC-12 (sub-watersheds)	Florida NHD http://geodata.dep.state.fl.us/	USGS, FDEP
	200 m depth bathymetric contour	Bathymetry Contours Southeast United States http://geodata.myfwc.com/datasets/bathymetry-contours-southeast-united-states	FWC
	Land cover	Cooperative Land Cover Mapv3.2.5 https://myfwc.com/research/gis/applications/articles/cooperative-land-cover/	FWC, FNAI
Socioeconomic importance	Boat ramps	FWC Florida Boat Ramp Inventory http://geodata.myfwc.com/datasets/fwc-florida-boat-ramp-inventory	FWC
	Existing recreational trails	Florida Greenways and Trails System—Existing Trails http://geodata.dep.state.fl.us/	FDEP
	Population	2010 U.S. Census Blocks in Florida https://www.census.gov/en.html	U.S. Census Bureau
	Hunting areas	2018–2019 Hunting Areas in Florida Contact FWC data librarian: GISLibrarian@MyFWC.com	FWC
	GFBT	FWC Office of Public Access and Wildlife Viewing Services	FWC
	Marinas	Marinas Florida http://geodata.myfwc.com/datasets/marinas-florida	FWC
	Piers	Florida Outdoor Recreation Inventory (FORI) https://floridadep.gov/parks/florida-outdoor-recreation-inventory	FDEP
	Commercial landings	Commercial Fisheries Landings Summaries https://public.myfwc.com/FWRI/PFDM/ReportCreator.aspx	FWC
	Distance from port	NOAA Environmental Sensitivity Index (ESI) https://response.restoration.noaa.gov/resources/environmental-sensitivity-index-esi-maps	NOAA
Fish & wildlife populations	Avian focal areas	North American Bird Conservation Joint Ventures https://acjv.org/	USFWS
	Critical habitat	NOAA Critical Habitat, U.S. FWS Critical Habitat, Critical Wildlife Areas Florida https://www.fisheries.noaa.gov/national/endangered-species-conservation/critical-habitat, https://ecos.fws.gov/ecp/report/table/critical-habitat.html, http://geodata.myfwc.com/search	NOAA, USFWS, FWC
	Tarpon nurseries	Bonefish Tarpon Trust	BTT
	Diamondback terrapin	Terrapin Observation Locations in Florida http://geodata.myfwc.com/search	FWC
	Eastern salt marsh snake	Florida Museum of Natural History, FWC records http://specifyportal.flmnh.ufl.edu/herps/	FL MNH, FWC
	Size (estuary complex w/in HUC 12)	CLC v3.2.5 https://myfwc.com/research/gis/applications/articles/cooperative-land-cover/	FWC, FNAI
	Size protected (area)	Florida Natural Areas Inventory. Florida Conservation Lands, April 2018 https://www.fnai.org/gisdata.cfm	FNAI
	CLIP	Critical Lands and Waters Identification Project (CLIP): Version 4.0 https://www.fnai.org/gisdata.cfm	FNAI
	Horseshoe crabs	FWC records	FWC
	Species richness	Fisheries Independent Monitoring Database	FWC
	Red drum	Fisheries Independent Monitoring Database	FWC
	Coral	Coral and Hard Bottom Habitats in Florida http://geodata.myfwc.com/searc	FWC
Restoration opportunities	Managed conservation areas	NOAA Environmental Sensitivity Index (ESI), https://response.restoration.noaa.gov/resources/environmental-sensitivity-index-esi-maps	NOAA
	Sea level rise	NOAA Sea Level Rise https://coast.noaa.gov/slrdata/	NOAA
	Impaired waters	FDEP verified impaired waters, Run 53 DEP - 2017 http://geodata.dep.state.fl.us/	FDEP
	Hardened shoreline	NOAA Environmental Sensitivity Index (ESI) https://response.restoration.noaa.gov/resources/environmental-sensitivity-index-esi-maps	NOAA
	Fragmentation	CLC v3.2.5 https://myfwc.com/research/gis/applications/articles/cooperative-land-cover/	FWC, FNAI
	Seagrass scarring	Bill Sargent seagrass propscour 1991–1994 and various FWC updates	FWC

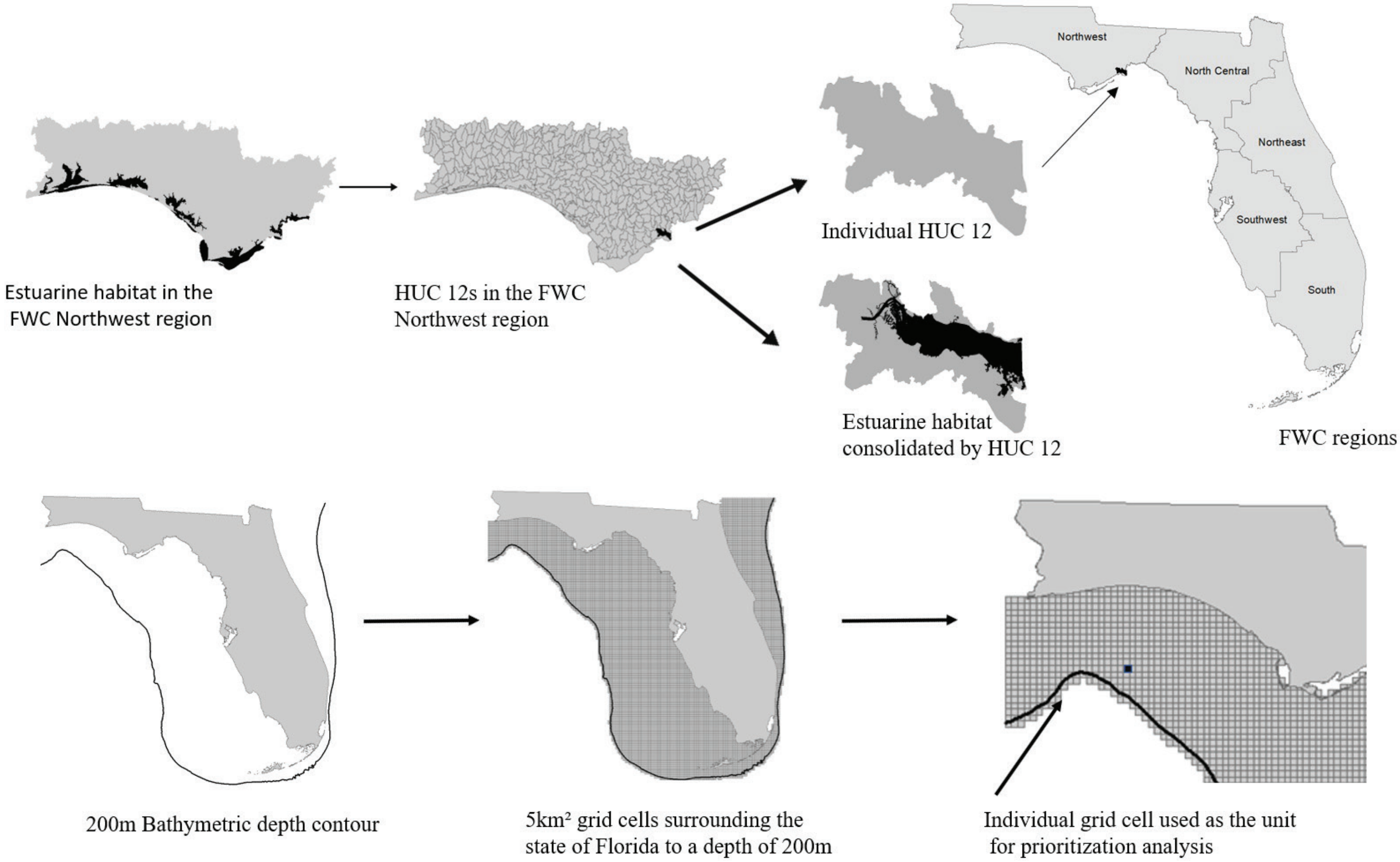

Figure 1. An example of how estuarine habitats were consolidated by sub-watersheds (a) and how marine habitats were partitioned into 5-km^2 grid cells (b) for use in the Florida estuarine and marine resource prioritization assessment tool, as well as an inset showing the five Florida Fish and Wildlife regions.

depth of 200 m represented the furthest working range for FWC and encompasses all currently mapped coral habitat near Florida. The 200-m bathymetric contour extends beyond Florida state waters; however, FWC works with partners to implement habitat enhancement and restoration projects on all public land, including federally managed submerged lands outside state waters boundaries. The 200-m depth contour was delineated (Appendix 1), and the area between this outer limit and the Florida coastline was partitioned into a grid of 5-km^2 cells using the create fishnet tool in ArcGIS; these areas served as the base-units for marine prioritization (Figure 1). Henceforth, in this discussion resource unit refers to sub-watersheds for estuarine habitat and grid cells for marine habitats.

Resource Valuation

Parameters quantifying physical and biological data relevant to socioeconomic value, value to fish and wildlife, and restoration opportunities in estuarine (Table 1) and marine habitats (Table 2) were identified at a state-wide level. An iterative, analytical process was used to overlay these parameters onto to the marine and estuarine base layers to evaluate their presence or absence and importance from the perspective of resource conservation. Availability of consistent state-wide data resulted in additional parameters being considered for estuarine habitat assessments compared to marine habitat. In all cases, a higher score resulted in a higher rank except for habitat fragmentation.

Socioeconomic Value Parameters.—We selected parameters for the socioeconomic category to measure the outdoor recreational opportunities offered by each marine (Table 2) and estuarine (Table 1) resource unit. All socioeconomic parameter data sources are listed in Appendix 1. Recreational trail length (e.g., public paved or unpaved trails intended for hiking, biking, equestrian, multiple use, paddling, or motorized vehicle use) was the summed kilometers of trail occurring in estuarine habitat for each sub-watershed. No attempt was made to standardize trail length based on sub-watershed size. Estimates of human population were calculated by

Table 1. Socioeconomic (SE), fish and wildlife (FW), and restoration opportunity (RO) parameters used to assess estuarine habitat as well as their range and mean (M) in each of the five Florida Fish and Wildlife Conservation Commission regions (NW = Northwest; NC = North Central; NE = Northeast; SW = Southwest; S = South) after normalization as well as the statewide mean. The statewide range was always zero to one.

		Region										
		NC		NE		NW		S		SW		State
Parameters		Range	M	Range	M	Range	M	Range	M	Range	M	M
SE	Recreational trail length	0.00–0.38	0.03	0.00–0.68	0.09	0.00–0.56	0.03	0.00–0.73	0.08	0.00–1.00	0.08	0.06
	Population within 80.5 km	0.00–0.41	0.17	0.18–0.56	0.31	0.03–0.15	0.08	0.00–1.00	0.52	0.20–0.73	0.47	0.30
	Hunting opportunities	0.00–0.32	0.07	0.00–1.00	0.09	0.00–0.57	0.09	0.00–0.57	0.05	0.00–0.48	0.03	0.06
	Great Fl. Birding trail sites	0.00–1.00	0.34	0.00–1.00	0.64	0.00–1.00	0.43	0.00–1.00	0.61	0.00–1.00	0.47	0.47
	Piers	0.00–0.16	0.02	0.00–0.53	0.12	0.00–0.37	0.05	0.00–1.00	0.12	0.00–0.79	0.08	0.07
	Commercial landings	0.10–1.67	0.76	0.02–1.37	0.66	0.07–1.04	0.41	0.05–2.03	0.59	0.00–3.10	1.30	0.79
	Accessibility	0.00–0.07	0.01	0.00–0.14	0.03	0.00–0.12	0.02	0.00–1.00	0.10	0.00–0.22	0.03	0.04
	Habitat value	0.00–0.37	0.01	0.00–0.08	0.01	0.00–0.05	0.00	0.00–1.00	0.08	0.00–0.20	0.01	0.02
	Sum	**0.31–3.07**	**1.40**	**0.26–5.17**	**1.94**	**0.16–2.73**	**1.11**	**0.48–5.70**	**2.14**	**0.30–6.07**	**2.48**	**1.81**
FW	Size	0.00–0.08	0.01	0.00–0.27	0.03	0.00–0.38	0.02	0.00–1.00	0.08	0.00–0.67	0.02	0.03
	Conservation area size	0.00–0.98	0.51	0.00–1.00	0.33	0.00–1.00	0.27	0.00–1.00	0.45	0.00–0.99	0.27	0.35
	Tarpon nurseries	0.00–0.05	0.00	0.00–0.57	0.08	0.00–0.10	0.01	0.00–1.00	0.10	0.00–0.43	0.04	0.03
	Diamondback terrapin	0.00–0.27	0.02	0.00–0.02	0.00	0.00–1.00	0.02	0.00–0.01	0.00	0.00–0.16	0.00	0.01
	Eastern saltmarsh snake	0.00–1.00	0.02	0.00–0.79	0.03	0.00–0.05	0.00	0.00–0.90	0.03	0.00–0.53	0.02	0.02
	Horseshoe crab	0.00–1.00	0.03	0.00–0.60	0.06	0.00–0.55	0.02	0.00–0.53	0.05	0.00–0.89	0.05	0.04
	Biodiversity	0.00–0.06	0.01	0.00–0.09	0.01	0.00–0.07	0.01	0.00–1.00	0.06	0.00–0.11	0.01	0.02
	Avian focus areas	0.20–0.80	0.68	0.40–1.00	0.79	0.60–1.00	0.84	0.40–0.80	0.56	0.40–0.80	0.52	0.67
	Critical habitat	0.00–0.92	0.07	0.00–0.39	0.10	0.00–1.00	0.12	0.00–1.00	0.26	0.00–0.92	0.12	0.13
	Species Richness	0.00–0.74	0.20	0.00–0.87	0.21	0.00–0.92	0.11	0.00–0.95	0.14	0.00–1.00	0.32	0.21
	Sum	**0.40–3.31**	**1.50**	**0.40–3.81**	**1.65**	**0.60–4.92**	**1.41**	**0.48–5.60**	**1.72**	**0.40–4.46**	**1.36**	**1.50**
RO	Fragmentation	0.00–0.13	0.02	0.00–1.00	0.05	0.00–0.19	0.01	0.00–0.08	0.01	0.00–1.00	0.02	0.02
	Impaired waters	0.00–0.78	0.22	0.00–0.86	0.41	0.00–0.98	0.23	0.00–0.72	0.27	0.00–.00	0.30	0.28
	Hardened shoreline	0.00–0.04	0.00	0.00–0.07	0.01	0.00–0.04	0.01	0.00–1.00	0.05	0.00–0.14	0.01	0.01
	Sea level rise	0.00–0.06	0.01	0.00–0.16	0.02	0.00–0.41	0.03	0.00–1.00	0.08	0.00–0.33	0.02	0.03
	Size of managed area	0.00–0.12	0.02	0.00–0.14	0.01	0.00–0.51	0.05	0.00–1.00	0.13	0.00–0.30	0.02	0.04
	Seagrass scarring	0.00–0.08	0.00	0.00–0.08	0.01	0.00–0.14	0.01	0.00–0.56	0.04	0.00–1.00	0.03	0.02
	Sum	**0.00–0.93**	**0.27**	**0.00–1.05**	**0.51**	**0.00–1.70**	**0.33**	**0.00–2.06**	**0.56**	**0.00–2.51**	**0.39**	**0.39**
Total		**1.20–6.43**	**3.22**	**1.59–9.20**	**4.10**	**1.09–8.15**	**2.85**	**1.61–11.05**	**4.43**	**1.23–11.43**	**4.23**	**3.70**

Table 2. Parameters used to assess marine habitat as well as their range and mean across 942,500 marine grid cells.

Category	Parameter	Range	Mean
Socioeconomic	Accessibility	0.00–1.00	0.18
	Habitat value	0.00–1.00	0.05
	Distance from a port	0.00–1.00	0.72
	Sum	**0.00–3.81**	**0.75**
Fish & wildlife	Avian focus areas	0.00–1.00	0.06
	Critical habitat	0.00–1.00	0.06
	Species Richness	0.00–1.00	0.04
	Red drum	0.00–1.00	0.00
	Coral	0.00–1.00	0.09
	Sum	**0.00–0.15**	**0.27**
Restoration opportunities	Size of managed area	0.00–1.00	0.08
	Seagrass scarring	0.00–1.00	0.00
	Sum	**0.00–2.50**	**1.49**
Total		**0.012–5.70**	**0.99**

multiplying census block data occurring within an 80.5-km buffer of estuarine habitat in sub-watersheds by population density. The 80.5-km radius represented a trip of one hour or less for day use for the 77% of Floridians (National Oceanic and Atmospheric Administration [NOAA] 2020) living in coastal communities. Higher numbers of people within close proximity provides an estimate of socioeconomic "value" relative to more remote locations. We recognize that some user groups will travel great distances to use certain waters, so the 80.5-km radius was considered a conservative estimator for the purpose of this assessment. Hunting opportunities were assessed by calculating the area of estuarine habitat in which hunting was permitted for each sub-watershed. The Great Florida Birding and Wildlife Trail (GFBT) is a statewide network of 515 wildlife viewing sites spread throughout the state (FWC 2012b). For estuaries, presence or absence of GFBT sites was assessed by sub-watershed. Piers were assessed by summing the number of saltwater and freshwater catwalks, jetties and piers occurring within 1 km of estuarine habitat.

The value of several species of commercially important estuarine and marine fish and invertebrates, including blue crabs (*Callinectes sapidus*), stone crabs (*Menippe* spp.), mullet (*Mugil* spp.), grouper (Serranidae), and all species of shrimp, as well as all food and bait landings were calculated; however, when determining the final priority score, each species was evaluated independently. Economic values were reported by county in Commercial Fisheries Landings Summaries, so the percentage of the area of each sub-watershed that occurred within each county was multiplied by the average value of the landings for that county over a 20-year period (1998–2018). Values were summed in areas where a sub-watershed intersected two or more counties. Accessibility of estuarine and marine habitats was assessed based on the number of boat ramps and marinas occurring within estuarine sub-watersheds, or within an 80.5-km radius of marine grid cells.

Diverse estuarine and marine habitats provide differing habitat-based values of ecosystem services. Blair et al. (2015) provided broad economic values per ha for oyster reefs ($138,866.25), seagrass ($98,430.69), salt marshes ($89,188.08), and mangroves ($52,635.20). These values were multiplied by the area of each of these four habitat types occurring within a sub-watershed or a marine grid cell. For marine habitats, the Euclidean distance from each grid cell to a commercial port was calculated and used as an area analog.

Fish and Wildlife Value Analysis.—Parameters included in the fish and wildlife category measured the ecological significance of estuarine (Table 1) and marine habitats (Table 2). All fish and wildlife parameter data sources are listed in Appendix 1. Larger habitat size generally enhances stability in the form of resiliency to major disturbances like hurricanes and fires, greater abundance of individuals, and primary food-web energy production. Larger habitat patch sizes also increase the number of species that can potentially use the site and increases potential for habitat complexity (FWC 2012b). Habitat size was assessed by the total area of estuarine habitat occurring in a sub-watershed. The percentage of each sub-watershed occurring within a federal, state, local, and private managed conservation area with a significant portion of undeveloped land which retains most of the attributes of the natural condition (Florida Natural Areas Inventory 2018) was calculated.

Occurrences of several species were considered important for valuation of habitat to fish and wildlife in estuarine habitat. Tarpon (*Megalops atlanticus*) nursery data, provided by the Bonefish and Tarpon Trust in a generalized form to exclude detailed location information as requested by the data providers, were summed by sub-watershed. Data from the Bonefish and Tarpon Trust (angler survey-based) and data collected by FWC support that tarpon nurseries are discrete locations (ponds) having particular characteristics, and not all estuarine ponds are used by young of the year or age-1 tarpon. Diamondback terrapin (*Malaclemys terrapin*) and eastern saltmarsh snake (*Nerodia clarkii*) occurrences recorded from 1998 to 2018 were tabulated by sub-watershed or the nearest sub-watershed for terrapins occurring outside sub-watershed boundaries. Citizen reports of observed horseshoe crab (*Limulus polyphemus*) mating from 2012 to 2018 were summed. Each of these species occurrence parameters were counted separately.

The Critical Lands and Waters Identification Project (CLIP) database combines several data sets in order to rank the value of land to the preservation of biodiversity from 1 (least valuable) to 5 (most valuable). Although species of greatest conservation need (SGCN) were considered as a variable in this study, both CLIP and critical habitat data make use of SGCN data. CLIP data is not based on observed species occurrences but is a combination of factors such as potential distributions, connectivity and priority natural communities (Oetting et al. 2016). Biodiversity value of estuaries was calculated by multiplying estuarine area by its CLIP value and summing these weighted values by sub-watershed. Avian focus areas (AFA) for wading birds, waterfowl, shorebirds, seabirds, and land birds were digitized from maps provided by the North American Bird Conservation Joint Ventures. Seabird data were absent for the FWC Northwest region, and therefore were not included in that regional score. Each of the five AFA occurring in a sub-watershed or marine grid cell contributed 0.20 (0.25 in the Northwest region) to the score.

Critical habitat data for 61 estuarine plant and animal species as well as broader classes such as nesting habitat, plants and classes and 11 marine plant and animal species were scored by examining critical habitat data from the NOAA, the U.S. Fish and Wildlife Service and FWC. We summed the number of unique species having critical habitat in either each sub-watershed or grid cell. Species diversity was assessed by summing the number of species per sub-watershed or grid cell based on data from the FWC fisheries independent monitoring database. Two parameters (red drum [*Sciaenops ocellatus*] and coral occurrences) were calculated only for marine habitat. The number of occurrences of red drum per cell was obtained from fisheries independent monitoring data. Red drum occurrences are associated largely with structural habitat (hard bottom reefs) and spawning habitat, which provides a priority location and species life-history activity. Because fisheries dependent GIS data is unavailable available for other reef fish, red drum provide a fisheries independent surrogate (Camp et al 2013). Coral was scored as absent (0) or present (1). Although other marine species are potentially important in assessing marine habitat value, a lack of state-wide data prevented their inclusion in the tool.

Restoration Opportunities Analysis.—Parameters selected for the restoration opportunity category measured the need and opportunity for estuarine (Table 1) and marine habitat restoration (Table 2). Habitat fragmentation was measured based on average patch size and average distance to nearest patch of estuarine habitat. Larger patches and shorter distances received higher scores; the mean of the two normalized scores was computed to produce a single fragmentation metric (all restoration opportunity parameter data sources are listed in Appendix 1). An impaired waters layer was intersected with estuarine habitat and percentages of estuarine habitat contaminated by each of the nine impairment parameters ranging from 0 to 100 (nutrients, conductivity, turbidity, pesticides/dioxin, un-ionized NH3, bacteria, metals, biological oxygen demand/dissolved oxygen, and coliforms). These parameters were summed for a maximum total of 900%. Hardened shoreline was assessed by calculating the length of hardened shoreline occurring in estuarine habitat. Intermediate high to extremely high sea levels rise predictions indicate a global mean sea level rise of between 1.5 and 2.5 m by 2100; however, because the rapid melting of the Antarctic ice sheet was not included in these calculations a 2-m rise in sea level by 2100 may be a conservative estimate (Sweet et al. 2017). Because the available data were reported in feet rather than m, vulnerability to sea-level rise was calculated as the area of estuarine habitat per sub-watershed that would be submerged by a 2.134-m rise in sea level as this was closest to a 2-m rise provided.

Managed area was calculated based on the area in acres of any estuarine or marine habitat that fell within a managed area (Appendix 1). It was possible for marine cells to fall within more than one type of management area, and therefore to have a value greater than their total area. This was appropriate because of the increased chances for forming partnerships. Based on FWC staff experience, stakeholders perceive larger areas of managed habitat as providing for bigger "bang for the buck" value and engage more readily with them toward their conservation. Larger areas of managed habitat received higher scores due to the ease of performing restoration activities in managed areas and the opportunity to leverage partnerships with other stakeholders. Seagrass scarring was measured based on propeller scar and vessel grounding (collectively referred to as propscars) surveys conducted by Sargent et al. (1995) from 1991to 1994 and by FWC during 2003 to 2011 using the same methodologies. Areas with propscars were multiplied by their assessed level of scarring (1—light scarring, 2—moderate scarring, and 3—severe scarring), and these weighted areas were summed by sub-watershed or grid cell. Although road density was considered for inclusion in the restoration opportunities category, the available statewide data did not include any roads in estuarine habitat.

Final Ranking

After creating the individual prioritization parameters, scores for each parameter were normalized to fall between 0 and 1 (Ouyang et al. 2011) for all estuarine sub-watersheds and marine grid cells. The unweighted normalized scores were then summed for categories and for an overall total per resource unit (i.e. sub-watershed for estuarine habitats, grid cell for marine habitats). An example of scoring is given for two sub-watersheds in Table 3.

Table 3. An example of how normalized values for parameters in the three categories (i.e., socioeconomic value, fish and wildlife value, and restoration opportunity) were summed for estuarine habitat within two sub-watersheds in Florida prior to employing the natural break optimization classification (Jenks 1967). CLIP is an acronym for the Critical Lands and Waters Identification Project. Commercial landings is a summation of the values of blue crabs (*Callinectes sapidus*), stone crabs (*Menippe* spp.), mullet (*Mugil* spp.), grouper (*Serranidae*), all species of shrimp, and all food and bait landings; therefore, it could total greater than 1.

	Estuary (HUC 12)	
Category and associated variable	**Apalachicola Bay (031300140201)**	**Wakulla River (031200011001)**
Socioeconomic		
Recreational trail length	0.56	0.00
Population within 80.5 km	0.03	0.07
Hunting opportunities	0.04	0.00
Great Florida birding trail sites	1.00	0.00
Piers	0.03	0.03
Commercial landings	1.03	0.25
Accessibility	0.03	0.02
Habitat value	0.01	0.00
Subtotal	**2.73**	**0.36**
Fish and wildlife		
Size	0.25	0.00
Conservation area size	0.98	0.08
Tarpon nurseries	0.00	0.00
Diamondback terrapin	0.03	0.00
Eastern saltmarsh snake	0.00	0.00
Horseshoe crab mating behavior	0.01	0.00
Species diversity	0.92	0.00
Avian focus areas	1.00	0.60
CLIP	0.03	0.00
Critical habitat	0.31	0.00
Subtotal	**3.53**	**0.68**
Restoration opportunity		
Fragmentation	0.04	0.01
Impaired waters	0.60	0.00
Hardened shoreline	0.02	0.00
Sea level rise	0.28	0.00
Size of managed area	0.50	0.04
Seagrass scarring	0.00	0.00
Subtotal	**1.45**	**0.05**
Total resource values	**7.71**	**1.09**

Summed parameter scores for each of the three categories, and overall total scores for each sub-watershed or marine grid cell, were binned into five classes using the Jenks (1967) natural breaks optimization method, which identifies breakpoints that minimize the sum of variance within classes and maximize the variance between classes (Jenks 1967, Jenks and Caspall 1971). Resource units were ranked such that the bin containing the lowest summed values received a ranking of low priority for restoration (value = 1), the second lowest summed value was ranked as medium-low priority (value = 2), and so on, until the highest summed value was ranked high (value = 5). Estuarine sub-watersheds were ranked relative to all sub-watersheds within their FWC region; whereas, marine grid cells (not being regionalized) were ranked relative to all marine grid cells statewide.

Category values and overall values were compared to other values within that region and habitat type, so there was no specific value or range that a resource unit had to achieve to be placed within a ranking class. Ranking estuarine and marine units by category and total scores and grouped by FWC region for estuaries allowed regional managers to identify high priority habitats within their areas of responsibility. Also, managers could identify specific issues within those resources, such as resources that were especially valuable from a fish and wildlife perspective.

Results

Of the 1295 sub-watersheds in Florida, 283 (22%) contained estuarine habitat with the remainder occurring inland, totaling 1,061,900 ha; marine habitat was estimated to occur in 9244 5-km^2 grid cells containing an area of 23,110,000 ha. Of these sub-watersheds and grid cells, 21 sub-watersheds (527,618 ha) and 377 grid cells (942,500 ha) were identified as containing high priority habitats for restoration (Table 4). The greatest range in potential scores tended to be found in the South and Southwest regions, allowing these regions to potentially achieve higher total scores (Table 1). The overall socioeconomic and fish and wildlife categories achieved higher mean normalized values than the restoration opportunities category for all estuaries, as well as for marine habitat. Fish and wildlife values were highest in the Northeast and South regions; whereas, socioeconomic values tended to become higher as regions progressed south and east, with the Northeast, Southwest, and South regions having higher values than other regions. Regional restoration opportunities were highest in the South and Southwest regions (Figure 2, Table 5).

For high priority habitats, mean scores tended to have higher socioeconomic and fish and wildlife values when compared to restoration opportunities. High priority estuarine habitats followed the pattern observed in socioeconomic values but differed

Table 4. Total number of resource units (sub-watersheds for estuarine or 5-km^2 grid cells for marine) and number of high priority resource units assessed in each Florida Fish and Wildlife Conservation Commission (FWC) regions for estuaries and total area for marine in hectares.

FWC region		Resource units	Area (ha)
North Central	Assessed	56	87,561
	High priority	9	28,641
Northeast	Assessed	33	116,377
	High priority	2	52,454
Northwest	Assessed	72	215,926
	High priority	2	53,304
Southwest	Assessed	81	243,562
	High priority	4	167,203
South	Assessed	41	398,438
	High priority	4	226,016
Marine	Assessed	9244	23,110,000
	High priority	377	942,500

Table 5. Mean values for each parameter category for high priority (HP) resource units (sub-watershed for estuarine habitats, grid cell for marine habitats) and all resource units summarized by Florida Fish and Wildlife Conservation Commission (FWC) region and marine area. *n* = the number of high priority resource units per FWC region and marine area.

		Socio-economic		Fish and wildlife		Restoration opportunity		Total	
Region	*n*	HP	Region	HP	Region	HP	Region	HP	Region
North Central	9	2.79	1.40	2.18	1.55	0.32	0.27	5.27	3.22
Northeast	2	4.83	1.94	3.44	1.65	0.79	0.51	9.07	4.10
Northwest	2	2.51	1.11	4.23	1.41	1.20	0.33	7.93	2.85
Southwest	4	4.54	2.48	3.17	1.36	1.54	0.39	9.25	4.23
South	4	4.12	2.14	3.89	1.72	1.57	0.56	9.58	4.43
Marine	377	2.45	0.76	0.73	0.15	0.46	0.09	3.63	0.99

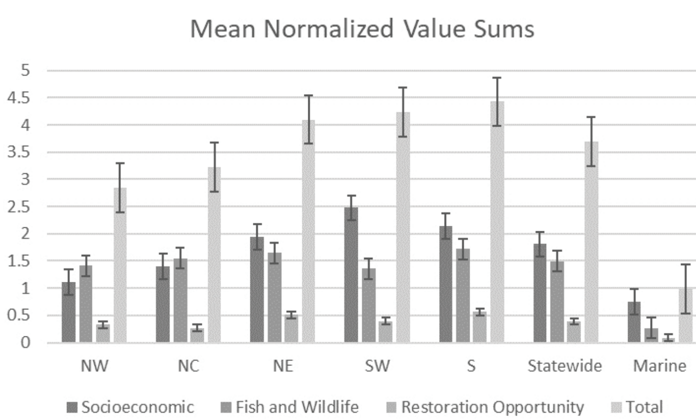

Figure 2. Mean normalized value sums by category and total value for each habitat type in Florida summarized by Florida Fish and Wildlife region (NW = Northwest; NC = North Central; NE = Northeast; SW = Southwest; S = South) and by the entire area of interest for marine resources.

from regional estuarine means in that the Northwest region and the South region had the highest fish and wildlife values. Restoration opportunities in high priority estuarine habitats were highest in the South and Southwest regions (Table 5). Marine habitat also had highest values in socioeconomic values and the lowest in restoration values for both high priority and all marine habitats (Table 5).

The highest priority estuarine areas for restoration and enhancement in each region were larger habitat patches ranging from 1334.53 ha to 125510.45 ha in size. Large bays with fringing marsh and oyster habitat ranked highest in the Northwest region. In the North Central region, expansive salt marsh and barrier oyster reefs ranked as highest priority areas. Estuarine marshes and bays dominated the highest ranked areas within the Northeast region, continuing southward into the upper portion of the South region where coastal wetlands transition to mangrove shorelines. Priority estuaries within the South region included a mix of bays, mangroves, and seagrass flats. Mangrove and seagrass-dominated estuaries ranked as high priorities within the Southwest region (Table 6). Finally, high priority areas within the marine region were dispersed around the state with the highest concentration in south Florida, based on mapped hardbottom and coral reef habitat.

Table 6. Identified high priority estuarine habitats listed by sub-watershed name in each of the five Florida Fish and Wildlife Conservation Commission regions (NW = Northwest; NC = North Central; NE = Northeast; SW = Southwest; S = South). Total values are shown for socioeconomic value, fish and wildlife value, restoration opportunities, and total values.

Name	Region	Socio-economic	Fish and wildlife	Restoration opportunity	Total
Nassau Sound-Fort George Inlet Frontal	NC	3.05	3.23	0.14	6.43
Barnett Creek-Black Point Swamp Frontal	NC	2.18	3.31	0.93	6.43
Mason Creek-Seven Cabbage Cutoff Frontal	NC	2.87	2.28	0.13	5.28
Clapboard Creek	NC	2.90	2.13	0.11	5.15
Crystal River	NC	2.95	1.63	0.43	5.01
Lower Pablo Creek	NC	2.93	1.21	0.72	4.87
Homosassa River	NC	2.94	1.84	0.05	4.83
Suwannee River	NC	2.17	2.37	0.28	4.83
Chicopit Bay	NC	3.07	1.58	0.11	4.76
Mosquito Lagoon	NE	4.50	3.65	1.05	9.20
Indian River Lagoon	NE	5.16	3.24	0.53	8.93
St. George Sound	NW	2.28	4.92	0.95	8.15
Apalachicola Bay	NW	2.73	3.53	1.45	7.71
Upper Florida Keys	S	5.70	3.79	1.56	11.05
Broad River-Taylor Slough Frontal	S	2.93	5.60	1.76	10.28
Lower Florida Keys	S	4.18	2.35	2.06	8.58
South Biscayne Bay	S	3.67	3.84	0.93	8.44
Estero Bay	SW	6.07	3.33	2.03	11.43
Charlotte Harbor	SW	3.79	4.46	1.38	9.63
Tampa Bay	SW	5.05	2.79	0.23	8.07
Pine Island	SW	3.28	2.08	2.51	7.87

Discussion

Estuarine and marine habitats support robust ecological communities and a thriving economy for the people of Florida. Florida's estuarine and marine environments encompass vastly different resource types, with saltmarsh and oyster reefs in the less populated Northwest region giving way to mangroves and coral reefs in the densely populated South region. The benefit of normalizing scores on a statewide basis versus regionally is that statewide data normalization allows the evaluation of estuarine habitats against one another on the statewide scale, while separating estuarine habitat by region and category enhanced the prioritization process by allowing a greater number of areas to be identified as management priorities. The higher mean scores for socioeconomic and fish and wildlife values when compared to restoration opportunities imply that habitats valued by stakeholders (socioeconomic) and providing greater value for fish and wildlife may be considered more viable restoration targets if they have only moderate habitat degradation (Figure 2). Habitats with low restoration opportunity values often warrant conservation protections rather than restoration (Bock et al. 2018).

The higher socioeconomic values noted in the Northeast, South and Southwest regions for both high priority habitats and all habitat within a region were likely due to higher human population in large cities such as Jacksonville in the Northeast, Miami in the South, and Tampa in the Southwest regions. The relatively undeveloped nature of the Northwest region and the large expanses of saltmarsh, seagrass, and mangrove habitat in the South region's national parks contribute to high ecosystem services and fish and wildlife value rankings observed in the high priority habitats identified in these areas. This trend also holds true for marine habitat with socioeconomic scores achieving the highest summed normalized values and most high scores for socioeconomic values occurring on the southeast area of Florida from West Palm Beach southward through the Florida Keys.

As noted by Bock et al. (2018), results indicated that careful consideration should be given to parameters and valuation used for assessment. Parameters with values based on presence/absence (e.g., scores of either 0 or 1 for the presence of Great Florida Birding Trail sites) and a defined-scale basis (e.g., values on a 0, 0.2, 0.4, 0.6, 0.8, and 1 scale for AFAs) had much higher scores and thus had greater influence on the category and overall values for habitats within a region. Parameter values based on continuous variables (e.g., percent of the estuary within a conservation area, length of recreational trails) had the potential for much lower values and a lower contribution to the category and overall values, depending on the prevalence of the parameter throughout the estuarine or marine area of interest (Figure 3). Because raw values were normalized at the state-level, rather than regionally, normalized values for continuous parameters tended to be even lower when compared to the "presence/absence" parameters. Weighting was considered in this assessment but was not ultimately used due concern that subjective assignment of weighting values would dilute the importance of potentially key factors. The influence of valuation methodology and normalization on priority ranking must be considered when developing other assessments. In developing future assessments of habitat, it might be prudent to assess areas of the state with differences in natural resource abundance and human development on a regional basis.

Identifying and prioritizing habitat areas in need of restoration and enhancement allows the FWC to use its finite resources in the most efficient way possible, and to leverage those resources through procurement of grants or other partner-based contributions to obtain the largest possible impact on natural habitat conservation. Prior to development of this prioritization tool, the procedure for evaluating and selecting wetland and marine habitats for enhancement and restoration involved considerable subjectivity. The FWC staff coordinated with partners and stakeholders in an annual process to propose and assess restoration and enhancement projects throughout the state. Project applications were pooled, and team members served as subject matter experts to evaluate the biological merit of proposed projects using a standardized scoring system, with state funding allocated to the highest ranked proposals. Periodic changes in team membership, as well as individual bias had the potential to introduce variations and subjectivity into this process.

The new prioritization tool employs a quantification process that reduces individual bias and maintains the continuity of the prioritization and selection process, while accounting for regional variations in aquatic habitats. The tool identifies high-value habitats from each FWC region and ranks estuarine and marine habitats based on their relative regional importance and abundance, demonstrating its usefulness as a decision support tool. Prioritization of habitats within each FWC region provides a science-based decision framework for identifying resources for which restoration will likely produce the greatest ecological benefits. Moving forward, FWC will be able to place an increased focus on those habitats with the highest restoration priorities within each FWC region. Development of this tool will provide regional experts and

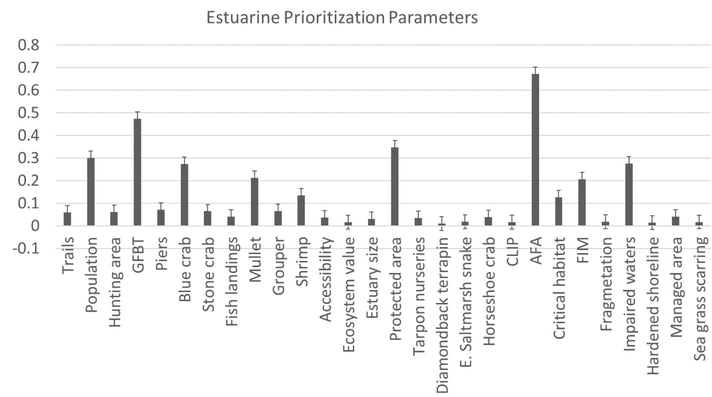

Figure 3. Mean normalized score by parameter (all Florida Fish and Wildlife regions combined) for estuarine habitats assessed for all sub-watersheds containing estuarine habitat in Florida ($n = 283$).

FWC managers with detailed maps, searchable geospatial databases, and GIS layers that support investigation of potential causes of habitat degradation, inform investments in restoration activities within specified areas, and aid in the development of project-based restoration plans and related funding. Furthermore, this tool is expected to help increase the objectivity of teams responsible for proposing and scoring habitat restoration projects, ensuring greater consideration and emphasis on project proposals that address high-priority habitats.

This habitat-focused prioritization process provides scientifically based regional and statewide maps to guide and inform FWC's estuarine and marine habitat conservation efforts into the foreseeable future. There are plans for the tool to be updated and refined on a five-year basis. The spatial datasets used for this evaluation, when combined with those previously described for freshwater habitats in Florida (Bock et al. 2018), allow for landscape-scale planning, prioritization, and conservation of aquatic habitat around the state. This tool allows resource managers to appropriately sequence and connect related projects to achieve optimal desired outcomes.

Although FWC did not reach out to partners and stakeholders to develop this prioritization tool, as the product is specifically to be used by the Commission for directing aquatic habitat restoration projects, the mapping products produced through this process will be publicly available via a web-based GIS mapping resource, providing transparency to stakeholders. Without partner input in the development of this tool, there are limitations to applicability of this product to prioritization goals of other organizations. However, coordinating with internal and external partners builds stronger synergistic relationships with stakeholders, increases scientific and technical knowledge of these resources, and provides opportunities to leverage or cost-share restoration and enhancement funds (FWC 2020). Collaborative, science-based restoration is especially critical for landscape scale restoration planning where projects cross multiple jurisdictions, including tribal, state and local government, and address large-scale issues and interests. A collective effort is needed to restore resilient healthy ecosystems, and this prioritization process, in concert with ongoing stakeholder coordination, is a significant tool to help achieve this goal.

In summary, the analyses detailed in this manuscript apply innovative science-based techniques to prioritize the allocation of the limited funding for aquatic habitat restoration provided to FWC by the Florida legislature and grant organizations consistently and in a defensible manner (Bock et al. 2018). This tool will help inform FWC resource management decisions to achieve the greatest conservation benefit from investments in habitat restoration and enhancement into the future. The tool identified multiple estuarine and marine areas with recent or ongoing habitat restoration projects as high priorities. Those projects are considered to validate the methodology and support the resulting ranking of estuarine systems and marine polygons by this study. Example projects in high priority systems include oyster reef restoration and enhancement in Apalachicola Bay (Northwest Region), Pine Island Sound (Southwest Region), seagrass recovery monitoring in the Upper Florida Keys (South Region), mangrove habitat enhancement in Tampa Bay (Southwest Region), oyster and saltmarsh restoration in Mosquito Lagoon (Northeast Region), and coral restoration in the Florida Keys (marine areas). The use of a scientifically grounded decision framework that incorporates benefits to people as well as to fish and wildlife has multiple advantages, including increased management accountability, greater stakeholder support and greater likelihood of project success.

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