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Waterbirds as indicators of ecosystem health in the coastal marine habitats of Southern Florida: 2. Conceptual ecological models

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ABSTRACT

In our companion manuscript we identified 11 waterbirds as indicators of various pressures on the coastal marine ecosystems of southern Florida. Here, we identify the habitats on which these species depend and the ecological linkages that make them representative of those habitats. Through the use of conceptual ecological models (CEMs), we develop tools that can be used by managers/decision makers to evaluate the health of the various habitats in order to rectify myriad problems that are occurring or will possibly occur in the future such that the valuable ecosystem services provided by these habitats can be maximized. We also demonstrate the practical use of these tools by documenting data availability, benchmarks, and scientific needs for each species.

1. Introduction

The National Oceanic and Atmospheric Administration has made a concerted effort to restore and maintain estuarine and marine habitats along the coast of southern Florida. Part of that effort was to establish the **MARES** (**MAR**ine and **E**stuarine goal **S**etting) project to facilitate ecosystem-based management of southern Florida's coastal marine ecosystems (Fig. 1; http://www.sofla-mares.org). The overall project goal was to reach a scientifically based consensus on the defining characteristics and fundamental regulating processes of southern Florida's coastal resources that are both sustainable and capable of providing the diverse ecosystem services upon which our society depends. MARES convened 124 relevant experts (both natural system and human dimensions scientists), stakeholders, and agency representatives in a series of workshops to reach consensus on our understanding of the natural process that make the coastal environments so valuable. The final step in the MARES process was to identify indices of ecosystem health that document trajectories toward (or away from) a sustainable and satisfactory condition.

This paper develops conceptual ecological models (CEMs) for the 11 taxa of waterbirds that represent (1) good indicators of pressures on waterbirds in southern Florida estuaries and marine habitats (Ogden et al., in this issue), and (2) indicators representative of the major coastal habitat types in this region. Birds have been frequent

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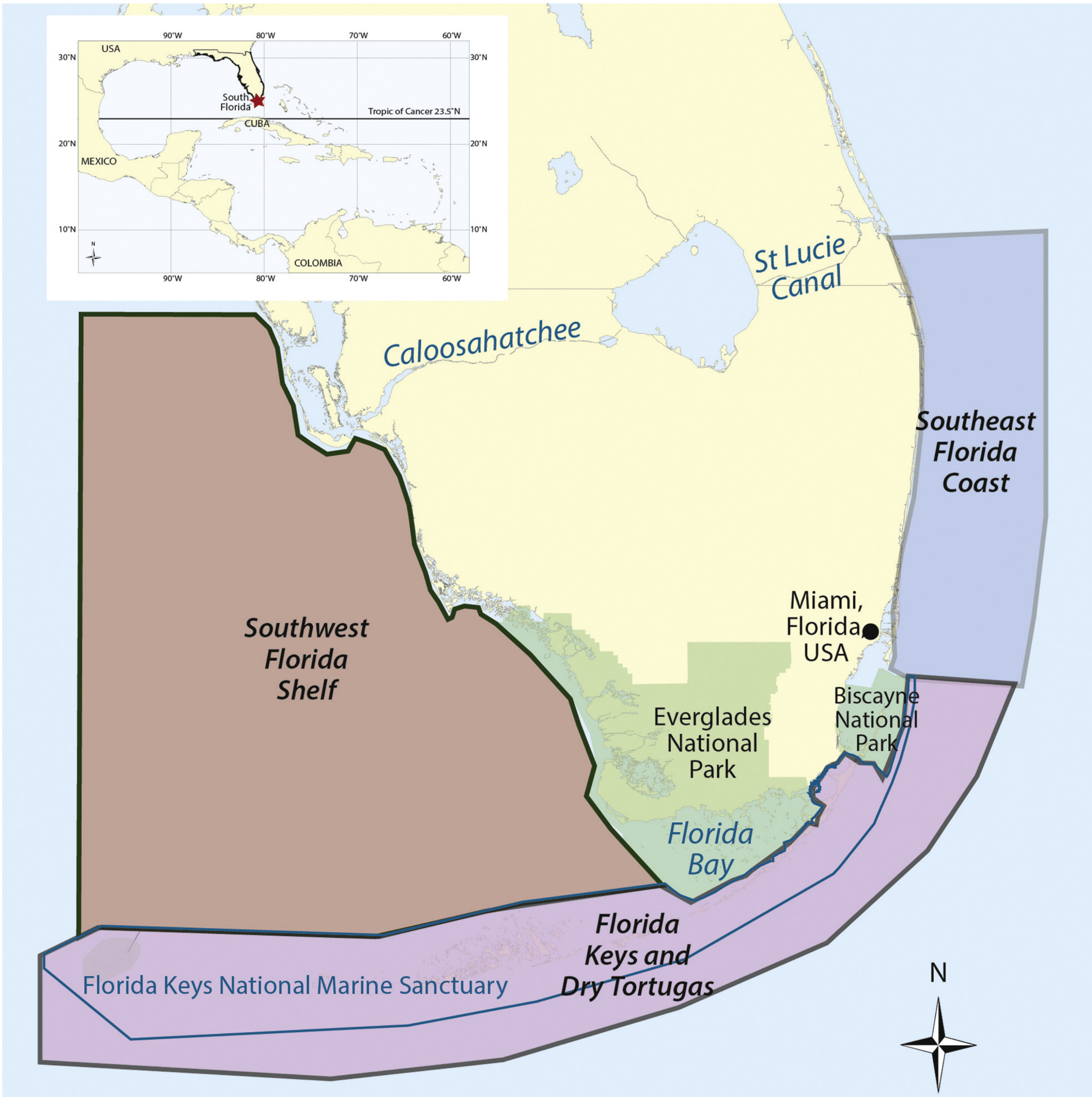

Fig. 1. The MARES domain includes three zones: the Southwest Florida Shelf, Florida Keys and Dry Tortugas, and Southeast Florida Coast.

choices as biological indicators (Caro and O'Doherty, 1999) because they are often high in trophic webs, are important energetic components of ecosystems, show remarkable movement abilities in response to both adversity and opportunity, and are conspicuous and relatively easy to quantify in space and time. There are also numerous examples where links between avian status and environmental variation has been effectively demonstrated and applied (Noss, 1990). Waterbirds have been frequently used to monitor the accumulation of contaminants (Erwin and Custer, 2000) and many contaminants have been shown to affect populations of a suite of aquatic species (e.g., DDT Carson 1962, PCBs and organochlorines, Fox, 2001). Populations of herons, egrets, ibises, and storks have been shown to respond reproductively to specific hydrological patterns in the Everglades (Ogden, 1994), primarily through availability of prey (Frederick and Spalding, 1994; Gawlik, 2002; Herring et al., 2010). Similarly, reproductive parameters of some seabirds are known to be strongly sensitive to changes in local availability of fish stocks (Wanless et al., 2007) and can become a useful tool in monitoring fisheries (Montevecchi, 1993; Frederiksen et al., 2007; Einoder, 2009). The 11 indicator taxa were selected (Table 1) through consensus of the authors, who collectively have more than 300 years of scientific experience in waterbird biology and/or ecology of southern Florida (Ogden et al., in this issue). The ultimate goal of this effort is to develop CEMs around indicator taxa linking drivers and pressures that were identified in Ogden et al. (in this issue) to the critical marine habitats for each species.

Conceptual ecological models are non-quantitative planning tools that link major drivers and pressures on natural systems to a high-priority group of ecological attributes or indicators (Ogden et al., 2005). CEMs link pressures to ecosystem attributes via processes termed ecological effects. Objectives for the development of CEMs include:

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Table 1
Impact scores of pressures on indicator species (From Ogden et al., in this issue)[a].

Drivers and pressures	Reddish Egret	Roseate Spoonbill	Great White Heron	Brown Pelican	Osprey	Bald Eagle	Least Tern	Oyster Catcher	Lesser Scaup	American Coot	Wintering Shorebirds	Mean	Maximum
Climate change													
Ocean acidification	1	1	1	1	1	1	1	3	1	1	1	1.18	3
Sea-level rise	2.5	2.5	2.5	0	0	0	5	5	2.5	2.5	5	2.50	5
Altered water and air temperature	4.5	4.5	4.5	4.5	2.5	2.5	2.5	2.5	0	0	0	2.55	4.5
Altered regional rainfall and evaporation patterns	3	3	3	1	1	1	1	1	1	1	1	1.55	3
Changes in tropical storm intensity, duration, frequency	3	3	3	3	3	3	3	3	3	3	3	3.00	3
Water-based activities													
Fishing	1	1	1	5	5	5	5	5	0	0	0	2.55	5
Marine debris	1	1	1	5	1	1	1	1	1	1	1	1.36	5
Contaminant releases	5	5	5	5	5	5	5	5	5	5	5	5.00	5
Groundings	0	0	0	0	0	0	0	0	0	0	0	0.00	0
Dredging	1	1	1	1	1	1	4.5	4.5	1	1	1	1.64	4.5
Human disturbance (noise etc.)	4	4	4	4	4	4	4	4	4	4	4	4.00	4
Invasive species	4	4	4	4	2	2	5	5	2.5	2.5	2.5	3.41	5
Land-based activities													
Changes in freshwater inflow	5	5	5	5	5	5	5	5	5	5	5	5.00	5
Alteration or loss of shorelines	4.5	1	4.5	1	1	1	5	5	1	1	4	2.64	5
Mean	2.82	2.57	2.82	2.82	2.25	2.25	3.36	3.50	1.93	1.93	2.32		
Maximum	5	5	5	5	5	5	5	5	5	5	5		

[a] Scoring range: 0 = no impact to 5 = most impacted.

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- A big-picture overview of the effects of human alterations at an ecosystem level.
- A basis for the development of working hypotheses, which are key elements in the development of a monitoring and assessment plan and adaptive management.
- A primary communication link between scientists, resource managers, and policy makers regarding the above objectives.

The major components of the CEMs developed here are modified from Ogden et al. (2005):

- Drivers are the major driving forces that operate at a scale larger than the ecosystem, and which have widespread influences on the ecosystem.
- Pressures are the physical and chemical changes that occur within the ecosystem that are brought about by drivers, causing significant changes in ecological components, patterns, and relationships in the system.
- Ecological effects include the physical, chemical, and biological responses caused by stressors, linking stressors to attributes through causal pathways.
- Indicators are comprised of those components of the ecosystem that are representative of overall ecological conditions of the system, and which are significantly affected by the stressors.

Using pre-defined driver/pressure pairs we evaluated expected responses of waterbird indicator species (although one indicator, wintering shorebirds, represents a group of species, we use the term *species* for all indicators for discussion purposes) to pressures using a dichotomous scheme based on Altman et al. (2011) (Ogden et al., in this issue). This process combined an assessment of the resiliency of the indicator with spatial and temporal impacts of the pressure to place the indicator on a zero-to-five scale with a score of five being the maximum negative impact. The conclusions from this companion manuscript are summarized in Table 1. Based on our rationale, only pressures that received a score of three or higher were included in the individual species CEMs (Table 1). The selection process required that we make predictions about how an indicator would respond to some future condition based on past population responses to perturbations (past trends of the indicators are summarized in Table 2). In some cases there was a lot of uncertainty. For example, ocean acidification may have a profound effect on these species throughout their ranges, however, the calcium carbonate substrate of peninsular Florida may buffer these effects within the MARES domain.

The objectives of this paper were to: (1) define key habitats for the selected indicators defined by Ogden et al. (in this issue, Table 1), (2) define ecosystem services provided by these habitats, (3) develop conceptual ecological models for each habitat/species pair and explain the pressures that bear on these pairs, and (4) describe how the model may be applied to make management decisions.

2. Habitats

We identified eight critical foraging or nesting habitats for each of the 11 indicators (Table 3). The birds selected to represent the various habitats were usually specialized in their foraging and nesting needs; however, we found that these needs often could be met in more than one ecosystem. For example, a species requiring submerged aquatic vegetation (SAV) for food might be found in both seagrass beds and interior wetlands. On the other hand, some species are so specialized in their use of a specific habitat that they may stand alone as the only indicator for that habitat type (e.g., great white herons and seagrass beds).

2.1. Habitat definitions

2.1.1. Coastal bays and lakes

Coastal bays and lakes are open water habitats that are partly or entirely enclosed by the mainland shoreline. Examples are Fakahatchee Bay and Chokoloskee Bay in the Ten Thousand Islands and Seven Palm Lake north of Florida Bay. Historically, these bays and lakes were highly productive estuarine habitats that supported many fishery species, either throughout their lives or as juveniles (Lorenz, 2013a; Wingard and Lorenz, in this issue). These places are critical habitat for pelicans, eagles, osprey, least terns, scaup, and coots, although each of these indicators uses the habitat in a different way.

2.1.2. Oyster reefs

Oyster reefs are present in many locations along the southwest Florida coast. Oysters provide ecosystem services in the form of water filtration, storm surge abatement, nutrient sequestration, food prey base support, and habitat for numerous other organisms; they also support a vital fishery (Volety et al., 2009). Oyster reefs are primary foraging habitat for American oystercatchers.

2.1.3. Mud flats, tidal ponds and salterns

Mud flats, tidal ponds and salterns are very shallow areas that generally have little or no submerged or emergent aquatic vegetation. Examples are the interior wetlands on Cape Sable and the interior lakes of Florida Bay keys. These habitats become almost fully exposed on a tidal or seasonal basis, concentrating fish and other prey in the remaining wetted area. Although quite productive themselves, they also receive the productivity of surrounding, more expansive habitats such as mangrove forests as those habitats dry seasonally. Reddish egrets and wintering shorebirds rely on this habitat for foraging.

2.1.4. Seasonally flooded wetlands

Seasonally flooded wetlands are typically estuarine and generally associated with mangrove habitat but are highly diverse and complex (Wingard and Lorenz, in this issue). Water levels go through a distinctive annual cycle (Marmar, 1954; Holmquist et al., 1989) in which water levels climb above the annual mean in May or June, remain above average through November (wet season), drop below the annual mean in December, and remain below average through May (dry season; Wingard and Lorenz, in this issue). One underlying cause of this cycle is seasonal changes in sea surface elevation caused by thermal expansion of Gulf of Mexico waters during summer months and subsequent contraction during the winter (Marmar, 1954; Stumpf and Hines, 1998). Seasonal rainfall patterns, with 60% of the rainfall occurring from June to September and only 25% from November through April (Duever et al., 1994), reinforce the underlying water level cycle. Spoonbills and some wintering shorebirds are dependent on this habitat type to concentrate and expose prey during the dry season.

2.1.5. Beaches

Beaches are high energy environments dominated by sand, shell or rocks. Beach habitat extends along both the southeast and southwest coasts of southern Florida but is rare in the Florida Keys and Florida Bay area. Beaches are primary nesting habitat for least terns and oystercatchers and are foraging and roosting areas for wintering shorebirds.

2.1.6. Near shore open water habitat

Near shore open water habitat is made up of the upper 2 m of littoral and sublittoral zones outside of defined coastal bays and lakes habitats. Marine littoral and sublittoral zones provide critical foraging habitat for brown pelicans, osprey and bald eagles,

Table 2
Summary of documented and inferred changes to waterbird indicator population in southern Florida.

Indicator	References	Type of evidence	Inferred change from historical conditions	Change from initial conditions
Reddish Egret	Powell et al. (1989), Paul (1996), Lowther and Paul (2002)	Quantiative, inferred from field studies	Extirpated by hunting c. 1910; initial population was estimated at 3000–4000 nesting pairs	1970-1980s: Recovered to c. 400 nesting pairs statewide with 169 nests in Florida Bay. 2013: c. 100 nests in southern Florida with < 50 in Florida Bay (JJL unpublished data).
Roseate Spoonbill	Lorenz (2000), Lorenz et al. (2002), Lorenz et al. (2009)	Quantitative,inferred from field studies	Reduced nesting success due to salinity-induced declines in prey number	1979: 1259 nests. 2013: 350 nests, declined 72% since 1979.
Great White Heron	Powell and Powell (1987), Powell et al. (1989)	Quantitative,inferred from field studies	Reduced nest productivity due to reduced prey base	1920s–mid-1980s: Significant decline in nesting success.
Eastern Brown Pelican	Kushlan and Frohling (1985), Ogden (1993)	Quantitative, qualitative professional judgment	Nested commonly in northeastern Florida Bay in the 1980s but have only nested twice since 1991	1976–1993: declined from 850 nests in 1976 to 350 nests in 1993 in Florida Bay.
Osprey	Ogden (1977), Poole (1989), Ogden (1993), Bowman et al. (1989)	Quantitiative, inferred from field studies	Reduced nest numbers and nesting success due to low prey productivity	Florida Bay declined from 200 nests in the 1970s to 70 nests recently.
Bald Eagle	Curnutt (1996), Baldwin et al. (2012)	Quantitative		Consistently about 30 territories in Florida Bay from 1958 to mid 1980s then declined to 50% occupancy in 2003, Territories in northeastern Florida Bay declined from 7 to 1 since mid-1980s.
Least Tern	Zambrano et al. (1997), FFWCC (2011a)	Quantitative, inferred from field studies	Reduced population due to plume hunting c. 1900; population rebounded c. 1970s, and transitioned to rooftops as beach habitat was lost, future loss of rooftop colonies is projected to reduce nest numbers and nesting success	Southeast: 1997 – 1400 pairs in 29 colonies, 93% on rooftops; Keys: 1997–770 pairs in 29 colonies, many on new development spoil; Southwest: early data fragmented, number of colonies locally stable in the last decade.
American Oystercatcher	Douglass and Clayton (2004), Schulte et al. (2010), Zambrano and Warraich (2012)	Quantiative, inferred from field studies	Population probably reduced due to plume hunting c. 1900, generally extirpated as nesters from south Florida due to habitat loss	Currently, c. 15 nesting pairs in the upper Atlantic and Southwest zones, with estd. 15% reduction in nesting pairs due to habitat loss, disturbance, and predation since the 1990s. c. 200 wintering birds on the Southwest shelf, otherwise infrequent in the MARES zone, oyster loss in mid-century likely reduced available forage
Lesser Scaup	Kushlan et al. (1982), National Audubon Society (2010)	Anecdotal warden reports (1930s–1950s), Coot Bay surveys (1951–present), Bay-wide surveys 1977–1980	Reduced wintering populations due to increased salinity and reduced prey productivity	For the region of Coot Bay, number of wintering scaup have declined from a mean of about 16,000 individuals in the early 1950s to about 3000 from 1955 to 1979 to less than 42 currently.
American Coot	Kushlan et al. (1982), National Audubon Society (2010)	Anecdotal warden reports (1930s–1950s), Coot Bay surveys (1951–present), Bay-wide surveys 1977–1980	Reduced wintering populations due to increased salinity and reduced production of submerged aquatic vegetation.	For the region of Coot Bay, number of wintering coots have declined from a mean of about 18,000 individuals in the early 1950s to about 4000 from 1955 to 1979 to less than 900 currently.
Wintering Shorebirds	National Audubon Society (2010)	Quantitative, qualitative	Reduced numbers along many historical wintering locations due to loss of coastal habitat from development	Of 15 species analyzed over the last 25 years, trends in abundance indicate declines for the majority of species, ranging from 22–69%; only Semipalmated Plover and Dunlin show increases while Wilson's Plover and Short-billed Dowitcher appear to be stable. Available data from the past 40–60 years in southern Florida indicates a decrease for all species, with only Semipalmated Plover and Short-billed Dowitcher remaining stable.

which forage in open, shallow nearshore waters, often adjacent to mangrove, seagrass and other productive habitats.

2.1.7. Coastal islands

Coastal islands, either natural or man-made (spoil or shell), are a common feature of the southern Florida landscape. Those islands that are largely free of mammalian predators provide critical nesting habitat for brown pelicans, bald eagles, osprey, and all three wading bird indicators, which commonly or exclusively nest in trees (usually mangroves) on coastal islands. Most of these species are highly vulnerable to mammalian nest predators, and even a single incursion by a raccoon can cause abandonment of an entire colony (Allen, 1942). Islands distant from the mainland are often the only places free of mammalian predators (Strong et al., 1991) and thus serve a vital habitat function for a critical life history stage of these birds.

Table 3
Matrix of habitat dependence for each indicator species identified by Ogden et al. (in this issue). Use of habitat is either foraging (F) or nesting (N).

Habitat	Reddish egret	Roseate spoonbill	Great white heron	Brown pelican	Osprey	Bald eagle	Least tern	American oyster catcher	Lesser scaup	American coot	Wintering shore birds
Coastal bays and lakes				F	F	F	F		F	F	
Oyster reefs								F			
Mud flats/tidal pools and salterns	F										F
Seasonally flooded wetlands		F									F
Beaches							N	N			F
Near shore open water				F	F	F					
Coastal islands	N	N	N	N	N	N					
Seagrass flats			F								

2.1.8. Seagrass flats

Seagrass flats are shallow banks in water less than about 1 m deep that are covered by dense seagrass. Seagrass flats can become exposed by extreme low diurnal or seasonal tides. Large seagrass flats occur throughout the MARES range. Great white herons are strongly dependent upon these areas for foraging, and many of the other indicator species prey upon fishes or crustaceans produced by seagrass flats.

2.2. Ecosystem services

Ecosystem services benefit society both directly and indirectly (Lubchenco, 2009). For example, food, recreation, and storm protection are ecosystem services that directly benefit people. Not only do they provide life's basic needs, but changes in their production impact economic conditions, movement of people, regulation of climate and disease, recreation and cultural opportunities, and security. Such changes can have wide-ranging impacts on human well-being (Carr et al., 2007). Whether humans recognize the influence of ecosystem services in their lives or not, they are reflected in the social and economic attributes of communities and can be measured through indicators such as health, safety, economic security, effective governance, education, food/water, housing, access to critical services, social cohesion, social conflict, and environmental use (Kerenyi, 2011).

A MARES goal was to reach a science-based consensus about the defining characteristics and fundamental regulating processes of a Southern Florida coastal marine ecosystem that is both sustainable and capable of providing the diverse ecosystem services on which our society depends (Kelble et al., 2013). To achieve this goal, it was necessary to consider regional, social, political, cultural, economic, and public health factors, in both a research and management context, along with ecological variables (Kelble et al., 2013). This effort resulted in the categorization of ecosystem services into cultural, regulating, and provisioning (Table 4). All of the habitats listed above provide the services in Table 4, although to varying degrees.

3. Conceptual ecological models

3.1. Pressures that affect all species and all habitats

In a companion manuscript (Ogden et al., in this issue), we determined that four of the pressures we defined (human disturbance, increased frequency of tropical storms, contaminant releases, and alteration of freshwater flows) affected the entire suite of indicators in much the same way (Table 1). Likewise, these four pressures also affected all of our defined habitats. Therefore, instead of including these four pressures in individual species CEMs, we placed them in a waterbird CEM that was not specific to species or habitat (Fig. 2).

Human recreational disturbance at both foraging and nesting sites is increasingly problematic. This stems from an increase in humans recreating and technological advances in the ability of small boats to access shallow water (Ault et al., 2008; York, 1994). Extremely shallow draft outboard boats, kayaks, paddleboards, and personal watercraft can operate in 8" or less of water. Much of the MARES study area is extremely shallow, and the development and popularity of these techniques has meant that boaters can now access nearly all of the area with relative ease. Target recreational activities also seem to put humans in close contact with critical habitats of birds – recreational fishermen, beachgoers, bird watchers, and casual explorers are attracted to spits, islands, bars, and bays – the very sites where birds are most likely to roost, rest, breed, and feed. Even unintended disturbance of nesting birds, especially

Table 4
Ecosystem services provided by the Florida Keys marine ecosystem.

Service type	Service	Description
Cultural	Esthetics and Existence	Provide esthetic quality of aquatic and terrestrial environments (visual, olfactory, and auditory), therapeutic benefits, and pristine wilderness for future generations
	Recreation	Provide a suitable environment or setting for beach activities and other marine activities such as fishing, diving, snorkeling, motorized or non-motorized boating
	Science and Education	Provide a living laboratory for formal and informal education, and scientific research
	Cultural Amenity	Support a maritime way of life, sense of maritime tradition, spiritual experience
Provisioning	Food/Fisheries	Provide safe to eat seafood
	Ornamental Resources	Provide materials for jewelry, fashion, aquaria, etc.
	Medicinal and Biotechnology Resources	Provide natural materials and substances for inventions and cures
Regulating	Hazard Moderation	Moderate extreme environmental events (e.g. mitigation of waves and stormsurge during hurricanes)
	Waste Treatment	Retain storm water; remove nutrients, contaminants, and sediment from water; and dampen noise
	Climate Regulation	Moderate temperature and influence or control other processes such as wind, precipitation, and evaportation
	Atmospheric Regulation	Exchange CO_2, O_2, mercury, etc. with the atmosphere
	Biological Interactions	Regulate species interactions to maintain beneficial functions such as seed dispersal, pest/invasive control, herbivory, etc.

if repeated, can result in strongly reduced reproductive success. Eggs and young chicks normally exist very close to their upper physiological thermal tolerance – even a short time unprotected in direct sun can lead to hyperthermia and death (PCF, unpublished data; Webb, 1987). If the predicted increases in global temperature are realized (IPCC, 2007), this problem will be exacerbated. Flushing birds from nests can also allow opportunities for predation of eggs by crows and other aerial predators (Bjork and Powell, 1990). Even for non-nesting birds, disruption of roosting, feeding, and loafing areas can lead to greatly increased energy expenditure, and low food intake. Humans often bring along dogs and other pets on their excursions, and dogs are excellent at finding nests that are otherwise cryptic to humans. Feral domestic cats also present a large predator hazard (Coleman et al., 1977; Winder and Wallace, 2006). Even single incursions of pets to nesting areas can cause abandonment of nesting and roosting areas. The effects of human disturbance are often hidden – birds flush but return, or appear to habituate to disturbance, making it seem that the effects of disturbance were momentary. However, repeated ecotour visits have been shown to cause abandonment of colonies (penguins) and increase susceptibility to other pressures (Bouton, 1999), both of which occur many weeks after the disturbance.

The IPCC (2007) predicts that the frequency and intensity of tropical storms in the north Atlantic may increase with global climate change. Southern Florida is highly susceptible to hurricane strikes (Duever et al., 1994) and hurricanes have had demonstrable impacts on population sizes in several of these species (e.g., great white herons; Powell et al., 1989). Tropical systems can have strong detrimental effects on habitat, including denuding mangrove forests (Smith et al., 1994), ravaging sand bars and beaches (Wanless et al., 1994), and making foraging impossible for many days afterward. Tropical storm systems have always been a part of the southern Florida environment, and avian species have the necessary life history and behavioral and physiological plasticity to deal with the effects of individual storms (Powell et al., 1989). At issue is whether the plasticity is capable of dealing with increasing frequency and intensity of storms – and the interactive effects of sea level rise. We predict that many species may find habitat grossly reduced by sudden episodic events (Wanless et al., 1994). Not all effects of storms are negative – terns and wintering shorebirds are dependent on mud flats, sand bars, and inlets, which can be created and maintained by storms. It is unclear whether increased storm frequency and higher sea level will result in a net increase or decrease in the various habitats we have described (Wanless et al., 1994).

Contaminant releases pose serious threats to water birds. Oil from the 2010 Deepwater Horizon blow out in the Gulf of Mexico could have infiltrated all southern Florida marine habitats (Smith et al., 2014) and would have had lethal effects on all of these species (Jenssen, 1994; Kajigaya and Oka, 1999). This event increased the realization that the MARES area is susceptible to spills occurring almost anywhere in the Caribbean and Gulf of Mexico, and new deep drilling and transport hundreds of miles away could pose direct threats to birds. Oiling also could have profound and long lasting effects upon habitat (Jackson et al., 1989; Maccarone and Brzorad, 1995; Duke et al., 1997). Other contamination could also come from land, water and aerial nonpoint sources, and now includes novel threats like a huge range of endocrine disrupting compounds (Beck et al., 2008; Gilbert, 2011; Harris et al., 2011), heavy metals (Bielmyer et al., 2005), perfluoronated surfactants (Neimark, 2008), herbicides and pesticides (Scott et al., 2002; Gelsleichterj et al., 2005; Hunt and Nuttle, 2007; Rattner, 2013). Many of these contaminants are bioaccumulative, and birds are at high risk of health impacts because of their position in the food web. Even those compounds that are not usually acutely toxic are known to have physiological and neurological effects that result in lower survival, lower immune function, and decreased reproduction (Rattner, 2013).

MARES habitats are heavily influenced by upstream water management practices. Water management can affect salinity and hydropatterns in wetlands, coastal lakes, and estuaries (Marshall et al., 2008), changing their fundamental properties, lowering overall productivity (Lorenz, 2013a), reducing prey availability (Lorenz and Serafy, 2006), and resulting in decreased nesting success (Lorenz, 2013a,b). Water releases to coastal systems are also strongly dependent upon rainfall. Southern Florida rainfall may become more variable and extreme (IPCC, 2007). If so, coastal systems could see-saw back and forth between saline and fresh in a more volatile fashion than historically or even currently. The effects upon avian habitats and food sources are not well understood; however, high and highly variable salinity has been shown to reduce prey in coastal wetlands (Lorenz, 1999; Lorenz and Serafy, 2006).

3.2. Wading bird CEM: Reddish egret (*Egretta rufescens*), Great White Heron (*Ardea herodias occidentalis*), and Roseate Spoonbill (*Platalea ajaja*)

CEMs for the three wading bird species are remarkably similar, differing only in foraging habitat (Fig. 3). Reddish egrets predominantly forage in shallow, sparsely vegetated or un-vegetated mud flats and salterns (Lowther and Paul, 2002), great white herons generally utilize vast seagrass flats (Meyer and Kent, 2011), and

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spoonbills principally forage in seasonally flooded wetlands and shallow creeks (Lorenz et al., 2002). All three are essentially estuarine, meaning that they depend on the dynamics of intermediate salinities to produce prey and create foraging habitat. This makes them vulnerable to changes in rainfall patterns and consequent water management actions (Lorenz, 2000). In general, water management tends to exaggerate deviations in rainfall, both by flooding avian habitats during periods of high rainfall, and preventing discharges to estuaries during periods of low rainfall (Lorenz and Frezza, 2007).

Changes in rainfall patterns that are predicted to occur with climate change (IPCC, 2007) could cause increased flooding of urbanized/agriculture lands during the nesting season of these three species, prompting massive freshwater discharges for flood control. Such activities have been shown to reverse drying or low water patterns in the foraging habitat of these species, thereby making prey less available during flooding (Lorenz, 2000, 2013b; Lorenz and Frezza, 2007) and reducing nesting success for spoonbills (Lorenz, 2013b). Conversely, under low rainfall scenarios, many important estuarine feeding areas could become euhaline, hypersaline, or highly variable in salinity, thereby lowering prey production (Lorenz and Serafy, 2006).

Many exotic fish species have become established in southern Florida (Kline et al., 2013) and in some cases may displace native species (Harrison et al., 2013). While some exotics are acceptable as prey items, many become too large or are too heavily armored. Even if birds could eat the palatable species, they may present an unstable food source, since cold winters preferentially reduce populations of many exotic fish species that originate from the tropics (Trexler et al., 2000). Competition with natives, reduced palatability, or large-scale weather-related dieoffs could lead to reduced prey availability on foraging grounds during nesting seasons. For example, Harrison et al. (2013) examined the impact of the introduced and ubiquitous (Trexler et al., 2000) Mayan cichlid (*Cichlasoma urophthalmus*) on the native fish community within the coastal mangrove swamps north of eastern Florida Bay. These swamps serve as the primary foraging habitat for nesting roseate spoonbills (Lorenz et al., 2002). Harrison et al. (2013) found that the presence of Mayan cichlids had deleterious affects on several native fish species that are principal components of the spoonbills diet (Powell and Bjork, 1990, Dumas, 2000). Mass mortality of Mayan cichlids occurred during record cold temperatures in January 2010 and they were found to be rare during the following hydrologic year (June 2011–May 2012) relative to collection made during hydrologic years from 1990 to 2010 (RECOVER, 2014). During this time, the native species that Harrison et al. (2013) found to be affected by Mayan cichlids increased in number to the degree that the biomass of the fish community remained similar to years where the much heavier Mayan cichlid was present. At one sampling location, the species that Harrison et al. (2013) found to be negatively affected by Mayan cichlids were four times more abundant than in years that had similar hydrologic conditions but also had Mayan cichlids present (RECOVER, 2014). If the endemic species are more valuable as food items, then the presence of Mayan cichlids may be deleterious to nesting spoonbills by compromising their primary diet.

Mammal and reptile free islands are a critical resource for nesting (Strong et al., 1991). All three species nest on mangrove islands, and commonly nest contemporaneously within the same colony (JJL, personal observation). All have virtually no defensive mechanisms against medium-sized predatory mammals or large reptiles, and the main response is to abandon the colony site and attempt to re-nest somewhere with less predation pressure (Allen, 1942; Lorenz et al., 2002). Single incursions of large nest predators into nesting colonies have resulted in abandonment of the entire colony (Allen, 1942; Strong et al., 1991). Raccoons and other native meso-mammals are becoming more numerous due to increased food resources and decreased predators in human dominated environments. In addition, a suite of reptilian predators (pythons, tegus, iguanas, and monitor lizards) has now become established in southern Florida, all are known to take birds and/or specialize in nest contents, and many are both arboreally adept and highly aquatic (Perez, 2012). Especially in combination with increased human disturbance of nest sites, the increased nest predation and decreased numbers of suitable nesting sites may strongly impact future reproduction of these colonially nesting birds in the MARES area.

Climate models predict higher temperatures and more variable weather patterns for southern Florida (IPCC, 2007; Wang et al., 2010). Higher overall temperatures can cause hyperthermia in unprotected nests (Webb, 1987). Thus, the predicted higher temperatures would exacerbate the effect of nesting colony disruptions by humans and nuisance species. Greater variability in weather patterns suggests an increase in the number and severity of continental cold fronts moving through the MARES domain (Wang et al., 2010). Severe cold fronts can result in nesting failure in the sub-tropical wading bird species by causing hypothermia in eggs or chicks (Webb, 1987, JJL personal observation). Furthermore, these events typically occur during the winter-early spring nesting season, and are accompanied by rainfall, strong winds, and cold temperatures. The three waders all depend to some extent upon a drying pattern of surface water during the normally dry season–increases in cold front frequency are likely to result in more reversals in water trend, which has been linked to poor foraging and nesting failure (Lorenz, 2013b). In addition, cold snaps depress activity of forage fishes and make them less available to foraging birds (Frederick and Loftus, 1993).

3.3. Open water foraging species CEM: Brown Pelican (*Pelecanus occidentalis*), Osprey (*Pandion haliaetus*), and Bald Eagle (*Haliaeetus leucocephalus*)

These three species have in common their types of foraging habitat (Table 3 and Fig. 4), their type of prey, and vulnerability to human impact. All three species eat fish, but they consume different fish species using very different capture methods.

All three species can be impacted by competition from human fishing pressures. Common baitfish harvested in Florida are the primary prey items for pelicans (Borboen et al., 2013) and to some extent osprey. Osprey and eagles commonly take game species that, in turn, depend on baitfish for prey (Ogden et al., in this issue). Both direct (fisheries that directly target their prey) and indirect (fisheries that reduce prey numbers through food web deterioration) food competition with humans will mean less food available for these species (Borboen et al., 2013), which, in turn, may directly affect individual bird's foraging success or reduce their population's reproductive success (Kushlan and Frohling, 1985; Bowman et al., 1989; Viverette et al., 2007).

Like the wading birds, the brown pelican is susceptible to chick mortality due to exposure (Ogden et al., in this issue), so predicted future increases in cold fronts and increased temperatures might have effects on the population (Webb, 1987). Osprey and bald eagles are believed to more tolerant of temperature stresses (Ogden et al., in this issue).

Brown pelicans are the single indicator that is known to experience frequent mortality from human fishing activity and resulting marine debris. Pelicans are frequently injured or die from ingesting fish hooks, or becoming entangled in fishing line (Schreiber, 1980). Pelicans also are strongly attracted to bycatch and will try to eat discarded (fileted) fish carcasses that are too big and puncture their pouch or internal organs (Sachs et al., 2013).

3.4. Beach nesting birds CEM: Least tern (*Sternula antillarum*) and American Oystercatcher (*Haematopus palliatus*)

These two species of beach-nesting birds had the highest adversity scores of all the species we selected (Table 1 and Ogden et al., in this issue). The greatest impact specific to these species was the potential loss of nesting sites through sea level rise, and anthropogenic alteration of shorelines (Fig. 5). Least terns nested historically throughout the MARES region. While only a few oystercatchers breed in the MARES region, this region's coastal habitats, particularly the southwest shelf, are important long duration wintering destinations for this species. Beaches are one of the most developed habitats in southern Florida making them poorly resilient to these pressures. Most beaches are backed by dense human development, and there simply is no place for beaches to migrate upland as sea level rises. Beaches are strongly attractive to people, especially in an urbanized environment that depends heavily on tourism. The consequence is that nest sites are frequently disturbed or destroyed by unaware beach goers or their dogs (Nol and Humphrey, 1994).

For the present population of least terns the effect of the loss of natural beach habitat is compounded by the recent loss of roof-tops – their alternative nesting habitat. Currently, an estimated 80 percent of least terns in Florida nest on roof-tops, and others nest on other artificial sites such as dredge-material and construction sites (Florida Fish and Wildlife Conservation Commission (FFWCC) 2011a). Low rates of nesting success on roof-tops, combined with the phasing out of gravel roofs in new buildings, has prompted the FFWCC to estimate a 30% population decline in least terns in Florida over the next 10 years (FFWCC, 2011a). With further beach loss, there will be little natural nesting habitat available to replace gravel roofs.

Invasive and nuisance species have a profound effect on the nesting success of both least terns and oystercatchers. Mammalian predators are primarily raccoons and feral cats (Hatley and Ankersen, 2003). Nest predators were responsible for more than 50% of nest failures in cases where the cause of failure could be identified (McGowan, 2004). Schulte et al. (2010) discussed increased pressure from nest predators as well as increased recreational disturbance during both the non-breeding and breeding season.

Fishing pressures affect both species but through different processes. The prey base of least terns is commonly harvested as baitfish on their foraging grounds. This harvest has the potential to be so large as to reduce the terns' ability to capture prey (Borboen et al., 2013). Oystercatchers, as their name implies, rely partly on the popular seafood item both for food and for provision of other prey that depend upon oyster reef habitat. Harvest prior to the mid-1940s (McIver, 1989) and use of oyster shell for roadbed material severely reduced the area of oyster bars in southern Florida, and oyster recovery has been strongly affected by altered salinity as a result of water management.

Oystercatchers may be more susceptible to ocean acidification than the other indicator species. A lower pH is likely to occur in most of the oceans as a result of increased CO_2 concentrations worldwide (IPCC, 2007). Lower pH will affect many planktonic forms including bivalves, which will be less able to form carbonate shells during development. The net effect could be a major reduction in ocean productivity worldwide (Doney et al., 2009). In nearshore Florida, it is likely that the effect will be ameliorated to an unknown extent because of buffering by the almost entirely carbonate rock of the peninsula (Borges and Gypens, 2010). But bivalves might be more vulnerable to pH changes because bivalve reefs are further away from shore than most of the other habitats. Therefore, the food and habitat of oystercatchers may be sensitive to this stressor.

3.5. Waterfowl CEM: Lesser Scaup (*Aythya affinis*) and American Coot (*Fulica americana*)

Although all of the pressures that affect these two species are covered in Fig. 2, we felt that the subtle differences between the two species warranted a simple CEM highlighting the effects of changes in freshwater flow on their forage base (Fig. 6). These two species overwinter in similar habitats in the open bays and brackish lakes located along the ecotone between the freshwater Everglades marshes and saltwater coastal environments. The scaup is primarily an invertivore (Austin et al., 1998) while the coot feeds chiefly on submerged aquatic vegetation (SAV; Brisbin and Mowbray, 2002). The coastal ecotone of the Everglades was once characterized by extensive areas of SAV (e.g., *Ruppia maritima* and *Chara* spp.), which supported complex food webs and provided the necessary energy resources for large populations of wintering waterfowl (Ogden, 1994; Simmons and Ogden, 1998; Tabb et al., 1962). Current SAV and waterfowl abundances are now all considerably reduced from pre-drainage (1931–1946) levels (Ogden, 1994). For example, annual Christmas Bird Counts (CBC) conducted in Coot Bay near Flamingo from 1951 to present (National Audubon Society, 2010) reveal that large populations of both species were present in the period 1951–1954 (mean count: 17,914 coots; 15,829 scaup), but these declined rapidly in the mid-1950s (mean counts from 1955 to 1979: 3728 coots, 3111 scaup), and then again in the early 1980s (mean counts 2001–2010: 875 coots and 42 scaup). Reduced SAV habitat has been attributed to increased salinities (Tabb et al., 1962; Simmons and Ogden, 1998) and altered phosphorus dynamics (Frankovich et al., 2011) caused by reduced freshwater inflows due to water management activities (Light and Dineen, 1994).

3.6. Wintering shorebirds CEM

Wintering shorebirds along the coastal regions of southern Florida are a diverse group, consisting of at least 26 species in three families (*Scolopacidae*, *Charadriidae*, *Recurvirostridae*) and 13 genera (*Charadrius*, *Pluvialis*, *Recurvirostra*, *Himantopus*, *Tringa*, *Actitis*, *Catoptrophorus*, *Numenius*, *Limosa*, *Arenaria*, *Calidris*, *Limnodromus*, *Gallinago*). While only a few breed in the MARES region, this region's coastal habitats are important long duration wintering destinations for this entire group. The group uses several different types of habitat (Table 3) and is commonly found in mixed flocks, although species habitat preferences differ by species. Each species forages in water depths favorable to its foraging style and the length of its legs and bill. In general, feeding is by probing for mollusks, crustaceans, marine worms, and/or aquatic insects. All wintering shorebird species are dependent on natural cyclical fluctuations in water levels and the continuous availability of appropriate water depths for their feeding.

Shorebird species occur primarily on broad, tidally-flooded mud/marl flats, around the edges of shallow estuarine pools, in seasonally flooded saline wetlands, and along sandy or rocky beaches. Much former foraging habitat for shorebirds has been developed by humans, and existing habitats are vulnerable to continued development, making the current and future status of these wintering populations a concern (Fernald and Purdum, 1992; Sprandel et al., 1997). Vitally important tidally influenced and often expansive mud and seagrass flats of Florida Bay and Biscayne Bay are protected from development within the boundaries of Everglades and Biscayne National Parks. Similar habitats in the Lower Keys Gulf of Mexico backcountry also have some protection as part of the national wildlife refuge system. However, some of the highest densities of wintering shorebirds within southern Florida use sand/mud flats and beaches close to highly urbanized areas in the seven county region of the southwest Florida coast (Sprandel et al., 1997). Alteration and loss of shorelines have driven shorebirds away from large tracts along both the Atlantic and Gulf coasts and may ultimately eradicate wintering habitat for a number of species if coastal development continues within this region. Hardening of shorelines with seawalls eliminates shoreline foraging habitat for shorebirds, as well as reducing the production of prey associated with shorelines. Ongoing beach renourishment projects in which dredged material is placed on beaches to replace sand lost to erosion could also reduce the productivity of small invertebrates and potentially affect the prey base and foraging accessibility for shorebirds along both coasts of southern Florida.

Sea level rise and subsequent flooding of tidal foraging habitat has the potential to have profound effects on the foraging ability of wintering shorebirds, especially for smaller shorebird species that feed in the shallowest water. Coastal beach erosion will likely lead to continued loss of foraging habitat along both coasts of southern Florida, especially in urban areas where the natural inland migration of beach habitat will be impeded by dense urban development.

Interior, seasonally flooded coastal wetlands are used regularly by a number of *Calidris* sandpipers, plovers, and perhaps other species for both foraging and roosting. Several species use stunted red and black mangroves and emergent vegetation, along tidally and seasonally exposed shorelines dominated by taller mangroves for roosting and resting, particularly during high tide. Several species also use emergent and terrestrial vegetation at the edge of marl pans or within tidally/seasonally exposed prairies of mainland Cape Sable, Everglades National Park (ENP) for roosting and perhaps foraging. For example, hundreds of *Calidris* sandpipers at a time have been observed foraging in open areas of the seasonally flooded succulent halophyte coastal prairies behind Clubhouse Beach, Cape Sable (PEF and RAG, personal observation). The openings in the coastal prairies were created by major hurricanes in 1935, 1960, and 1965, which swept bare the coastal hardwoods that had been in place prior to the hurricanes (Craighead, 1971). This habitat is in close proximity to Lake Ingraham, which Sprandel et al. (1997) described as having the highest mean number of individual shorebirds (2611) during aerial and ground surveys of both coasts of Florida. Due to their close proximity to the open Gulf of Mexico, the only separation being a narrow beach ridge along most of the outer boundary, these habitats will be increasingly exposed to erosion processes as sea levels rise. It is unclear whether higher sea level will result in a net increase or decrease in these types of habitats for wintering shorebirds. Their creation or maintenance may be dependent upon hurricane passage.

Mud flats/banks and tidal pools may be the most ecologically significant foraging habitat for wintering shorebirds. It is uncertain what effects rising sea level will have on these habitats. It is possible that flats development through deposition of sediment may keep pace with a rising sea. Enos and Perkins (1979) documented succession of mud banks on top of carbonate bedrock within the Florida Bay region during Holocene sea level rise and projected the Bay would evolve into a coastal carbonate plain with inland mangrove swamps, similar to the present southwest Florida mainland. This would indicate mud bank environments in open bay habitat could persist. However, their study did not consider a possibly increasing rate of sea level rise.

4. Application of the CEMs

4.1. Reddish egret

4.1.1. Data availability and methods

Multiple sources of data from past efforts provide information on reddish egrets in the MARES region:

- Wading birds were surveyed periodically after Audubon stationed wardens in the Keys and Florida Bay in the 1930s, and old wardens' notes provide historical context for wading bird populations in the 1930s–1950s (Audubon Florida, Everglades Science Center, unpublished data; will be available electronically via the University of South Florida Library in 2015).
- Many areas were surveyed during the winter CBC at twenty-seven count circles since 1900 (National Audubon Society, 2010).
- The Everglades Science Center has intermittent data for Florida Bay (Audubon Florida, Everglades Science Center, unpublished data).
- National Wildlife Refuges in the lower Keys conduct counts periodically (T. Wilmers, Key Deer National Wildlife Refuge, unpublished data).
- Wading Bird Atlases have some quantitative data (Custer et al., 1980; Nesbitt et al., 1982; Runde et al., 1991; Rodgers et al., 2003).
- Florida's Breeding Bird Survey (Kale et al., 1992) provided some data, however, surveys were incomplete for many sites, particularly offshore locations in Monroe County.
- Aerial surveys in 2009 as part of a U.S. Fish and Wildlife funded survey program (ABH, unpublished data).
- National Oceanic and Atmospheric Administration – National Marine Fisheries Service (NOAA-NMFS) and ENP collaborated in a series of systematic monthly counts of water birds in Florida Bay from 1995 through December 1999 (Browder et al., 2000).
- Long-term satellite tracking in the Florida Keys and expanded to Florida's Gulf coast was implemented to examine site fidelity, range sizes, seasonal movements, and survivorship (KDM, unpublished data). These studies will complement wider-ranging research in the western Gulf of Mexico by refining characterizations of suitable foraging habitat and identifying specific critical areas where improved nest-site management might increase local breeding effort and productivity.
- A state-wide survey will be conducted in 2014–2015, funded by the FFWCC.

4.1.2. Benchmarks

Statewide, the reddish egret population is about 10% of the estimated pre-settlement population (Paul, 1991, 1996; Green, 2006); a 43% increase from the currently estimated 350 pairs to 500 pairs statewide might be a reasonable target given the remaining habitat. In the MARES region, the proposed benchmark is 200 pairs (an increase of 33% over 1990 population estimates, and probably 25% of pre-settlement historical nest estimates; Wilmers and Arnett, 2003; FFWCC, 2011b).

4.1.3. Scientific needs

The rarity of the species across such a large spatial expanse has made it very difficult to enact a concerted state-wide monitoring effort. No state-wide survey has been accomplished, although some regional surveys have been conducted (Hodgson et al., 2006; Hodgson and Paul, 2011, 2013). For a statewide survey to be successful, the effort will need to: (1) develop collaborative programs among all interested parties (Kushlan et al., 2002), (2) standardize the method for estimating the population size of reddish egrets (and other wading birds) throughout the MARES region, and (3) integrate standardized surveying into current wading bird monitoring programs. As with other species, accumulating, cataloging, and evaluating the historical field notes of wardens and all the other management programs, could provide useful contextual population information. These data representing almost 100 years of observations that will help put current information into a more useful context. In addition, a management plan should be developed and implemented that results in habitat and population protection.

4.2. Roseate spoonbill

4.2.1. Data availability and methods

The Audubon Florida Everglades Science Center has monitored spoonbill nesting activities in southern Florida intermittently since 1935 and almost continuously from 1987 through present (Lorenz, 2013b). In recent decades, the monitoring program has been funded by the South Florida Water Management District and the U.S. Army Corps of Engineers as part of their Everglades restoration activities. This ongoing program consists of repeated visits to historical nesting locations to count nests and monitor nesting success (spoonbills nest low in the mangrove canopy so aerial surveys are not effective tools for accurate counts). During this process new colonies are discovered or reported and investigated as well. The results produce a total nest count and estimates of nest production (chicks per nest) for various regions of the MARES domain (Lorenz, 2013b).

4.2.2. Benchmarks

Lorenz et al. (2009) proposed the use of roseate spoonbills as an ecosystem indicator and suggested the following targets: (1) at least 1258 nests overall in Florida Bay with 688 nests in the northeastern region of the bay (based on peak historical nesting count), (2) nest production of at least 1.38 chicks per nest (based on the historical production levels), (3) a return to multiple nesting colonies along the southwestern coast of Florida, (4) an average of at least one chick per nest for at least 7 of every 10 years and (5) that the prey base consist of more than 40% freshwater species as defined by Lorenz and Serafy (2006). The last benchmark is an indicator of how productive the foraging grounds are with lower salinity resulting in a larger prey base.

4.2.3. Scientific needs

Currently the spoonbill monitoring program is well funded for the Florida Keys, Florida Bay and Biscayne Bay. Unfortunately, there is no monitoring program along the southwest coast. Extension of monitoring to this area would be costly because these colonies are so remote that a helicopter would be necessary to access most of the colonies. Currently there is little support to implement such work.

4.3. Great white heron

4.3.1. Data availability and methods

The ability to track population size and reproduction in the great white heron is supported by publications, reports, and presentations that provide excellent historic context:

- Published historical information on great white heron population size and reproductive success is extensive (Stevenson and Anderson, 1994; Robertson and Woolfenden, 1992; Powell et al., 1989; Powell, 1996; Cook and Call, 2006; Meyer and Kent, 2011).
- 1885–1971: Numbers of individuals and nesting information for ENP, the Florida Keys, and lower East Coast regions; much of these data come from areas where there are currently long-running CBCs (Audubon Florida, Everglades Science Center, unpublished data; provided as Electronic Supplementary Material).
- 1936–1939: Daily report forms prepared by wardens employed by the National Association of Audubon Societies and stationed in the Florida Bay-Florida Keys area (these reports include numbers of great white herons, including adults and young), also available at the Everglades Science Center.
- 1995–2000: Monthly counts of great white herons and their nests were collected in an aerial census conducted by NOAA-NMFS and ENP with the assistance of Air Station Miami of the U.S. Coast Guard (Browder et al., 2000).

4.3.2. Benchmarks

Population size pre-dating hydrologic perturbations in Florida Bay is thought to have been 2000–2500 breeding individuals or about 1000 breeding pairs (Powell et al., 1989). Historical clutch size was 3.82 ± 0.04 (Powell and Powell, 1987). Recent clutch size, as well as reproductive success, is thought to be considerably less (Meyer and Kent, 2011). This decline may be related to prey availability, as studies indicated that food supplementation increased clutch size, survival of nests, and size of young (Powell and Powell, 1987).

4.3.3. Scientific needs

No comprehensive population survey has been undertaken for this species since the mid-1980s, and regular surveys should be a high priority. There has been no study of the effects of human disturbance on this species, or of the level of disturbance in Florida Bay and the Keys.

4.4. Brown pelican

4.4.1. Data availability and methods

This species nests conspicuously in the upper or outer edges of tree canopies and, therefore, can be easily monitored via aerial surveys following methods described by Kushlan and Frohling (1985).

- Estimates of brown pelican individuals and nesting data within ENP were summarized for the period 1906–1971 (Audubon Florida, Everglades Science Center, unpublished report; provided as Electronic Supplementary Material).
- National Association of Audubon Societies wardens in the Florida Bay and the southwest Gulf Coast regions recorded numbers of adult and young brown pelicans during routine waterbird surveying in 1938 and 1941; these data could provide historical context for brown pelican abundance and nesting dynamics (Audubon Florida, Everglades Science Center, unpublished data; will be available electronically via the University of South Florida Library in 2015).
- Statewide nesting estimates for Florida by individual county from 1971 to 1976 admittedly underestimated the numbers in Florida Bay because the timing of their flights did not synchronize with peak nesting times in that area (Nesbitt et al., 1977).
- Kushlan and Frohling (1985) provide a summary of known pelican nesting in Florida Bay intermittently from 1926 to 1982 including aerial surveys that they performed from 1976 to 1982. They determined that Florida Bay accounted for approximately half to all of the nesting activity in southern Florida.
- Ogden (1993) reported 350 nests in Florida Bay in 1993.
- ENP has made anecdotal observations of pelican nesting numbers while performing aerial surveys of bald eagles nests (OLB and LDO, unpublished data).

4.4.2. Benchmarks

Based on the nest counts of Nesbitt et al. (1977), there were on average 2000 nesting pairs in the MARES domain from 1968 to 1975, not including Florida Bay. Kushlan and Frohling (1985) suggested Florida Bay made up at least half of the total number of nests in southern Florida but they also indicated that these numbers were from an already compromised population number (i.e., their total nest estimates should not be used as a benchmark). Based on these findings we set a benchmark of about 4000 nests in the MARES domain with 2000 occurring in Florida Bay. This would also include a return to consistent nesting in the northeastern region of Florida Bay (Lorenz, 2013b; Ogden et al., in this issue), which has largely been abandoned as a nesting area in recent years (LDO, unpublished data).

4.4.3. Scientific needs

At the very least, the aerial counts made by ENP while surveying bald eagles should continue but financial constraints currently threaten even this minimal effort (LDO, personal observation). Since this species' nesting efforts are so conspicuous from the air, monitoring would take minimal effort if funds were available to perform flights. We propose that at a minimum, monthly flights like those performed by Kushlan and Frohling (1985) should be reinstated and extended to the southwest coast and lower keys. Most studies suggest that pelicans are in decline in the MARES region due to a compromised prey base (Kushlan and Frohling, 1985; Ogden, 1993; Lorenz, 2013b,) however, making the correlation of nesting productivity with prey fish populations would be very valuable in understanding the population trends in this species.

4.5. Osprey and bald eagle

4.5.1. Data availability and methods

- Bald eagles: ENP has one of the longest running monitoring programs for any large raptor species worldwide, with reproductive data collected monthly during the breeding season since 1958 (Baldwin et al., 2012).
- FFWCC has monitored bald eagles throughout the rest of the state, outside of ENP, since 1972, typically with aerial surveys twice a breeding season. Beginning in 2008, FFWCC employed a modified "dual frame method" survey protocol to get a statewide production estimate for bald eagles (Brush and Nesbitt, 2009).
- Ospreys: ENP has bird and nest observation data for the years 1961–1984, 1986–1988, 1990–1991, 1993–1994, 1996-present within ENP with limited data in southern coastal Florida.
- Although recent count data are not available, the FFWCC (2013a) currently estimates 100–150 breeding pairs for the Florida Keys, based on Florida Bay holding 50–70% of the zone's population.

4.5.2. Benchmarks

Bald eagle: an average of 1.5 young/successful territory is generally cited as typical of a healthy population of eagles (Buehler, 2000). Bald eagle nesting success in Florida averages 0.74 (Nesbitt, 2001), exceeding the state's management goal of 0.68 (Brush and Nesbitt, 2009). Productivity of Florida's bald eagle population averaged 1.17 for the period 1999–2008 (Brush and Nesbitt, 2009). In Florida Bay (1996–2010), nesting success was 0.58 (Baldwin et al., 2012). Florida Bay had an average brood size of 1.48 young per successful territory consistently from 1958 to 2010 (Baldwin et al., 2012). However, because brood size remains fairly constant, and the number of contributing territories continues to decrease, total production will eventually suffer (Baldwin et al., 2012).

Osprey: a minimum of 0.8–0.9 young/active nest is thought to be needed for population stability for the species (Poole et al., 2002). Henny and Ogden (1970a,b) found an average of 1.22 young/active nest in Florida Bay during a time when the Florida Bay population was estimated at a healthy 200 pairs. Bowman et al. (1989) found an average of 0.56 young/active nest in Florida Bay during a period of population decline, while they found 1.21 young/active nest in a stable upper Florida Keys population. The non-migratory osprey population of southern Florida has an average clutch size of 2.8 that varies little and does not appear to correlate with pre-laying feeding rates (Poole, 1985; Bowman et al., 1989).

4.5.3. Scientific needs

Occupation of a territory by a mated pair is a key factor in the reproductive output of both the osprey and the bald eagle. The declining number of occupied territories in Florida Bay is a cause of concern that requires continued long-term monitoring of osprey and bald eagle territories, reproductive success, and nest locations in southern coastal Florida. The FFWCC (2013a) has proposed a draft action plan for osprey in southern coastal Florida with 14 action items, each of which would work for bald eagles as well. These include determining occupancy status, reproductive outcome, distribution, and abundance of breeding ospreys and bald eagles through enhanced coordination between ENP and FWC. Genetic analysis, satellite telemetry, and banding programs are strongly needed to examine the potential of non-migratory subpopulations. The availability of forage for the two species in Florida Bay should be monitored by conducting on-the-ground observations of food and feeding rates, possibly through the use of video-nest cameras, at selected nest sites.

4.6. Least tern

4.6.1. Data availability and methods

- National Association of Audubon Societies wardens in the Florida Bay and the southwest Gulf Coast regions recorded numbers of adult and young least terns during routine waterbird surveying in 1938 and 1941; these data could provide historical context for least tern abundance (Audubon Florida, Everglades Science Center, unpublished data; will be available electronically via the University of South Florida Library in 2015).
- A complete census of the Keys found 1400 terns in 1976 (Kushlan and White, 1985).
- Approximately 1000 least terns nested historically in the Dry Tortugas (Kushlan and White, 1985).
- Least terns were breeding in all counties in the three MARES zones in the 1990s (FFWCC, 2003).
- The Florida population of breeding least terns was estimated at 12,562 pairs, based on surveys from 1998–2000 (Gore et al., 2007).
- In 2010, the FFWCC collaborated with multiple partners to create a Florida Shorebird Database (FSD) (https://public.myfwc.com/crossdoi/shorebirds/index.html). The FSD is an online tool and repository for data collected on shorebirds in Florida with a data entry interface that allows for submittal and management of observations. All entered data become freely available.
- The Shorebird Database indicates there are at least 82 known colonies, almost all on rooftops, in the MARES region.
- The Shorebird Database aggregates recent survey years and these data, when analyzed, will provide contemporary population trend assessments.
- Statewide, the species is entirely limited to rooftop colonies in some regions (Zambrano et al., 1997; Gore et al., 2007). Rooftops are currently estimated to support over 80% of the breeding population, which represents a significant shift from the late 1970s when it was estimated that only 21% of the state's least terns nested on rooftops (Fisk, 1978a,b; Zambrano and Warraich, 2012).
- The increase in the least tern population via use of alternative rooftop habitats in southern coastal Florida differs from a pattern of declines by many other shorebirds/seabirds throughout this region; however, recent state construction codes disallow gravel roofs and this habitat will become less available as roofs are remodeled.

4.6.2. Benchmarks

Florida's recent biological status review did not define a minimum target population management goal (FFWCC, 2011a). A logical target would be maintaining the approximate number of colonies and numbers of nesting pairs that occur presently, then defining sites that could be managed in the future to increase the population. New usable habitat is created periodically during various types of construction projects and is available for various time periods, but should not be relied on to provide long-term conservation options.

4.6.3. Scientific needs

A draft species action plan was proposed for four imperiled shorebirds, including least tern (FFWCC, 2013b). Action items applicable to southern coastal Florida in part, include determining occupancy status and reproductive outcome, distribution, and abundance of breeding Least Tern through enhanced coordination between land managers and FWC. Satellite telemetry and banding programs are needed to learn about survivorship at Florida colonies.

4.7. American oystercatcher

4.7.1. Data availability and methods

Recent surveys of oystercatchers that include the MARES domain are:

- Nesting surveys (Douglass and Clayton, 2004; Brush, 2010),
- Winter aerial surveys in 2003, 2008, 2012/2013 (S. Schulte, Manomet Center for Conservation Sciences, personal communication, unpublished data),
- Christmas Bird Counts (National Audubon Society, 2010).
- The FSD provides access to information on nesting Oyster Catchers.

4.7.2. Benchmarks

Florida's recent biological status review defined a minimum target population management goal of 500 breeding pairs, which is thought to be in alignment with historic populations and represents progress toward recovery (FFWCC, 2013b). Although most oystercatchers in the MARES zone are wintering migrants, additional surveys for territories, followed by monitoring occupancy and productivity, would contribute to management strategies that might achieve this goal. A productivity rate of 0.39 fledges/pair was projected to support a stable population of American oystercatchers in North Carolina (Simons and Schulte, 2008). In the recent biological status review the FFWCC (2013b) proposed a minimum 5-year running average productivity rate of 0.5 fledges/nesting pair as a reasonable basis for growth and stabilization of the Florida population of American oystercatchers.

4.7.3. Scientific needs

Current monitoring programs need to be continued and performed regularly using standardized methods. The primary needs for wintering and nesting oystercatchers are: (1) land/water management strategies to acquire and manage habitat and reduce disturbance at winter roosts, foraging sites, and the few nesting territories in the zone; and (2) water management practices that ensure ample estuarine bivalve populations; and range-wide terrestrial predator control. More intensive research such as banding and satellite telemetry programs to follow resident or migrant over-wintering birds or genetic analysis could be conducted in the future.

4.8. Lesser Scaup and American Coot

4.8.1. Data availability and methods

The Coot Bay CBC, held annually from 1949 to present, provides a long-term record of a single-day census of avian abundance in a fixed area (458 km^2) near Flamingo. While the census is limited in areal coverage, and does not account for spatial movements of birds, it is useful for understanding annual variability in waterfowl numbers during a period that covers important changes in water management practices. The census includes both aerial and ground based counts (National Audubon Society, 2010).

Systematic censuses conducted by ENP provide the most extensive data set in terms of spatial coverage (Kushlan et al., 1982). Censuses were conducted by fixed-wing aircraft in each month from November to March during the winters of 1977–1978, 1978–1979 and 1979–1980 and covered all suitable waterfowl habitats in coastal southern and south-west Florida Bay. The counts provide estimates of total scaup and coot abundances in the Everglades estuaries for these years, as well as information on seasonal and geographic distributions.

Waterfowl counts are also available from the notes of Audubon wardens stationed in Florida Bay from the 1930s to 1950s (Audubon Florida, Everglades Science Center, unpublished data) and from those of ENP rangers from the 1940s to 1960s. Though these counts were largely circumstantial in nature, they represent a period prior to 1946 that was largely unaffected by water management practices allowing subsequent data to be considered in a relevant historical context.

4.8.2. Benchmarks

Currently there are no targets for waterfowl in MARES domain. Candidate benchmarks might include the system-wide population estimates of Kushlan et al. (1982), which represents a period (1977–1980) of moderately healthy waterfowl populations in Florida Bay (prior to the population declines of the early 1980s). The average annual Bay-wide populations (calculated from Appendix 4, Kushlan et al., 1982) are 27,713 coots and 8582 scaup.

4.8.3. Scientific needs

To successfully restore waterfowl populations in the Everglades estuaries a greater understanding is needed of the strong linkages among hydrologic patterns, SAV production and invertebrate prey communities. Priority research in this respect should focus on the environmental constraints limiting SAV abundance and distributions, and the underlying mechanisms that have driven ecosystem regime change in these habitats (see Frankovich et al., 2011). An important uncertainty regarding the response of waterfowl to hydrologic restoration is the role of stopping short, wherein ducks overwinter at sites north of traditional wintering areas. Understanding the responses of waterfowl to hydrologic restoration and the role of shortstopping (i.e., stopping at Indian River Lagoon rather than flying further south) will require regular comprehensive waterfowl surveys, which have not been conducted since the late 1970s.

4.9. Wintering shorebirds

4.9.1. Data availability and methods

- The CBC (National Audubon Society, 2010) is the longest running count effort that covers habitat for wintering shorebirds throughout the region and provides the best available data source, both current and historical. Twenty seven count circles presenting shorebird information have been identified within the MARES region, with period of record beginning in 1904. Fifteen of these circles are currently (2012–13) still reporting data with effective period of record for seven of these beginning in the 1950s, four in the 1960s, and one each in 1970, 1980, 1998 and 2001. A complicating factor with these data is that expertise of participants has become more sophisticated over time, particularly in regards to the identification of shorebirds, a taxonomic group renowned for identification difficulties in the field.
- Additional data may be available from shorebird surveys conducted quarterly by the Florida State Park System, which have occurred along the Atlantic coast and the Keys, beginning in 1990. These surveys are conducted the first four days of June,

September, December, and March. The locations of the parks conducting these surveys is unknown and surveying at a number of them are known to have been dropped, however quarterly monitoring is still being performed at Bahia Honda State Park in the middle Keys (Janice Duquesnel, Florida Department of Environmental Protection-Florida State Park Service, personal communication 2013).

- The Shorebird Database aggregates recent survey years and these data, when analyzed, will provide contemporary population trend assessments.
- National Association of Audubon Societies wardens in the Florida Bay and the southwest Gulf Coast regions reported on shorebird species presence and abundance during routine waterbird surveying in 1938 and 1941; these data could provide historical context for shorebird species diversity and abundance (Audubon Florida, Everglades Science Center, unpublished data; will be available electronically via the University of South Florida Library in 2015).

4.9.2. Benchmarks

Currently no standardized benchmarks have been established for wintering shorebirds on their wintering grounds within the MARES region. Unlike locally nesting and permanent southern Florida resident bird species, benchmarks are difficult to define for wintering shorebirds due to their highly transient nature and migratory cycles, where the overall population is strongly influenced by factors external to their wintering habitat in southern Florida. Benchmarks should be established based on known regional habitat affinities, analyses of historic habitat loss, and a candid assessment of what habitat could be conserved in the future. An alignment with hemispheric targets for each species would give regional efforts greater relevance.

During a 1993–1994 survey of locations identified to be important sites for wintering shorebirds along the entire coastal region of Florida, Sprandel et al. (1997) estimated a mean total of 30,502 individual shorebirds wintering at 60 sites during multiple surveying events. Of these sites, 11 were located within the MARES scope along the southwest coast and Everglades regions. The mean total number of individual shorebirds estimated at these 11 sites was 7616, accounting for 25% of the statewide estimate. Statewide, 5 sites averaged >1000 shorebirds per visit, two of which were located in the MARES region: Lake Ingraham, southeast end ($\bar{x} = 2611$ individual birds; 7.3 species) and northwest of Palm Key ($\bar{x} = 1753$ individual birds; 3.3 species). Some of the survey sites were only monitored aerially during this study and findings may not be representative of the true wintering population. Notably, as part of the 2012–13 Coot Bay CBC (CBC circle code: FLCE), a total of 20,836 individual wintering shorebirds, comprising 16 species were estimated on the one day count conducted on December 29, 2012 by the authors (PEF, RAG); 20,045 of these birds were counted within the southeast end of Lake Ingraham.

4.9.3. Scientific needs

A standardization of methods for estimating population dynamics of wintering shorebirds within this region is a primary need, with the goal of setting a benchmark to allow accurate future assessment of population trends. This may be accomplished through assessment of shorebirds as a whole or by choosing a number of specific species. A framework for strategic future sampling has been outlined by Johnson (2011) for use in the Audubon Coastal Bird Survey. Integration of standardized surveying techniques into current shorebird monitoring programs will be essential for making future resource based management decisions. Another immediate scientific need is to identify and catalog current shorebird aggregations, taking into account any different habitat needs or habitat use patterns among the species and determining the conservation status of the habitat. The most feasible approach is to join with the State Interagency Partnership coordinated by FFWCC. A list of sites showing, at minimum, place name, general location description, coordinates, approximate acreage, viewing date, conservation status, nearest CBC site, and species and estimated number of shorebirds sighted on viewing date would be advantageous. In southern Florida, no other effort has consistently documented wintering shorebirds for as long a period as the CBC. Some of the regional circles have had traditional styles of coverage or protocols over significant periods, however, the project's weak standardization renders much of its data unsuitable for controlled population trend analyses. A strengthening of protocols to increase the scientific value of future data collection is needed.

5. Discussion

Some of the pressures identified will present themselves in fairly obvious ways. For example, if great white herons turn up coated in oil, there is likely an oil spill problem in either the nesting (mangroves) or foraging (seagrass beds) habitats, or more likely in both. In this case it is fairly obvious what actions mangers/decision makers will have to take. However, this tool can be used for more subtle pressures. For example, if the numbers of least terns, oystercatchers and wintering shorebirds all decline simultaneously, the problem is likely affecting beach habitats because all three indicators depend on that habitat. Managers may take a closer look at beach nesting sites and find widespread disturbance issues, thereby defining what corrective actions need be taken. On the other hand, if only oystercatchers begin to decline while the other two remain steady or increase then the manager is directed to looking at potential pressures that affect oyster reefs rather than beaches. In this way, the multiple species approach can help lead managers/decision makers to the root of changes in the hydroscape.

No indicator or suite of indicators can be absolute in their ability to evaluate change, especially for future, novel conditions. On multiple occasions we have speculated about the response of the indicator to some future condition and there is a high degree of uncertainty in these cases (as indicated by dashed lines in Figs. 2–7). These speculative responses to possible future conditions, are, however, based on our best understanding of the biological functioning of the indicator within the ecosystem at this time. It is also possible that the indicators can respond negatively to a positive condition or vice versa. For example, conditions with the coastal bays and lakes may improve ecologically with increased freshwater flow but the waterfowl may decline due to some unrelated condition in their geographically distant summer habitats. Finally, this suite fails to assess major portions of the MARES landscape. For example, coral reefs and offshore benthic habitats have no representative water bird indicator. There simply are not species of birds that depend solely on these habitats for their existence.

The successful use of any waterbird as an indicator therefore includes several common elements. First, correlative (or preferably) mechanistic links between environmental variation and avian parameters are necessary for use of birds as indicators. Second, the links need to be matched appropriately in type, timing, and space with the environmental variables of interest. Third, the parameter predicted or monitored by birds needs to be of predictive value with respect to some broader ecosystem function–if other species or resources are not affected, the inference is of little value. In each of the indicator species we cite here, we have attempted to satisfy all three of these prerequisites.

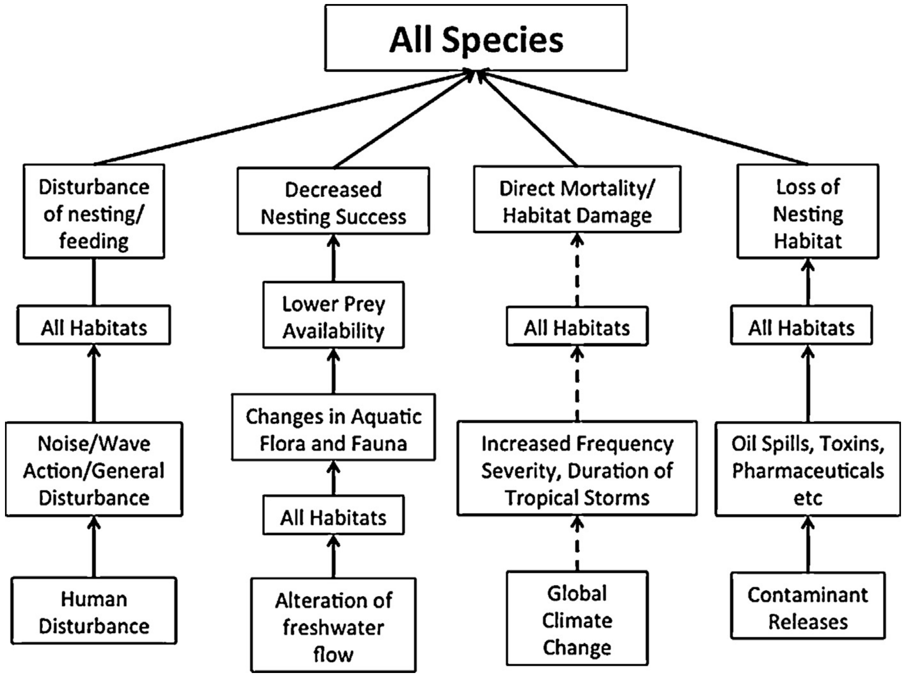

Fig. 2. Conceptual Ecological Model of pressures that affect all species/habitat combinations. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

A critical criterion for selecting an indicator is that its responses can be communicated easily to non-scientists. Water birds, because of their size, appearance, habitat, and behavior, are highly conspicuous and esthetically pleasing. Furthermore, there is an intuitive realization that their number and well-being are related to ecosystem health, with declines in bird diversity and number suggesting declining ecosystem health. Because there may have been a thrill and memory associated with seeing brilliant birds in close proximity, people will ask "what happened to all the roseate spoonbills we used to see in the wetlands along the highway?" It is also relatively easy for ecologists to track these changes (as compared to quantifying, for example, the number of a given fish species in Florida Bay) and to equate them to ecosystem functions. Since the loss of brilliantly colored birds demands an explanation, it is easy to intuit a simple connection: Everglades drainage has resulted in less freshwater flow to the estuaries, which raised salinity and lowered productivity, resulting in a diminished number of spoonbills. This statement belies the immense amount of money, scientific effort,

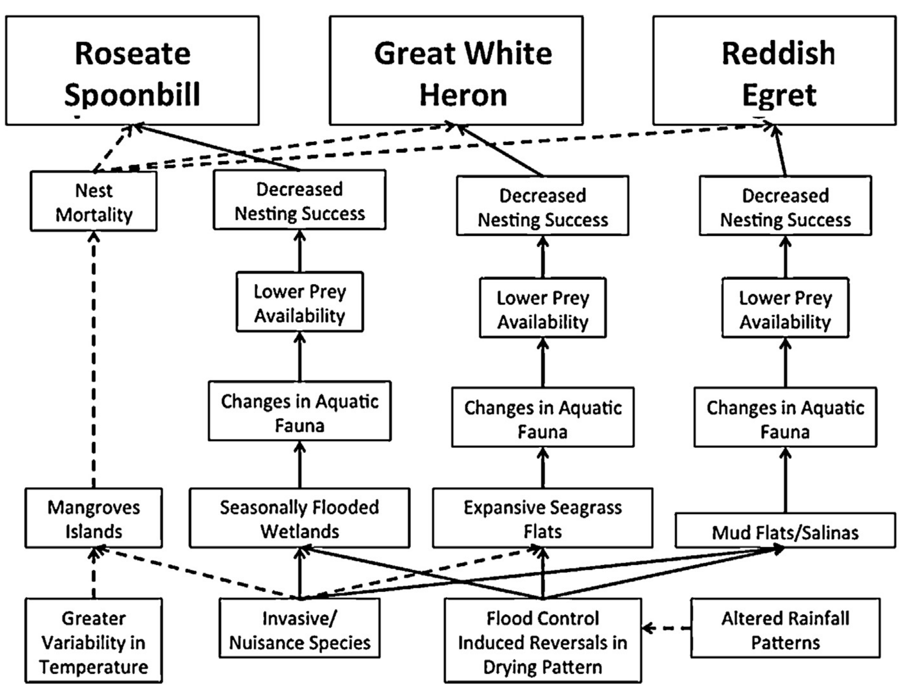

Fig. 3. Wading bird conceptual ecological model. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

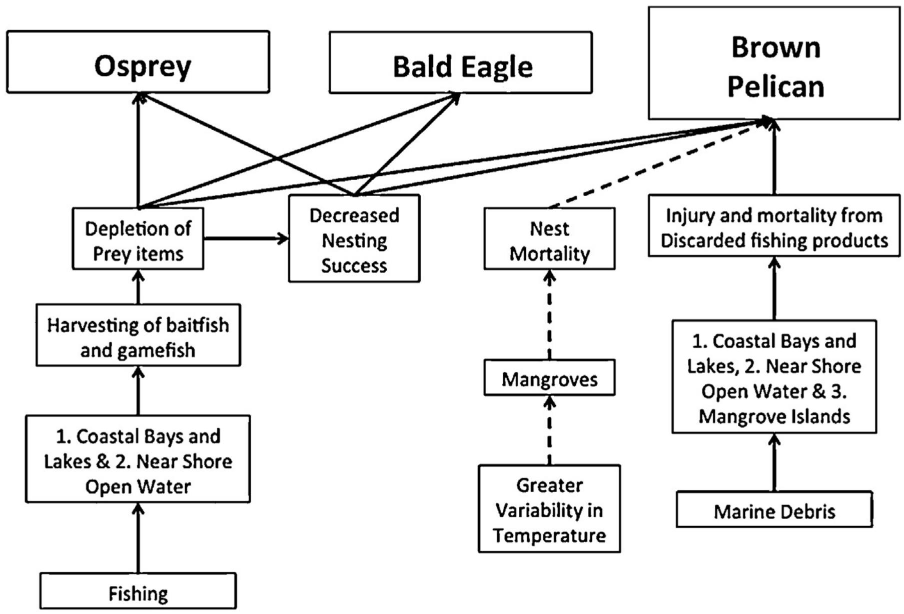

Fig. 4. Open water piscivores conceptual ecological model. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

and sorting of ecological complexity that backs the relationship. In addition, a positive response of these species from habitat protection or restoration effort is instantly accepted by the public as a positive result. People seeing noticeably more of these birds and being able to equate those numbers to their tax dollars being spent on restoration efforts support the concept that the money was not wasted.

In our companion manuscript (Ogden et al., in this issue), we evaluated the sensitivity of this suite of waterbirds to anthropogenic pressures in the coastal marine environments of southern Florida. This manuscript examined the ecological links between the pressures and the indicators through ecosystem processes such that the health of overall hydroscape could be evaluated. Through the use of this suite of indicators, the ecological function of the various ecosystems and habitats can be evaluated to guide restoration and protection efforts of this invaluable resource (Table 4). It is important to remember that no single indicator or even suite of indicators can reflect all there is to know about the health of the hydroscape. However, it is also clear that we can use responses by individual species to infer pressures based on known ecological relationships. The avian indicators demonstrate that the hydroscape is badly degraded compared with historical conditions (Table 2). They further identify changes necessary to reduce the current pressures that are negatively impacting waterbirds and their coastal habitats in southern Florida.

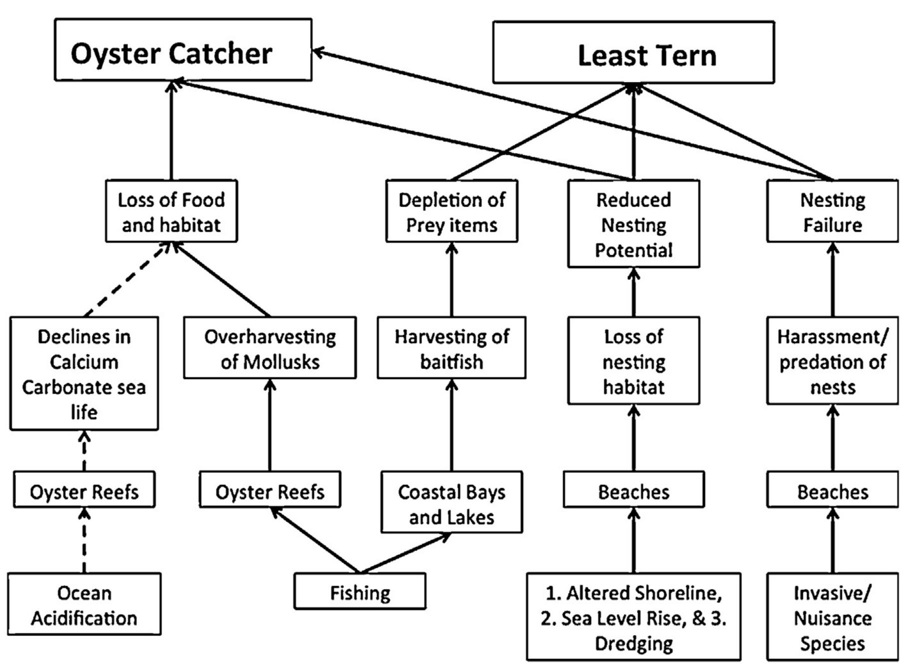

Fig. 5. Beach nesting birds conceptual ecological model. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

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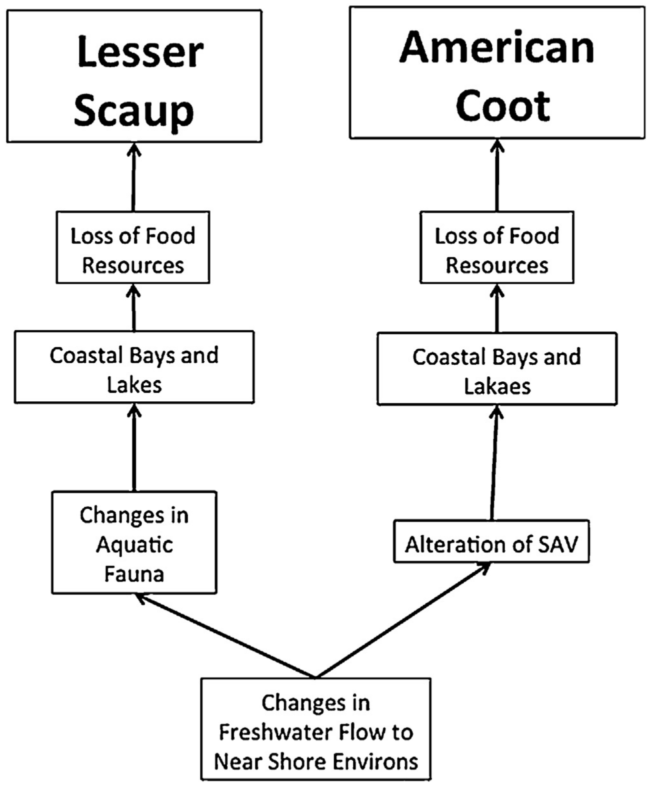

Fig. 6. Waterfowl conceptual ecological model. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

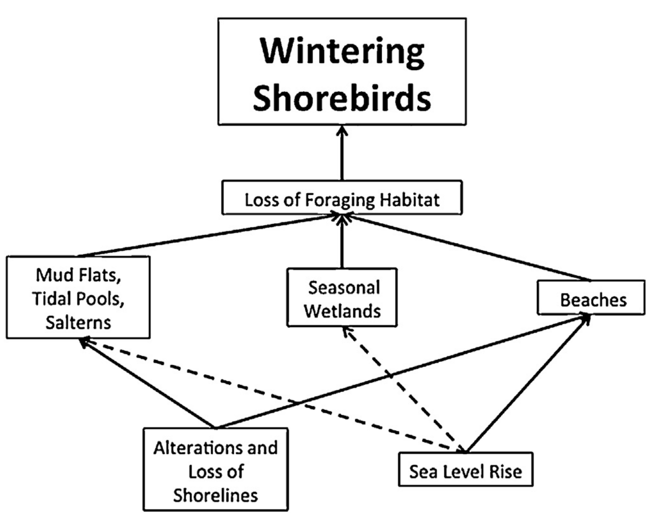

Fig. 7. Wintering shorebird conceptual ecological model. Dashed lines represent relationships that have a higher degree of uncertainty than solid lines.

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The late John C. Ogden, renowned ornithologist and southern Florida ecologist, took the lead in developing the waterbird ecosystem indices. In cooperation with the senior author (JJL), JCO identified species that were representative of as many of the marine habitat types as possible. The ultimate goal of this effort was to develop Conceptual Ecological Models (CEM's) around indicator species linking drivers and pressures that were identified in the companion manuscript (Ogden et al., in this issue) to the critical marine habitats for each species. Well into this process, the lead author was diagnosed with and succumbed to a rapidly developing form of cancer. The senior author then enlisted the help of the remaining authors to complete the original task.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2014.03.008.

References

Allen, R.P., 1942. The Roseate Spoonbill. Dover Publications Inc., New York.

Altman, I., Blakeslee, A.H.E., Osio, G.C., Rillahan, C.B., Teck, S.J., Meyer, J.J., Byers, J.E., Rosenberg, A.A., 2011. A practical approach to implementation of ecosystem-based management: a case study using the Gulf of Maine marine ecosystem. Front. Ecol. Environ. 9 (3), 183–189, http://dx.doi.org/10.1890/080186.

Ault, J.S., Smith, S.G., McClellan, B., Zurcher, N., McCrea, A., Vaughan, N.R., Bohnsack, J.A., 2008. Aerial surveys of boater use in Everglades National Park marine water: Florida Bay and Ten Thousand Islands. NOAA Technical Memorandum NMFS-SEFC-581.

Austin, J.E., Custer, C.M., Afton, A.D., 1998. Lesser Scaup (*Aythya affinis*). In: Poole, A. (Ed.), The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/338 doi:10.2173/bna.338 (accessed 30.08.13).

Baldwin, J.D., Bosley, J.W., Oberhofer, L., Bass, O.L., Mealey, B.K., 2012. Long-term changes, 1958–2010, in the reproduction of Bald Eagles of Florida Bay, southern coastal Everglades. J. Raptor Res. 46 (4), 336–348.

Beck, G., Miller, R., Ebersole, H., 2008. Significance of immune responses in *Diadema antillarum* to Caribbean-wide mass mortality. In: Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, FL, 7–11 July 2008 Session number 7.

Bielmyer, G.K., Brix, K.V., Capo, T.R., Grosell, M., 2005. The effects of metals on embryo-larval and adult life stages of the sea urchin, *Diadema antillarum*. Aquat. Toxicol. 74, 254–263.

Bjork, R.B., Powell, G.V.N., 1990. Studies of Wading Birds in Florida Bay: A Biological Assessment of the Ecosystem. National Audubon Society, Comprehensive report to the Elizabeth Ordway Dunn Foundation, Tavernier, Florida.

Borboen, M., Liston, S., Lorenz, J., Korosy, M., Wraithmell, J., Podey, A., 2013. Fins and Feathers: Why Small Fish are a Big Deal for Florida's Coastal Birds. Report to the Pew Charitable Trusts. Audubon Florida, Tallahassee FL.

Borges, A.V., Gypens, N., 2010. Carbonate chemistry in the coastal zone responds more strongly to eutrophication than to ocean acidification. Limnol. Oceanogr. 55 (10), 346–353.

Bouton, S.N., 1999. Ecotourism in Wading Bird Colonies in the Brazilian Pantanal: Biological and Socioeconomic Implications. University of Florida.

Bowman, R.G., Powell, G.V.N., Hovis, J.A., Kline, N.C., Wilmers, T., 1989. Variations in reproductive success between subpopulations of the osprey (*Pandion haliaetus*) in south Florida. Bull. Mar. Sci. 44, 245–250.

Brisbin Jr., I.L., Mowbray, T.B., 2002. American Coot (*Fulica americana*). In: Poole, A. (Ed.), The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, http://dx.doi.org/10.2173/bna.697a, Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/697a (accessed 30.08.13).

Browder, J., Bass, O., Jackson, T., Gebelein, J., Wong, H., Osborne, J., Oberhofer, L., Alvarado, M., 2000. Wading bird activity in Florida Bay. In: Presentation to First Annual Florida Wading Bird Symposium: Monitoring Wading Bird Populations. Nov 10, 2000 at the Archbold Biological Station, Highlands County, FL.

Brush, J., 2010. American Oystercatcher Monitoring Annual Report, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Wildlife Research Section, Avian Research Subsection. Tallahassee, FL.

Brush, J.M., Nesbitt, S.A., 2009. Annual Report Bald Eagle Population Monitoring for State of Florida. Florida Fish and Wildlife Research Institute, Gainesville, Florida.

Buehler, D.A., 2000. bald eagle (*Haliaeetus leucocephalus*). In: Poole, A. (Ed.), The Birds of North America. Cornell Lab of Ornithology, Ithaca, New York.
Carr, E.R., Wingard, P.M., Yorty, S.C., Thompson, M.C., Jensen, N.K., et al., 2007. Applying DPSIR to sustainable development. Int. J. Sustain. Dev. World Ecol. 14, 543–555.
Caro, T.M., O'Doherty, G., 1999. On the use of surrogate species in conservation biology. Conserv. Biol. 13, 805–881.
Cook, M.I., Call, E.M., 2006. South Florida Wading Bird Report 12. South Florida Water Management District, West Palm Beach, Florida.
Craighead, F.C., 1971. The Trees of South Florida, vol. 1. University of Miami Press, Coral Gables, FL.
Coleman, J., Temple, S., Cravin, S., 1977. Cats and Wildlife: A Conservation Dilemma. Texas Parks and Wildlife, Austin, TX.
Curnutt, J.L., 1996. Southern bald eagle. In: Rodgers, J.A., Kale, H.W., Smith, H.T. (Eds.), Rare and Endangered Biota of Florida, volume 5: birds. University of Florida Press, Gainesville, pp. 179–187.
Custer, T.W., Osborn, R.G., Stout, W.F., 1980. Distribution, species abundance, and nesting-site use of Atlantic coast colonies of herons and their allies. Auk 97, 591–600.
Doney, S.C., Fabry, V.J., Feely, R.A., Kleypas, J.A., 2009. Ocean acidification: the other CO_2 problem. Annu. Rev. Mar. Sci. 1, 169–192.
Douglass, N.J., Clayton, L.C., 2004. Survey of Breeding American Oystercatcher (*Haematopus palliatus*) Populations in Florida. FWC Bureau of Wildlife Diversity Conservation Final Report, Tallahassee, FL.
Duever, M.J., Meeder, J.F., Meeder, L.C., McCollom, J.M., 1994. The climate of south Florida and its role in shaping the Everglades ecosystem. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL, pp. 225–248.
Duke, N.C., Zuleika, M., Pinzon, S., Prada, M.C., 1997. Large scale damage to mangrove forests following two large oil spills in Panama. Biotropica 29, 2–14.
Dumas, J.V., 2000. Roseate Spoonbill (*Platalea ajaja*). In: Poole, A. (Ed.), The Birds of North America. Cornell Lab of Ornithology, Ithaca, New York, http://dx.doi.org/10.2173/bna.490 http://bna.birds.cornell.edu/bna/species/490 (accessed 10.11.12).
Einoder, L.D., 2009. A review of the use of seabirds as indicators in fisheries and ecosystem management. Fish. Res. 95, 6–13.
Enos, P., Perkins, R.D., 1979. Evolution of Florida Bay from island stratigraphy. Geol. Soc. Am. Bull. Pt. I 90, 59–83.
Erwin, M.A., Custer, T.W., 2000. Herons as indicators. In: Kushlan, J., Hafner, H. (Eds.), Heron Conservation. Academic Press, San Diego California, pp. 311–331.
Fernald, E.A, Purdum, E.D (Eds.), 1992. Atlas of Florida. Univ. Press Florida, Gainesville, pp. 280–289.
Fisk, E.J., 1978a. Least Tern. In: Kale, H.W. (Ed.), Rare and Endangered Biota of Florida, vol. 2, Birds. University Presses of Florida, Tallahassee, FL, pp. 40–43.
Fisk, E.J., 1978b. Roof-nesting terns, skimmers, and plovers in Florida. Fla. Field Nat. 6, 1–8.
Florida Fish and Wildlife Conservation Commission, 2003. Florida's Breeding Bird Atlas: A Collaborative Study of Florida's Birdlife. http://myfwc.com/bba (accessed 07.15.13).
Florida Fish and Wildlife Conservation Commission, 2011a. Least Tern Biological Status Review Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL http://myfwc.com/media/2273337/Least-Tern-BSR.pdf (accessed 15.07.13).
Florida Fish Wildlife Conservation Commission, 2011b. Reddish Egret Biological Status Review Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL http://myfwc.com/media/2273367/Reddish-egret-BSR.pdf (accessed 12.02.13).
Florida Fish Wildlife Conservation Commission, 2013a. Draft: A Species Action Plan for the Osprey (Pandion haliaetus) of Monroe County. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL http://share1.myfwc.com/ISMP/Bird Management Plans/Osprey SAP with CAT_Final Draft.pdf (accessed 08.02.13).
Florida Fish Wildlife Conservation Commission, 2013b. Draft: A Species action plan for four imperiled beach-nesting birds: American oystercatcher Haematopus palliatus, Snowy plover Charadrius nivosus, Least tern Sternula antillarum Black skimmer Rynchops niger. http://share1.myfwc.com/ISMP/Bird Management Plans/Beachnesting Bird SAP with CAT_Final Draft.pdf
Frankovich, T.A., Morrison, D., Fourqurean, J.W., 2011. Benthic Macrophyte Distribution and Abundance in Estuarine Mangrove Lakes and Estuaries: Relationships to Environmental Variables. Estuar. Coasts 34, 20–31.
Fox, G.A., 2001. Wildlife as sentinels of human health effects in the Great Lakes – St. Lawrence basin. Environ. Health Perspect. 109, 853–861.
Frederick, P.C., Spalding, M.G., 1994. Factors affecting reproductive success of wading birds (Ciconiiformes) in the Everglades. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades: The Ecosystem and its Restoration. St. Lucie Press, Del Ray Beach, FL, pp. 659–691.
Frederick, P.C., Loftus, W.F., 1993. Responses of marsh fishes and breeding wading birds to low temperatures; a possible behavioral link between predator and prey. Estuaries 16, 216–222.
Frederiksen, M., Furness, R.W., Wanless, S., 2007. Regional variation in the role of bottom-up and top-down processes in controlling sandeel abundance in the North Sea. Mar. Ecol. Prog. Ser. 337, 279–286.
Gawlik, D.E., 2002. The effects of prey availability on the numerical response of wading birds. Ecol. Monogr. 72, 329–346.
Gelsleichterj, J., Manire, C.A., Szabo, N.J., 2005. Organochlorine concentrations in bonnethead sharks (Sphyrna tiburo) from four Florida estuaries. Archiv. Environ. Contam. Toxicol. 48 (4), 474–483.
Gilbert, N., 2011. Drug waste harms fish. Nature 476, 265.
Gore, J.A., Hovis, J.A., Sprandel, G.L., Douglass, N.J., 2007. Distribution and Abundance of Breeding Seabirds along the Coast of Florida 1998–2000. Final Performance Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.
Green, M.C., 2006. Status Report and Survey Recommendations on the Reddish Egret (*Egretta rufescens*). U. S. Fish and Wildlife Service, Atlanta, GA.
Harris, C.A., Hamilton, P.B., Runnalls, T.J., Vinciotti, V., Henshaw, A., Hodgson, D., Coe, S., Jobling, S., Tyler, C.R., Sumpter, J.P., March 2011. The consequences of feminization in breeding groups of wild fish. Environ. Health Perspect. 119 (3).
Harrison, E., Lorenz, J.J., Trexler, J.C., 2013. Per capita effects of non-native Mayan Cichlids (*Cichlasoma urophthalmus*; Gunther) on native fish in the estuarine southern Everglades. Copeia 2013, 80–96.
Hatley, P.J., Ankersen, T., January 2003. Feral Cat Colonies in Florida: The Fur and Feathers are Flying. A Report to the U. S. Fish and Wildlife Service. University of Florida Conservation Clinic, Gainesville.
Henny, C.J., Ogden, J.C., 1970a. Estimated status of osprey populations in the United States. J. Wildl. 34, 214–217.
Henny, C.J., Ogden, J.C., 1970b. Estimated status of osprey populations in the United States. J. Wildl. Manage. 34, 214–217.
Herring, G., Gawlik, D.E., Cook, M.I., Beerens, J.M., 2010. Sensitivity of nesting Great Egrets (*Ardea alba*) and White Ibises (*Eudocimus albus*) to reduced prey availability. Auk 127, 660–670.
Hodgson, A.B., Paul, A.F., 2011. The Status of Reddish Egrets in Tampa Bay, Florida, USA, 1874–2008. Prepared for U. S. Fish and Wildlife Service, Atlanta, GA.
Hodgson, A.B., Paul, A.F., 2013. Reddish Egret (*Egretta rufescens*) nesting in Clearwater Habor and St. Joseph Sound, Pinellas County, and Crystal Bay, Citrus County, Florida, from 1991 to 2011. Fla. Field Nat. 41 (2), 29–41.
Hodgson, A.B., Paul, A.F., Rachal, M.L., 2006. Chapter 14 Birds. Baywide Environmental Monitoring Report, 2002–2005, Technical Publication 06-06. Tampa Bay Estuary Program, St. Petersburg, FL, pp. 14-1–14-14.
Holmquist, J.G., Powell, G.V.N., Sogard, S.M., 1989. Sediment, water level and water temperature characteristics of Florida Bay's grass-covered mud banks. Bull. Mar. Sci. 44, 348–364.
Hunt, J., Nuttle, W. (Eds.), 2007. Florida Bay Science Program: A Synthesis of Research on Florida Bay. Florida Wildlife Research Institute Technical Report TR-11.
IPCC, 2007. Climate change 2007: The scientific basis. Contribution of Working Group I. In: Soloman, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Jackson, J.B.C., Cubit, J.D., Keller, B.D., Batista, V., Burns, K., Caffey, H.N., Caldwell, R.L., Garrity, S.D., Getter, C.D., Gonzalez, H.M., Guzman, H.M., Kaufmann, K.W., Knap, A.H., Levings, S.C., Marshall, M.J., Steger, R., Thompson, R.C., Weil, E., 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. Science 243, 37–44.
Jenssen, B.M., 1994. Effects of oil pollution, chemically treated oil, and cleaning on the thermal balance of birds. Environ. Pollution 86 (2), 207–215.
Johnson, E.I., 2011. A Strategic Sampling Plan for the Audubon Coastal Bird Survey. National Audubon Society, Baton Rouge, LA, pp. 10.
Kajigaya, H., Oka, N., 1999. Physical effects of oil pollution on birds. J. Yamashina Inst. Ornith. 31 (1), 16–38.
Kale II, H.W., Pranty, B., Stith, C.W., Biggs, B.M., 1992. The atlas of the breeding birds of Florida. Final Report. Florida Game and Fresh Water Fish Commission, Tallahassee, FL.
Kelble, C.R., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Cook, G., Lorenz, J., Boyer, J.N., Wood, M., 2013. The EBM-DPSER model: integrating ecosystem services into the DPSIR framework. PLoS ONE 8 (8), e70766, http://dx.doi.org/10.1371/journal.pone.0070766.
Kerenyi, A., 2011. The better life index of the organization for economic co-operation and development. Pub. Finance Q. 56, 518–538.
Kline, J.L., Loftus, W.F., Kotun, K., Trexler, J.C., Rehage, J.S., Lorenz, J.J., Robinson, M., 2013. Recent fish introductions into Everglades National Park: an unforeseen consequence of water-management? Wetlands, http://dx.doi.org/10.1007/s13157-012-0362-0.
Kushlan, J.A., Steinkamp, M.J., Parsons, K.C., Capp, J., Cruz, M.A., Coulter, M., Davidson, I., Dickson, L., Edelson, N., Elliot, R., Erwin, R.M., Hatch, S., Kress, S., Milko, R., Miller, S., Mills, K., Paul, R., Phillips, R., Saliva, J.E., Sydeman, B., Trapp, J., Wheeler, J., Wohl, K., 2002. Waterbird Conservation for the Americas: The North American Waterbird Conservation Plan, Version 1. Waterbird Conservation for the Americas, Washington, DC.
Kushlan, J.A., Frohling, P.C., 1985. Decreases in the Brown Pelican population in southern Florida. Colonial Waterbirds 8, 83–95.
Kushlan, J.A., White, D.A., 1985. Least and Roseate Tern nesting sites in the Florida keys. Fla. Field Nat. 13, 98–99.
Kushlan, J.A., Bass, O.L., McEwan, L.C., 1982. Wintering waterfowl in Everglades National Park. Report T-670, Everglades National Park, Homestead, FL.
Light, S.S., Dineen, J.W., 1994. Water control in the Everglades: a historical perspective. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades: The Ecosystem and its Restoration. St. Lucie Press, Boca Raton, FL, pp. 47–84.
Lorenz, J.J., 2013a. A review of the effects of altered hydrology and salinity on vertebrate fauna and their habitats in northeastern Florida Bay. Wetlands, http://dx.doi.org/10.1007/s13157-013-0377-1.

Lorenz, J.J., 2013b. The relationship between water level, prey availability and reproductive success in Roseate Spoonbills foraging in a seasonally-flooded wetland while nesting in Florida Bay. Wetlands, http://dx.doi.org/10.1007/s13157-012-0364-y.
Lorenz, J.J., (Ph.D. dissertation) 2000. Impacts of Water Management on Roseate Spoonbills and their Piscine Prey in the Coastal Wetlands of Florida Bay. University of Miami, Coral Gables, FL.
Lorenz, J.J., 1999. The response of fishes to physicochemical changes in the mangroves of northeast Florida Bay. Estuaries 22, 500–517.
Lorenz, J.J., Frezza, P.F., 2007. Development of Hydrologic Criteria for the Southern Everglades and South Dade Conveyance System to Benefit Roseate Spoonbill Colonies of Northeastern Florida Bay. Final Report to the South Florida Water Management District, Purchase Order #PC P402044. Audubon Florida, Everglades Science Center, Tavernier, FL.
Lorenz, J.J., Langan-Mulrooney, B., Frezza, P.E., Harvey, R.G., Mazzotti, F.J., 2009. Roseate spoonbill reproduction as an indicator for restoration of the Everglades and the Everglades estuaries. Ecol. Indic. 9S, S96–S107.
Lorenz, J.J., Ogden, J.C., Bjork, R.D., Powell, G.V.N., 2002. Nesting patterns of Roseate Spoonbills in Florida Bay 1935–1999: implications of landscape scale anthropogenic impacts. In: Porter, J.W., Porter, K.G. (Eds.), The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, FL, pp. 563–606.
Lorenz, J.J., Serafy, J.E., 2006. Changes in the demersal fish community in response to altered salinity patterns in an estuarine coastal wetland: implications for Everglades and Florida Bay restoration efforts. Hydrobiologia 569, 401–422.
Lowther, P.E., Paul, R.T., 2002. Reddish Egret (*Egretta rufescens*). In: Poole, A., Gill, F. (Eds.), The Birds of North America. Cornell Lab of Ornithology, Ithaca, New York http://bna.birds.cornell.edu/bna/species/633 (accessed 09.06.13).
Lubchenco J., 2009. NOAA Annual Guidance Memorandum. In: Commerce Do (Ed.), p. 14.
Maccarone, A.D., Brzorad, J.M., 1995. Effects of an oil spill on the prey populations and foraging behavior of breeding wading birds. Wetlands 15, 397–407.
Marmar, H.A., 1954. Tides and sea level in the Gulf of Mexico. In: Galstoff, P.S. (Ed.), Gulf of Mexico, its Origin, Waters, and Marine Life. U.S. Fishery Bulletin 89, Washington, DC, pp. 101–118.
Marshall, F.E., Wingard, G.L., Pitts, P., 2008. A simulation of historic hydrology and salinity in Everglades National Park: coupling paleoecologic assemblage data with regression models. Estuar. Coasts, http://dx.doi.org/10.1007/s12237-008-9120-1.
McIver, S., 1989. True Tales of the Everglades. Florida Flair Books, Miami, FL.
McGowan, C.P., (unpublished M.Sc. thesis) 2004. Factors Affecting Nesting Success of American Oystercatchers (*Haematopus palliatus*) in North Carolina. North Carolina State University, Raleigh, NC.
Meyer, K.D., Kent, G., 2011. The Decline of the Great White Heron in Florida: Explanations and Recommendations for recovery of this Small and Highly Vulnerable Population. Final Report 07156 to Florida Fish and Wildlife Conservation Commission.
Montevecchi, W.A., 1993. Birds as indicators of change in marine prey stocks. In: Furness, R.W., Greenwood, J.J.D. (Eds.), Birds as Monitors of Environmental Change. Springer, New York, pp. 217–266.
National Audubon Society, 2010. The Christmas Bird Count Historical Results. http://www.christmasbirdcount.org (accessed 25.02.13).
Nesbitt, S.A., 2001. Bald Eagle Population Monitoring. Annual Performance Report. Florida Fish and Wildlife Conservation Commission, Gainesville, FL, USA.
Nesbitt, S.A., Ogden, J.C., Kale II, H.W., Patty, B.W., Rowse, L.A., 1982. Florida Atlas of Breeding Sites for Herons and their Allies: 1976–78. U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS – 81/49.
Nesbitt, S.A., Fogarty, M.J., Williams, L.E., 1977. Status of Florida Nesting Brown Pelicans 1971–1976. Bird Banding 48, 138–144.
Neimark, J., May 2008. The dirty truth about plastic. Discover Magazine.
Nol, E., Humphrey, R.C., 1994. In: Poole, A. (Ed.), American Oystercatcher (*Haematopus palliatus*). The Birds of North America Cornell Lab of Ornithology, Ithaca, NY http://bna.birds.cornell.edu/bna/species/154 (accessed 07.01.13).
Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conserv. Biol. 4, 355–363.
Ogden, J.C., Baldwin, J.D., Bass, O.L., Browder, J.A., Cook, M.I., Frederick, P.C., Frezza, P.E., Galvez, R.A., Hodgson, A.B., Meyer, K.D., Oberhofer, L.D., Paul, A.F., Fletcher, P.J., Davis, S.M., Lorenz, J.J., 2014. Waterbirds as indicators of ecosystem health in the coastal marine habitats of Southern Florida: 1. Selection and justification for a suite of indicator species. Ecol. Indic., http://dx.doi.org/10.1016/j.ecolind.2014.03.007 (in this issue).
Ogden, J.C., Davis, S.M., Jacobs, K.J., Barnes, T., Fling, H.E., 2005. The use of conceptual ecological models to guide ecosystem restoration in south Florida. Wetlands 25, 797–809.
Ogden, J.C., 1994. A comparison of wading bird nesting colony dynamics (1931–1946 and 1974–1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades: The Ecosystem and its Restoration. St. Lucie Press, Boca Raton, FL, pp. 533–570.
Ogden, J.C., 1993. Florida Bay Vertebrates: Status Reports for Osprey, Roseate Spoonbill, Brown Pelican and Northwestern Wading Bird Colonies, Everglades National Park, Homestead, Florida.
Ogden, J.C. (Ed.), 1977. Transactions of the North American Osprey Research Conference. Transaction and Proceeding of the Service No. 2. U.S. National Park Service.
Paul, R.T., 1991. Status report – *Egretta rufescens* (Gmelin) Reddish Egret. U. S. Fish and Wildlife Service, Houston, TX.
Paul, R.T., 1996. Reddish Egret. In: Rodgers, J.A., et al. (Eds.), Rare and Endangered Biota of Florida, vol. V. Birds. University Press of Florida, Gainesville, pp. 281–294.
Perez, L., 2012. Snake in the Grass: An Everglades Invasion. Pinapple Press, Inc., Sarasota, FL, pp. 220.
Poole, A.F., Bierregaard, R.O., Martell, M.S., 2002. In: Poole, A. (Ed.), Osprey (*Pandion haliaetus*), The Birds of North America Online. Cornell Lab of Ornithology, Ithaca http://bna.birds.cornell.edu/bna/species/683 (accessed 13.02.13).
Poole, A., 1985. Courtship feeding and osprey reproduction. Auk 102, 479–492.
Poole, A.F., 1989. Ospreys: A Natural and Unnatural History. Cambridge, New York.
Powell, G.V.N., 1996. Great White Heron – Species of Special Concern. Endangered Biota of Florida, vol. 5, Birds. University of Florida Press, Gainesville, FL, USA.
Powell, G.V.N., Bjork, R.D., 1990. Relationships Between Hydrologic Conditions and Quality and Quantity of Forgaing Habitat for Roseate Spoonbills and other Wading Birds in the C-111 Basin. National Audubon Society, Tavernier Florida, Second Annual Report to the South Florida Research Center, Everglades National Park, Homestead Florida.
Powell, G.V.N., Bjork, R.D., Ogden, J.C., Paul, R.T., Powell, A.H., Robertson, W.B., 1989. Population trends in some Florida Bay wading birds. Wilson Bull. 101, 436–457.
Powell, G.V.N., Powell, A.H., 1987. Reproduction by Great White Herons in Florida Bay as an indicator of habitat quality. Biol. Cons. 36, 101–113.
Rattner, B.A., 2013. Contaminant exposure and impacts on waterbirds and selected wildlife. Chapter 9. In: USGS Circular 1316: Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management. U.S. Department of the Interior U.S. Geological Survey http://pubs.usgs.gov/circ/circ1316/html/circ1316chap9.htm/Accessed (accessed 30.08.13).
RECOVE.R., 2014. Draft System Status Report – Section 8.5: Effects of the 2010 Cold Event on Everglades Biota C/O U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL and South Florida Water Management District, West Palm Beach, FL http://www.evergladesplan.org/pm/ssr_2014/ssr_main.aspx
Robertson, W.B., Woolfenden, G.E., 1992. Florida Bird Species: An Annotated List, Florida Ornithological Society Special Publication No. 6.
Rodgers Jr., J.A., Kubilis, P.S., Nesbitt, S.A., Delaney, M.F., Bowman, K.T., Dodge, J.B., Felix Jr., R.K., Swan, J., 2003. Atlas of Breeding Sites for Colonial Waterbirds in Florida During 1999. Florida Fish and Wildlife Conservation Commission, Bureau of Wildlife Diversity Conservation.
Runde, D.E., Gore, J.E., Hovis, J.A., Robson, M.S., Southall, P.D., 1991. Florida Atlas of Breeding Sites for Herons and their Allies: Update 1986–89. Florida Game and Fresh Water Fish Commission Nongame Wildlife Program, Technical Report No. 10.
Sachs, E., Brush, J., Hayman, B., Zambrano, R., 2013. A Species Action Plan for the Brown Pelican, *Pelecanus occidentalis*. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.
Schulte, S., Brown, S., Reynolds, D., American Oystercatcher Working Group, 2010. Version 2.1. A Conservation Action Plan for the American Oystercatcher (*Haematopus palliatus*) for the Atlantic and Gulf Coasts of the United States.
Schreiber, R.W., 1980. The Brown Pelican: an endangered species? BioScience 30, 742–747.
Scott, G.I., Fulton, M.H., Wirth, E.F., Chandler, G.T., Key, T.B., Daugomah, J.W., Bearden, D., Chung, K.W., Strozier, E.D., DeLorenzo, M., Sivertsen, S., Dias, A., Sanders, M., Macauley, J.M., Goodman, L.R., LaCroix, M.W., Thayer, G.W., Kucklick, J., 2002. Toxicological studies in tropical ecosystems: an ecotoxicological risk assessment of pesticide runoff in South Florida estuarine ecosystems. J. Agric. Food Chem. 50 (15), 4400–4408.
Simmons, G., Ogden, L., 1998. Gladesmen. University Press of Florida, Gainesville, FL.
Simons, T.R., Schulte, S., 2008. American Oystercatcher (*Haematopus palliatus*) Research and Monitoring in North Carolina. 2007 Annual Report to the National Park Service, U.S. Fish and Wildlife Service and the National Audubon Society., pp. 58.
Smith, R.H., Johns, E.M., Goni, G.J., Trinanes, J., Lumpkin, R., Wood, A.M., Kelble, C.R., Cummings, S.R., Lamkin, J.T., Privoznik, S., 2014. Oceanographic conditions in the Gulf of Mexico in July 2010 during the Deepwater Horizon oil spill. Continent. Shelf Res. 77, 118–131.
Smith, T., Robblee, M., Wanless, H., Doyle, T., 1994. Mangroves, hurricanes, and lightning strikes: assessment of Hurricane Andrew suggests an interaction across two differing scales of disturbance. Bioscience 44 (4), 256–262.
Sprandel, G.L., Gore, J.A., Cobb, D.T., 1997. Winter Shorebird Survey. Final Performance Report. Florida Game and Fresh Water Fish Commission, Tallahassee, FL.
Stevenson, H.M., Anderson, B.H., 1994. The Birdlife of Florida. University of Florida, Gainesville, FL, USA.
Strong, A.M., Sawicki, R.J., Bancroft, G.T., 1991. Effects of predator presence on the nesting distribution of White Crowned Pigeons in Florida Bay. Wilson Bull. 103, 415–425.
Stumpf, R.P., Hines, J.W., 1998. Variations in tidal level in the Gulf of Mexico and implications for tidal wetlands. Estuar. Coast. Shelf Sci. 46, 165–173.
Tabb, D.C., Dubrow, D.L., Manning, R.B., 1962. The Ecology of Northern Florida Bay and Adjacent Estuaries. State of Florida Board of Conservation Technical Series No. 39. Miami, FL.
Trexler, J.C., Loftus, W.F., Jordan, F.C., Lorenz, J.J., Chick, J.H., Kobza, R.M., 2000. Empirical assessment of fish introductions in a subtropical wetland ecosystem: an evaluation of contrasting views. Biol. Invas. 2, 265–277.

Viverette, C.B., Garman, G.C., McIninch, S.P., Markham, A.C., Watts, B.D., Macko, S.A., 2007. Finfish-waterbird trophic interactions in tidal freshwater tributaries of the Chesapeake Bay. Waterbirds 30 (Suppl. 1), 50–62.

Volety, A.K., Savarese, M., Tolley, S.G., Arnold, W.S., Sime Goodman, P., Chamberlain, R.H., Doering, P.H., 2009. Eastern oysters (*Crassostrea virginica*) as an indicator for the restoration of Everglades ecosystems. Ecol. Indic. 9 (S6), S120–S136.

Wang, C., Liu, H., Lee, S., 2010. The record-breaking cold temperatures during the winter of 2009/10 in the northern hemisphere. Atmos. Sci. Lett. 11, 161–168.

Wanless, S., Frederiksen, M., Daunt, F., Scott, B.E., Harris, M.P., 2007. Black-legged kittiwakes as indicators of environmental change in the North Sea: evidence from long-term studies. Prog. Oceanogr. 72, 30–38.

Wanless, H.R., Parkinson, R.W., Tedesco, L.P., 1994. Sea level control on stability of Everglades wetlands. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL.

Webb, D.R., 1987. Thermal tolerance of avian embryos: a review. Condor 89, 874–898.

Winder, L., Wallace, G., 2006. Impact of Feral and Free-ranging Cats on Bird Species of Conservation Concern: A Five-state review of New York, New Jersey, Florida, California and Hawaii. World Conservation Union.

Wilmers, T., Arnett, J., 2003. A Survey of Reddish Egrets in the Lower Florida Keys. Florida Keys National Wildlife Refugees, Big Pine Key, FL.

Wingard, G.L., Lorenz, J.J., 2014. Coastal wetlands conceptual ecological model. Ecol. Indic., http://dx.doi.org/10.1016/j.ecolind.2014.01.007 (in this issue).

York, D., 1994. Recreational-boating Disturbances of Natural Communities and Wildlife: An Annotated Bibliography. U.S. Department of the Interior, National Biological Survey. Biological Report 22.

Warraich, R., Zambrano, T.N., 2012. 2010 Statewide Nesting Seabird and Shorebird Survey in Florida: Ground and roof. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.

Zambrano, R., Robson, M.S., Charnetzky, D.Y., Smith, H.T., 1997. Distribution and status of least tern nesting colonies in southeast Florida. Fla. Field Nat. 25, 85–91.

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