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Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SHOREBIRDS

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Group of foraging Red Knots (*Calidris canutus*). Photo credit: Pat Leary

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Chapter 7

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SHOREBIRDS

DESCRIPTION OF SPECIES GROUPS AND IMPORTANT HABITATS IN THE GULF OF MEXICO REGION

THERE ARE 215 RECOGNIZED SHOREBIRD SPECIES worldwide and approximately 50 species that breed in North America (Colwell 2010). Shorebirds are distributed among 14 families in the order Charadriiformes. The order Charadriiformes also includes seabird families such as jaegers, gulls, terns, skuas, alcids and skimmers (See Seabird Chapter 6). At least 39 shorebird species can be found in the Gulf of Mexico (GoM) for portions of their annual cycle (Withers 2002). The Gulf of Mexico Avian Monitoring Network (GoMAMN) considers 10 of the 39 shorebird species to be species of conservation concern: American Oystercatcher (*Haematopus palliatus*); Buff-breasted Sandpiper (*Calidris subruficollis*); Dunlin (*Calidris alpina*); Long-billed Curlew (*Numenius americanus*); Marbled Godwit (*Limosa fedoa*); Piping Plover (*Charadrius melodus*); Red Knot (*Calidris canutus*); Snowy Plover (*Charadrius nivosus*); Western Sandpiper (*Calidris mauri*); and Wilson's Plover (*Charadrius wilsonia*) (Table 7.1; see also Appendix 1). The Red Knot and Piping Plover are federally listed under the Endangered Species Act and most of the other shorebird species of conservation concern are state-listed in one or more GoM states. Six of the ten GoMAMN shorebird species of conservation concern have geographic ranges that include the majority of the GoMAMN region (Figure 1.2). Species with limited ranges include Buff-breasted Sandpiper, Long-billed Curlew, Marbled Godwit, and Snowy Plover. Three shorebird species, American Oystercatcher, Snowy Plover, and Wilson's Plover, breed and winter in the northern GoM. All the species of conservation concern except the Buff-breasted Sandpiper, Marbled Godwit, and Long-billed Curlew were confirmed as injured during the Deepwater Horizon oil spill (DHNRDAT 2016: module 4).

Many life history and behavioral attributes of shorebirds are relevant to the development of monitoring plans and study questions, and as such are specifically referenced in subsequent sections of this chapter. Although shorebirds are a diverse group, there are overlapping factors that characterize them and guide management strategies. For example, shorebirds are generally long-lived, solitary breeders that raise semi-precocial (e.g., American Oystercatcher) or precocial (e.g., Snowy Plover, Wilson's Plover) young. The GoM shorebird species of conservation concern overlap significantly in site use, habitat requirements, and threats. Shorebirds are largely dependent on management because habitats that are critical for both reproduction and survival overlap with areas of near-constant anthropogenic influence (Burger 2016, 2017).

Breeding Season

Shorebirds rely on a variety of coastal habitat types for reproduction across the GoM. Broadly, the coastal habitat types include beach/dune, unconsolidated shore, and estuarine emergent wetland (Table 7.1; see also Appendix 2). Common plants associated with coastal habitats in the GoM are Sea Oats (*Uniola paniculata*), Beach Elder (*Iva imbricata*), and Saltmeadow Cordgrass (*Spartina patens*). Three GoMAMN shorebird species of conservation concern (American Oystercatcher, Snowy Plover, Wilson's Plover) breed in every state in the northern GoM and breeding locations often overlap (Page et al. 2009, American Oystercatcher Working Group et al. 2012, Zdravkovic et al. 2018). These species nest almost exclusively in coastal habitats in the GoM; however, a small number of Snowy and Wilson's Plovers have been documented nesting at inland sites, primarily in Texas and Florida (Page et al. 2009, Zdravkovic et al. 2018). The Snowy Plover commonly nests in open sand habitats and sparsely vegetated beach/dunes (Page et al. 2009). In contrast, the Wilson's Plover and American Oystercatcher nest in sparsely to densely vegetated habitats that include beach/dunes, salt flats, coastal lagoons, dredge spoil islands, salt marsh islands, and oyster shell rakes (Schulte et al. 2010, American Oystercatcher Working Group et al. 2012, Zdravkovic et al. 2018). The American Oystercatcher feeds almost exclusively on shellfish (e.g., bivalves, mollusks, crustaceans) and consequently usually nests on or near oyster shell rakes (American Oystercatcher Working Group et al. 2012). All three species exhibit strong nest site fidelity (Warriner et al. 1986, Stenzel et al. 2007, American Oystercatcher Working Group et al. 2012) and can be found in a wide variety of habitats.

Shorebird nest initiation typically begins February to April depending on the species, location in the GoM, and

Table 7.1. *Shorebird species to be considered for monitoring programs at multiple geographic scales across the northern Gulf of Mexico. Table includes species residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).*

Common Name	Latin Name	Breeding	Wintering	Migratory	Landcover Association(s)[a]	Trend Score	Continental Concern Score
American Oystercatcher	*Haematopus palliatus*	X	X	X	Beach/Dune, Estuarine Emergent Wetland, Oyster Reef, Unconsolidated Shore	3	14
Piping Plover	*Charadrius melodus*		X	X	Beach/Dune, Estuarine Emergent Wetland, Unconsolidated Shore	5	18
Wilson's Plover	*Charadrius wilsonia*	X	X	X	Beach/Dune, Estuarine Emergent Wetland, Oyster Reef, Unconsolidated Shore	4	16
Snowy Plover	*Charadrius nivosus*	X	X		Beach/Dune, Estuarine Emergent Wetland, Unconsolidated Shore	4	15
Long-billed Curlew	*Numenius americanus*		X	X	Beach/Dune, Cultivated, Estuarine Emergent Wetland, Grassland/Herbaceous, Unconsolidated Shore	2	12
Marbled Godwit	*Limosa fedoa*		X	X	Beach/Dune, Estuarine Emergent Wetland, Grassland/Herbaceous, Oyster Reef, Palustrine Emergent Wetland, Unconsolidated Shore	3	14
Red Knot	*Calidris canutus*		X	X	Beach/Dune, Estuarine Emergent Wetland, Unconsolidated Shore	5	13
Dunlin	*Calidris alpina*		X	X	Beach/Dune, Estuarine Emergent Wetland, Unconsolidated Shore	4	11
Buff-breasted Sandpiper	*Calidris subruficollis*			X	Cultivated, Grassland/Herbaceous	4	14
Western Sandpiper	*Calidris mauri*		X	X	Beach/Dune, Estuarine Emergent Wetland, Oyster Reef, Palustrine Emergent Wetland, Unconsolidated Shore	3	12

[a] See Chapter 1 and Appendix 2 for full description of landcover associations.

annual weather patterns. Chicks fledge throughout the summer months until the end of August. Shorebirds start breeding earlier in the nesting season than beach-nesting colonial seabird species (i.e., gulls, terns, skimmers) and often earlier than their conspecifics in northern nesting areas. The tendency to nest earlier in the GoM is likely because many of the breeding individuals, particularly Snowy Plover and American Oystercatcher, are year-round residents in the GoM and initiate nesting based on warming spring subtropical temperatures (Working Group et al. 2012). The long breeding season accommodates the potential for multiple breeding attempts and shorebirds will typically renest if earlier nests or broods are lost (Warriner et al. 1986, Zdravkovic et al. 2018).

Snowy Plovers follow a serial polygamous mating system, maximizing their ability to breed multiple times a season, and adults generally acquire multiple mates within the same breeding season after successfully hatching early clutches (Page et al. 2009). Females may breed more frequently than males because males are more likely to tend the chicks after the female departs in search of a new mate (Warriner et al. 1986). Under ideal conditions, Snowy Plovers can fledge chicks from multiple broods during a single season.

Habitat requirements for breeding shorebirds include nesting sites and territories, chick-rearing areas, and foraging areas. Landscape-level habitat features, such as the availability, quantity, and quality of foraging habitat, influence the nest territory selection and habitat use patterns of shorebirds. Parental foraging typically occurs near the vicinity of the nest (Snowy Plover, Wilson's Plover) to allow adults to defend their territories from conspecifics, interspecifics and predators (Page et al. 2009). The American Oystercatcher often nests adjacent to foraging areas, but may regularly commute varying distances to feed elsewhere, depending on the distance to preferred foraging habitat (e.g., oyster beds) (Thibault 2008, Virzi and Lockwood 2010, Working Group et al. 2012).

Shorebird chick-rearing may occur at areas near or far from nest sites depending on the availability and quality of foraging habitat. Snowy Plovers, whose chicks are both nidifugous and precocial, may move large distances with their chicks to access more productive foraging locations (up to 15 km) (Pruner et al. 2015). At breeding sites with higher disturbance pressures and where access to high quality foraging habitat is unavailable, plover chicks may exhibit a protracted brood-rearing period and chicks remain vulnerable for longer periods of time before becoming flight-capable (Pruner et al 2015). Unlike other shorebirds, American Oystercatcher chicks can be dependent on their parents for at least 25 days post fledging (60 days total) as newly fledged chicks learn sophisticated prey-handling skills (i.e., learn to open shellfish; Working Group et al. 2012).

Monitoring and conservation of breeding shorebirds and habitats can be extensive, fluctuating, and ephemeral; yet to encompass the monitoring and conservation needs in a given season requires vast resources and protracted effort. Effective monitoring requires specific knowledge of the landscape and the distribution of required habitat features. Additionally, all three of the GoM breeding shorebird species may breed in close proximity to other beach-nesting shorebirds or seabirds; as such, monitoring, management, and conservation efforts may affect more than one species at a given location.

Spring and Autumn Migration Seasons

Shorebirds undertake some of the longest-distance migrations of all animals (Brown et al. 2001). The GoM is a vitally important region for migratory shorebirds, most of which either conduct Trans-Gulf or circum-Gulf migrations when traveling between North America and the Neotropics (Russel 2005). For many migratory species, the wetlands, barrier islands, and other coastal habitats in the GoM represent the first areas of suitable stopover habitat between near-arctic breeding grounds and distant wintering grounds in South America. There are seven migratory shorebird species of conservation concern that breed completely outside of the GoM, but use the region as a stopover during migration (Table 7.1). The Buff-Breasted Sandpiper, one of the longest distant migrants that breeds in North America, is the only species of conservation concern that can be found in the GoM only during migration (McCarty et al. 2017). The Long-billed Curlew primary uses the GoM during migration with only a few locations in the GoM documenting rare nonbreeding resident birds (Dugger and Dugger 2002). Nearly half a million Western Sandpipers use stopover habitats in the GoM during fall migration (Franks et al. 2014). Many species of migratory shorebirds use a 'long-hop' strategy, meaning that some sections of their journeys are completed in long, nonstop flights. For example, Red Knots have been documented stopping over in Texas on their northbound migration route following nonstop flights (6 days) from Argentina (Newstead et al. 2013).

Shorebirds expend substantial amounts of energy during long-distance migration and rely on stopovers along the way to replenish their fat reserves before continuing to their northern breeding or southern wintering grounds. Successful migration and subsequent reproduction depends on food availability at refueling stops (Krapu et al. 2006) and typically relies on seasonally wet areas that include mudflats, wetlands, impoundments, flooded agriculture fields or coastal shorelines and estuaries. Stopover habitat should also provide a matrix of undisturbed resting sites in addition to foraging locations.

Migrating shorebirds exhibit predictable seasonal movement patterns and consequently depend on stopover habitats that are consistent from year-to-year to gain the weight necessary (often at short time intervals) to complete their migration in good condition. For many shorebirds, spring migration begins in March or April and peaks in May, while fall migration begins in late July and peaks in August or September. However, migratory patterns and thus, dependence on specific stopover habitat differs among shorebirds species. For example, peak fall migration for Buff-breasted Sandpipers through the GoM occurs in August and September (McCarty et al. 2017), while Dunlin do not begin to arrive in the GoM until late September, with peak arrival occurring in November (Warnock and Gill 1996). In addition, differences in migration ecology (i.e., stopover duration) have been documented not only among species, but also within species (Henkel and Taylor 2015).

Winter Season

The species that winter in the GoM consist of a mix of individuals or species with varying migratory tendencies, where some portions of the population migrate through the GoM and others remain in the area as winter residents. All the shorebird species of conservation concern, except the Buff-Breasted Sandpiper, winter in the GoM (Table 7.1). The GoM is particularly important for wintering Piping Plover and American Oystercatcher. Range-wide winter census results indicate that 65-93% of known wintering Piping Plovers use the GoM, with Texas supporting the greatest numbers (Plissner and Haig 1997, Ferland and Haig 2002, Elliott-Smith et al. 2009, Elliott-Smith et al. 2015). Coastal Texas is particularly important for Piping Plovers from the Prairie Canada and Northern Great Plains breeding populations (Gratto-Trevor et al. 2012). Wintering American Oystercatchers can be found in every GoM state, with Florida having the largest wintering concentrations (Schulte et al. 2010).

Wintering birds frequently move between intertidal flats and inland areas depending on tidal stages and foraging and roosting habitat availability. They can be found widely distributed among coastal habitats as prey item preference and foraging strategies differ by species. For example, wintering Red Knots in the GoM generally use sandy beaches, although they also use other available habitat types such as salt marshes, brackish lagoons, tidal mudflats, and mangrove islands (Baker et al. 2013, Newstead 2014). Dunlin and Western Sandpipers use coastal beaches, but are more commonly observed in coastal estuaries, bays, interior seasonal wetlands, flooded fields, and other agricultural lands (Warnock and Gill 1996). Long-billed Curlews and Marbled Godwits primarily use shallow inundated mudflats, flooded fields, and estuaries (Gratto-Trevor 2000, Dugger and Dugger 2002). Marbled Godwits will also use sandy beach habitats (Gratto-Trevor 2000).

Overwintering groups of American Oystercatchers, Snowy Plovers and Wilson's Plovers consist of a mix of resident GoM breeders and individuals that breed in northern portions of their range. Snowy Plovers are predominantly found on coastal beaches during the winter, but also utilize tidal mudflats and pools when available (Page et al. 2009). American Oystercatchers use a variety of habitats during the tidal cycle and are commonly found in intertidal areas, mud flats, shell rakes, and oyster reefs (Working Group et al. 2012). Wilson's Plover habitat use is often tied to the presence of fiddler crabs (*Uca* spp.) and includes intertidal mudflats, beaches, salt ponds, saltmarshes, and mangrove wetlands (Zdravkovic et al. 2018).

Throughout the remaining sections of this chapter, we use the term 'nonbreeding' to refer to wintering and migratory shorebirds, as well as shorebirds that are not breeding, but present in the GoM during the breeding season.

Wilson's Plover *(Charadrius wilsonia)*. Photo credit: Britt Brown

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

Shorebirds are relatively long lived and as such, adult mortality combined with low productivity tend to be limiting factors in population recovery (Colwell 2010). Although most shorebirds likely have relatively high adult survival rates (e.g., Working Group et al. 2012), data are lacking for the lesser studied species due to expansive ranges. Shorebirds tend to have high interannual site fidelity; however, the connectivity of populations via dispersal and immigration has important implications for the stability of GoM-wide populations.

Coastal habitats are naturally dynamic environments that are globally stressed by human population growth, climate change, and perturbations such as oil spills, resulting in the need for increased management for coastal habitats and coastal-dependent species. Coastal habitats (i.e., beach/dunes) are highly sought after for development and tourism because of their aesthetic and recreational values. Consequently, there is little undeveloped beach habitat remaining, and what does remain is often disturbed and degraded to the detriment of shorebirds. The greatest limitations to rebuilding shorebird populations are the threats associated with human-related disturbance and the rapid rate of habitat loss or alteration (Burger 2018).

As the processes of climate change and sea-level rise accelerate, the coastal habitats of the GoM are expected to experience increased levels of flooding and saltwater intrusion, leading to accelerated and dramatic habitat loss and change (Burger et al. 2012, Burger 2018). The consequences to shorebirds will depend on the vulnerability of the species to environmental change and habitat loss, as well as impacts to food resources. Alterations to the coastal environment that affect prey resources can have devastating effects on migratory and wintering shorebirds (Baker et al. 2004, McGowan et al. 2011). Migratory shorebirds are particularly vulnerable to habitat loss and alteration as they require sites that have abundant, predictable food resources. There is potential for catastrophic loss of populations where individuals congregate in large numbers (e.g., Buff-breasted Sandpiper along migration routes) (McCarty et al. 2017). There is much uncertainty related to the impacts of sea-level rise and changing temperatures on prey base and the resulting impacts to potential stopover, wintering, and breeding locations for shorebirds in the GoM (Gallbraith et al. 2002, Rehfisch and Crick 2003, Piersma and Lindstrom 2004).

Many studies have documented the effects of anthropogenic disturbance on shorebird abundance, behavior, and habitat use patterns (USFWS 1996, USFWS 2009, Brown et al. 2001, Gill et al. 2001, Thomas et al. 2003, Burger et al. 2004, Blumstein et al. 2005, Yasue 2006, Niles et al. 2010). Shorebirds are considered highly susceptible to disturbance because they commonly use areas that are subject to repeated high levels of human recreation (e.g., beaches, wetlands) and generally experience human disturbance throughout their lifecycle (Gill et al. 2001). Shorebird response to disturbance may be related to site-specific variables, time of year, as well as fitness costs (Stillman and Goss-Custard 2002, Beale and Monaghan 2004, Gibson et al. 2018). Shorebirds have higher metabolic rates compared to other avian taxa (Kersten and Piersma 1987) and need to forage more frequently to compensate for rapid energy expenditure. The energetic cost of disturbance to roosting or foraging shorebirds has been studied extensively (e.g., Hill et el. 1997, Rogers et al. 2006), demonstrating that repeated disturbance of foraging and roosting shorebirds creates stress and potential loss of fitness over time (Schlacher et al. 2013, Gibson et al. 2018). Reoccurring disturbances can also result in the abandonment of sites that are otherwise of high-quality (Burger 1986, Brown et al. 2001, Koch and Paton 2014) or force shorebirds to find alternative undisturbed feeding sites, especially at higher tides, which is energetically costly (Hill et al. 1997).

The presence of human activity and disturbance can have serious impacts during the nesting season resulting in the direct and indirect loss of nests and chicks and adult mortality. The body condition of breeding shorebirds can influence reproductive success and for chicks can be a limiting factor for survival to fledging (Ens et al. 1992, Hunt et al. 2017). Nest abandonment may occur after prolonged or repeated disturbance events. In addition, shorebirds may leave their eggs or young exposed to environmental conditions and opportunistic predators (e.g., gulls, crows) when responding to disturbance (e.g., pedestrians, dogs, vehicles), and young may be subjected to reduced parental brooding and limited foraging (Yalden and Yalden 1990). Regular and repetitive disturbance can contribute to protracted chick-rearing periods (>7 weeks instead of 4), thus reducing fledge rates (Pruner et al. 2015). Recreational activities can push prematurely fledged chicks into habitats with lower food availability, resulting in lower feeding rates, slower growth, and decreased survival (DeRose-Wilson et al. 2018).

Incompatible beach management practices are one of the primary threats to shorebirds in the GoM. Incompatible practices include, but are not limited to, mechanical beach cleaning, beach driving, incompatible recreation (i.e., dune surfing), large organized social events (i.e., concerts, parties), and even revegetation projects. Incompatible management activities can result in the abandonment of sites or decreased body condition, reproductive success and survival. The direct loss of eggs, chicks, and adults may occur due to beach driving, roads adjacent to nesting areas, and mechanical beach cleaning. Many of the shorebird species of conservation concern prefer sparsely vegetated, early successional habitats. Coastal revegetation projects are often undertaken in response to catastrophic impacts in the wake of tropical activity (e.g., hurricanes, tropical storms, etc.), as a restoration tool to improve the beach/dune ecosystem. However, in the absence of repeated hurricane or tidal overwash events, prime habitat can quickly succeed to densely vegetated, unsuitable habitats for shorebirds and the rate of succession is heightened following revegetation.

An additional and often overlooked incompatible management practice that impacts shorebirds is freshwater management. Worldwide, the loss and degradation of wetland habitats has been associated with the decline of shorebird populations, where loss of wetland habitat influences individual mortality and population size (Colwell 2010). Freshwater input can drive the composition, distribution, and health of estuaries and is important for the management of coastal wetlands, in terms of influence on the wetland habitat and via water depth and the consequent influence on the availability of food for shorebirds. Reduced freshwater flows to estuaries are becoming more common in coastal areas (Alber 2002) and could become a major threat to local populations of shorebirds. Intermediate salinities typical of estuaries are at least partly responsible for greater productivity of fishes and invertebrates found there (Livingston et al. 1997), as well as

Long-billed Curlew (*Numenius americanus*). Photo Credit: Woody Woodrow

structuring habitat in other ways (Flemer and Champ 2006).

Predation is often the primary cause of reproductive failure for shorebirds and could have important population-level consequences by reducing recruitment (Chalfoun et al. 2002) and survival. There is limited knowledge linking shorebird survival to predators although it is generally assumed that predators are a key limiting factor. High predation rates of shorebirds have been linked to the local abundance of predator species (Angelstam 1986, Pruner et al. 2015) and habitat features and connectivity (Powell and Collier 2000, Hood 2006). However, relatively little is known about the importance of individual predators on observed patterns of reproductive success, and how the ecology of predators may influence patterns of loss (Benson et al. 2010). Greater densities of coyotes and other potential mammalian predators are related to an increase in vegetation density and structure (Thompson and Gese 2007), thus, seasonal changes in habitat (e.g., impacts from hurricanes, vegetation succession) across the GoM influence annual predator pressures. Additionally, humans have fundamentally altered predator-prey dynamics in many coastal systems. As a result, there is an increase in predator presence and predation of shorebirds across temporal and spatial scales in the GoM in relation to human use patterns that are both seasonal and patchy. Shorebirds are equally at risk of predation when foraging and roosting and often form dense flocks as an antipredator strategy. Roosting shorebirds typically choose to roost in habitat characterized by high visibility, low predator density, and absence of vegetation that may harbor predators (e.g., wooded areas, perches, dense vegetation) (Brush et al. 2017).

Predation is included as a major threat category in shorebird conservation planning initiatives because it could have catastrophic impacts on shorebird populations (Schulte et al. 2010, AFSI 2015, Schulte 2016). Integrated predator control is implemented throughout the GoM as a management tool. However, predator removal programs may have unforeseen consequences for nesting beaches by altering the predator community structure (Stapp 1997). Equivalently, removing the top predator from a system can result in the compensatory predation on shorebirds (Ellis-Felege et al. 2012).

Avian survival during the non-breeding season is linked to availability of food, local weather events, and refuge from predation (Sherry and Holmes 1996, Placyk and Harrington 2004). Roosting and its associated activities such as rest, digestion, and maintenance are also critical for shorebird survival (Conklin et al. 2008). Roost and breeding site selection is typically associated with proximity to feeding habitats because of the energetic costs of commuting (van Gils et al. 2006). The selection of habitat for foraging and roosting often takes the form of local daily movement within the landscape of a wintering area which is often a tradeoff between prey availability, habitat quality, and predation risk. Food resources may likely be the predictor of foraging distribution, as prey availability has been shown to outweigh predation risk in some areas (Schwarzer 2011).

Shorebirds face a range of anthropogenic stressors such as oil, metals, contaminants, wind towers, agricultural and urban runoff, and pesticides. Contact with any of these stressors could produce adverse effects and the risk to shorebirds depends on the probability of exposure (Burger 2018). The timing and magnitude of anthropogenic stressors are critical in understanding the potential effects on shorebirds. Given the quantity and extent of agriculture across the GoM landscape, pesticides probably have a larger impact on shorebird productivity and survival than has been documented (Colwell 2010). Additionally, activities associated with stressors, such as a clean-up response following an oil spill, can have negative consequences for shorebirds (Henkel et al. 2014). The impacts of red tides and other harmful algal blooms have been documented to impact shorebirds in the GoM (Newstead 2014). The full scale of impacts of red tides to shorebirds is largely unknown, but potentially significant since they can occur on almost any shoreline used by shorebirds and can occur at any time of year. Brevetoxin, a potent neurotoxin produced by a red tide dinoflagellate (*Karenia brevis*), is capable of accruing to lethal concentrations and has been found in the tissues of dead shorebirds. In addition, exposure could contribute to secondary infections, neurological disorders, and increased chance of mortality (e.g., Newstead 2014). In addition, disease is something that shorebirds will be increasingly vulnerable to as they continue to be stressed by habitat loss and change, environmental contaminants, toxins, and climate change.

Framing the Uncertainty – Influence Diagrams

The GoMAMN developed species-specific shorebird conceptual models (influence diagrams) to: 1) connect management decisions to outcomes; 2) identify key variables to monitor; 3) facilitate development of questions of interest for monitoring and adaptive management; and 4) identify uncertainties related to management and ecological processes (Figure 7.1, Appendix 7, Tables 7.2 and 7.3). The most common type of uncertainty that can influence the management of shorebirds is structural or process uncertainty. Structural or process uncertainty is a lack of understanding about the structure of biological and ecological relationships that drive resource dynamics (Williams 2011). In addition, uncertainty related to environmental variation should be considered for the suite of shorebird species of conservation concern.

IDENTIFICATION OF PRIORITIES

Priority Status and Trend Assessments

The structured decision-making tool (Fournier et al. (in press)) developed by the GoMAMN assumes that changes in status and trends derive from two main sources: management actions and ecological processes. The creation of strategies that identify what to monitor for shorebirds will depend strongly on the development of questions about specific management actions and ecological processes, with prioritization dependent on uncertainty and effect size. Overall, reducing uncertainty and addressing the questions are a central means of learning about the GoM as a system, of distinguishing management effects and ecological processes from background variation, and will provide a critical mechanism for accomplishing adaptive management of monitoring.

The GoMAMN has defined the values that a comprehensive shorebird monitoring program in the GoM should reflect (Figure 2.2). These include maximizing the relevance of monitoring data to increase the: 1) ability to detect population changes in species of conservation concern; 2) ability to measure effects of restoration, management, and conservation actions; and 3) ability to understand the ecological processes between shorebirds, their habitats, and other components of their environment, biotic and abiotic. Scientific rigor in design and implementation of monitoring plans and projects is valued to ensure that there is a reduction in uncertainty about effects of management actions and ecological processes on population status and trends. In addition, GoMAMN has included prioritization of integration, through partnerships, leveraging resources, data sharing, and other mechanisms to maximize the use of resources and the likelihood that data from monitoring are shared, used, and have maximal impact on conservation outcomes for shorebirds.

Status and trends monitoring is important for shorebird populations and the habitats on which they depend. Understanding both species and habitats increases the likelihood of managers and decision-makers being able to respond to changes at appropriate spatial and temporal scales. Monitoring should focus on the status and trends of the species of conservation concern to understand mechanisms underlying change, and to appropriately assess the full geographic scale and time frame for protection of populations. Monitoring a geographic area appropriate to each species and habitat within the GoM increases the ability to distinguish between local population fluctuations and regional population change. In addition, because of the complexity of factors influencing both population size and habitat extent, it is important to support monitoring across longer temporal scales to detect delayed effects, changes that occur at thresholds, and to detect trends that are overwhelmed in short time spans by natural variability.

The collection and quality of status and trend data for species is critical to inform conservation planning, management monitoring, and decision making. For the shorebird species which do not breed in the GoM, and for which we do not know the proportion wintering in the GoM, population-level status and trends assessment specific to the GoM may not be available. Within the GoM, status and trend data for specific species of conservation concern that breed are largely available at the state-level. However, monitoring efforts throughout the GoM are typically not coordinated (i.e., timing, standardized protocols). Although each state collects some level of data on abundance of breeding and non-breeding shorebirds, efforts are not yet regionally coordinated or integrated in a way that would allow regional assessments to occur. Region-wide monitoring efforts are most effective when data can be compiled among states and readily accessed via shared and/or compatible databases (e.g., The American Oystercatcher Working Group). Refining data collection methods to ensure data compatibility and establishing regional baseline estimates should be a high priority to ensure clear and comprehensive data are available to develop meaningful interpretations, inform species conservation, and to evaluate the outcomes of management or restoration actions.

Most states in the GoM monitor breeding shorebirds and to a lesser extent, wintering and migratory shorebirds. Monitoring of shorebirds should be framed within the context of the full-life cycle of the species, where they may face severe pressures outside the GoM (AFSI 2016). Assessments of regional reproductive metrics, movement patterns and survival trends for breeding and non-breeding shorebirds would greatly enhance the understanding of mechanisms underlying population dynamics and trends in the GoM. Spatially and temporally extensive baseline measures of distribution, abundance, and status are necessary for effective conservation and management of breeding, migratory and wintering shorebirds in the GoM. For species where this information is available, a focus on identifying and standardizing how key metrics are measured is a priority. Additionally, priority

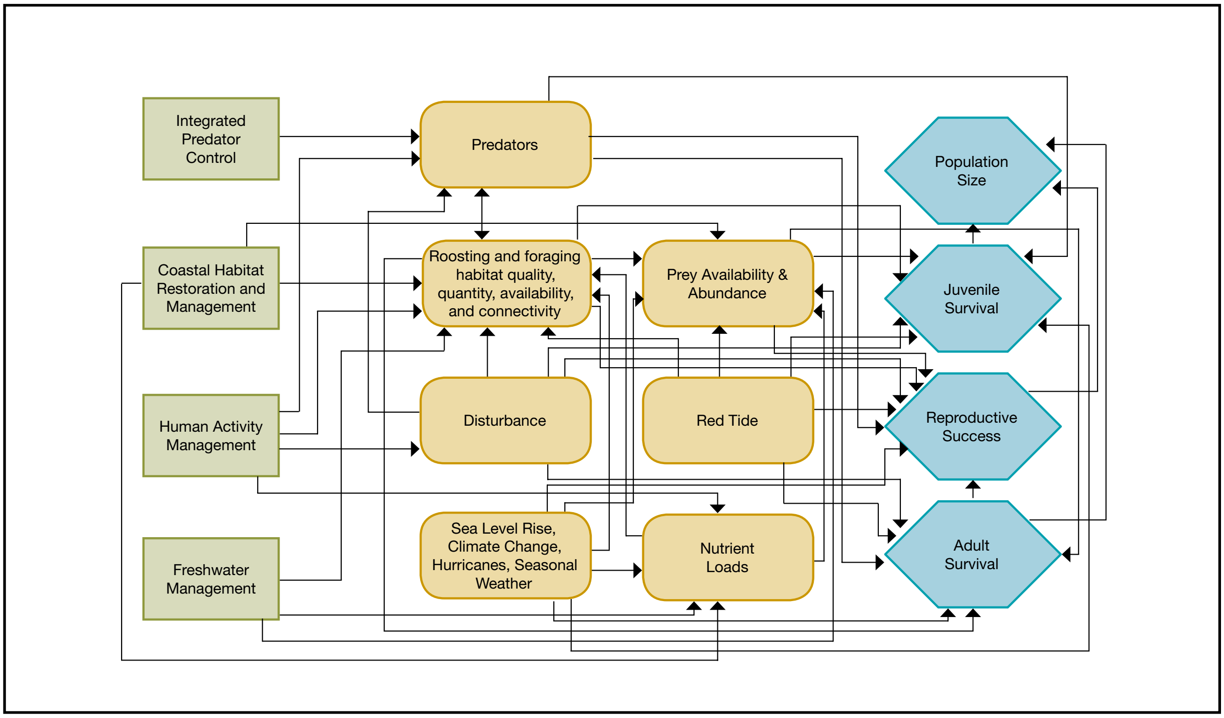

Figure 7.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the* ***American Oystercatcher*** *(Haematopus palliatus) within the Gulf of Mexico Region (see Appendix 7 for additional influence diagrams of priority shorebirds).*

Shorebirds

should be placed on determining site-specific and region-wide population limiting factors to guide adaptive management strategies. Important metrics such as reproductive success, prey availability, body condition, and annual survival (adult and juvenile) should be investigated to understand variability through the GoM and how they are influenced by local threats, management practices, restoration activities, predation, predator presence, climate patterns, and disturbance.

The species of conservation concern were chosen because: 1) they are listed species at state and/or federal levels, 2) they had Partners in Flight (2017) Species Assessment scores >3, indicating high uncertainty as to population status, 3) they are species that were particularly at risk during the Deepwater Horizon oiling event, or 4) they are common species that are able to serve as surrogates for less widespread or abundant species and the management actions or ecological processes that maintain the latter.

The population status of each of the GoMAMN species of conservation concern can be found in Table 7.1. These trends are from the Partners in Flight (PIF) Species Assessment (2017). Shorebirds for which the population trend is highly uncertain or highly variable receive a score of at least 3. Species with a score <3 are of less concern, those with a score >3 are of higher concern. Of the 10 shorebirds included in the GoMAMN birds of conservation concern list, one received a PIF score <3, three received a score of 3, and six received a score >3 (Table 7.1). Furthermore, the Piping Plover (endangered and threatened) and Red Knot (threatened) both received a PIF score of 5. The need for status and trends data parallel the ranking received for each species by their PIF score.

Snowy Plover (*Charadrius nivosus*). Photo Credit: Britt Brown

Priority Management Actions

Management and restoration are the broad tools available to resource managers and conservationists to mitigate the threats facing shorebirds. For the purposes of this document, restoration actions are a subset of management actions; these actions are ways to manage, mitigate, and offset threats, both natural and anthropogenic, and to create benefits, such as new habitats or new configurations of resources within existing habitats. Management actions may be designed to eliminate or reduce a direct threat, to improve habitat (directly or indirectly), or to provide additional resources to species of conservation concern. It is imperative that managers and the conservation community understand, prioritize, and use actions that benefit each shorebird species of conservation concern and their associated habitats.

The best way to reduce uncertainty associated with management actions is to integrate monitoring into a decision-making adaptive management framework (e.g., Lyons et al. 2008). Adaptive management can be an application of structured decision making (Williams et al. 2009), incorporating integrative decision making with respect to uncertainty (Williams 2011). This context monitoring: 1) provides information necessary for state-dependent decision making, 2) evaluates management/restoration actions, and 3) facilitates improved management through learning (Nichols and Williams 2006). Monitoring that is statistically rigorous and designed to capture potential changes in key shorebird response variables (i.e., prey availability, body condition, habitat features, etc.) will contribute to the assessment of performance metrics (i.e., population size, reproductive success, survival). The management actions (Table 7.2) include a list of the specific priority questions, uncertainty descriptions, and associated response metrics for measuring management and restoration performance.

Response metrics related to some component of breeding, roosting, and foraging habitat underpin the monitoring associated with determining management or restoration performance as well as reducing uncertainty. Management and restoration strategies may have a substantial impact on predation and survival of shorebirds, as well as the availability and/or quality of habitat and prey resources. Several studies (Wolff 1969, Sherfy et al. 2000, Dugan et al. 2003, Placyk and Harrington 2004, Colwell et al. 2005) have highlighted the role of prey density in influencing shorebird distributions. The influence diagrams for each shorebird species show where the management actions intersect with habitat-related variables leading to avian response variables and ultimately performance metrics. The habitat node in the influence diagram includes habitat quality, quantity, availability, and connectivity. These habitat characteristics are also specifically referenced in Table 7.2.

The highest priority management actions for shorebirds in the GoM include: 1) coastal habitat restoration and management, 2) human activity management, 3) integrated predator control, and 4) freshwater management. These priority management actions affect the greatest number of shorebird species of conservation concern, are applied frequently in the GoM, have a potentially large foot-print, have high uncertainty, and have high or unknown effect size (Table 7.2). Sustainable agriculture is a medium priority management action, because it benefits fewer species and is typically implemented at smaller spatial scales.

Coastal habitat restoration and management actions can directly or indirectly affect shorebirds either positively or negatively. These management actions typically impact some habitat component and have the potential to alter breeding habitat, prey availability, and roosting or foraging habitats. There are eight questions associated with coastal habitat restoration and management actions (Table 7.2), each with high uncertainty and high or unknown effect size. Reducing the uncertainty associated with coastal habitat restoration and management should focus on: 1) how habitat structure and composition relate to reproductive success and survival, 2) understanding the trade-offs for staying vs. emigrating into new habitats considering site-specific variables (i.e., habitat alteration, predation, disturbance), 3) impacts to prey, body condition, reproductive success, and survival, 4) nest site selection, movement patterns, and intra- and inter-specific competition and effects on reproductive success, and 5) clearly documenting incompatible management practices.

Incompatible management practices (i.e., beach raking, beach driving, revegetation) are one component of coastal habitat management that has a great deal of uncertainty associated with impacts to shorebirds. These management practices could have impacts to habitat structure and function, prey availability, vegetative structure, and distance between foraging, roosting, and nesting locations. Shorebirds may exhibit declines in fat gain and overall body condition and experience increased predation risk with subsequent declines in reproductive success and survival due to incompatible management impacts to the habitat (Ruhlen et al. 2003, Weston et al. 2011, Webber et al. 2013, Maslo et al. 2016). For example, shorebirds may have decreased survival due to planting woody vegetation that can harbor predators near a critical roosting area.

A management action that intersects with almost every response metric is human activity management. Human activity management (i.e., beach closure to vehicles, posting sensitive areas, disturbance management) can influence shorebird habitat use and behavior. In particular, human activity management can impact prey availability, prey abundance, foraging success, body condition, fat gain, time of departure, predation rates, habitat quality, disturbance, survival, and reproductive success. There are eight questions associated with human activity management (Table 7.2). While one question has a high effect size with low uncertainty; most aspects of human activity management have high uncertainty. Reducing the uncertainty associated with human activity management should focus on: 1) population-level impacts; 2) quantifying disturbance events and associated impacts to shorebirds; 3) disturbance thresholds and buffer distances; and 4) how human activity intersects with integrated predator control and predation.

Integrated predator control includes both lethal and non-lethal control and can be applied during the breeding and non-breeding seasons. A systematic review of lethal (Coté and Sutherland 1997, Smith et al. 2010) and nonlethal (Smith et al. 2010, Smith et al. 2011) predation management suggests that both can be effective strategies for increasing productivity of nesting birds. The shorebird influence diagrams (Figure 7.1, Appendix 7) show that reductions or increases in predation can be a direct result of integrated predator control or human activity management. Human presence at a location may: 1) increase diversity of predators and realized depredation rates (nests, chicks, adults), 2) increase abundance/activity of predators, and 3) introduce mesopredators. Predation can also be related to habitat type and quantity. A management or restoration activity can increase or decrease the amount of vegetation that can harbor predators. The presence/abundance of predators can also be a sublethal pressure resulting in decreased body condition and survival. There are three questions associated with integrated predator control (Table 7.2) and all have a high effect size with high uncertainty. Reducing the uncertainty associated with integrated predator control should focus on: 1) efficacy of targeted predation management in an adaptive management framework, 2) removal of predators and subsequent survival estimates for breeding and nonbreeding shorebirds, and 3) removal of predators and impacts to reproductive success of breeding shorebirds.

Freshwater management can influence salinity in estuaries impacting habitat and prey abundance and availability. These impacts can directly affect reproductive success during the breeding season or influence other response variables (i.e., fat gain, time of departure) during the non-breeding season. There is uncertainty associated with predicting the future state of estuarine communities and how much of an impact freshwater management will have on estuary habitat, prey abundance, and nutrient loads. Alterations to estuaries may push shorebirds into sub-optimal habitats potentially impacting reproductive success, survival, and ultimately, shorebird populations.

Table 7.2. *Uncertainties underpinning the relationship between management decisions and populations of shorebirds in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
American Oyster-catcher, Dunlin, Long-billed Curlew, Marbled Godwit, Piping Plover, Red Knot, Snowy Plover, Western Sandpiper, Wilson's Plover All	Site/Area Management (Habitat Management)	Do incompatible coastal habitat management practices impact prey availability and the required distance necessary in order to obtain prey, leading to decreases in body condition, fat gain, and time of departure and subsequent declines in reproductive success and annual survival for breeding and non-breeding shorebirds?	Reproductive Success, Survival, Population Size	Uncertainty in how and to what extent coastal management practices impact prey availability, body condition and survival. Monitoring associated with management practices typically is not conducted at appropriate temporal and spatial scales to determine direct or indirect impacts to shorebirds.	High	High
American Oyster-catcher, Snowy Plover, Wilson's Plover, Breeding	Site/Area Management (Habitat Management)	Does incompatible habitat management (i.e., beach raking, over planting, etc.) decrease reproductive success and survival for breeding shorebirds?	Reproductive Success, Survival, Population Size	High uncertainty in how reproductive success and survival are reduced by incompatible management. Limited research outside of documented direct take of nesting birds. Impact likely varies based on the degree and type of incompatible management implemented.	High	High
American Oyster-catcher, Dunlin, Long-billed Curlew, Marbled Godwit, Piping Plover, Red Knot, Snowy Plover, Western Sandpiper, Wilson's Plover Wintering, Migratory	Site/Area Management (Habitat Management)	Will the alteration of coastal habitat influence reproductive success, survival and population size?	Survival, Population Size, Reproductive Success	This action can be positive and negative. It creates habitat, but a variety of habitats are required for shorebirds. Need to examine how habitat structure relates to reproduction and survival. It is unclear how it equates to population level metrics and population trends.	High	High
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Habitat Restoration)	Will islands designed and managed for shorebirds support larger nesting populations?	Population Size	The creation of islands is known to be successful for seabird colonies, uncertainties in the colonization of created sites by solitary species (AMOY, SNPL, WIPL). Tolerance to nearby pairs unknown. Little information is available for WIPL. Few documented records of SNPL nesting on dredge spoil islands and may not tolerate nesting within large colonies of mixed seabirds.	High	Unknown
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Habitat Restoration)	Does creation of new shorebird breeding habitat move existing nesting individuals or expand nesting?	Population Size	Uncertainity related to population size and reproductive success. Does newly created shorebird breeding habitat move shorebirds from adjacent nesting sites or grow numbers of nesting birds? If birds moved, are they more productive at the new site?	High	Unknown

Table 7.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Habitat Restoration)	Will shorebirds have greater reproductive success when islands are designed and managed specifically for them?	Reproductive Success	Uncertainty is high because species of interest (American Oystercatcher, Snowy Plover, Wilson's Plover) typically nest in solitary situations and often experience higher predation rates when nesting in high nest densities. Additionally, other site specific factors contribute to reproductive success (e.g., proximity to Laughing Gull colonies or other avian predator species), much less information is available for Wilson's Plover.	High	Unknown
All All	Invasive/ Problematic Species Control (Vegetation)	Will targeted removal of woody vegetation (pines, etc.) near key roosting and nesting sites decrease predation rates and increase reproductive success and survival?	Reproductive Success, Survival, Population Size	It is known that nonbreeding shorebirds select roosting locations that are far from habitat features that may be attractive to mammalian and avian predators (ex. woody vegetation, perches, etc.). This management strategy has not been implemented in an adaptive management framework.	High	Unknown
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Habitat Management)	Does increased density of non-woody vegetation at or near breeding sites limit reproductive success and survival?	Reproductive Success, Survival, Population Size	This specific metric has not been studied tied to integrated predator control. Presence of dense vegetation potentially provides cover for mammalian predators, likely contributes to increases in ghost crabs and may contribute to the increased presence of overwintering raptor species (e.g., Northern Harrier).	High	Unknown
American Oyster-catcher, Dunlin, Long-billed Curlew, Marbled Godwit, Piping Plover, Red Knot, Snowy Plover, Western Sandpiper, Wilson's Plover Wintering, Migratory	Site/Area Management (Habitat Management)	Does increased density of non-woody vegetation at or near wintering foraging and/ or roosting sites limit overwinter survival?	Survival, Population Size	There is very little information on the sources of overwinter mortality events for most shorebirds. However, the presence of dense vegetation potentially provides cover for mammalian predators and may contribute to the increased presence of overwintering raptor species (e.g., Northern Harrier).	High	Unknown

Table 7.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
All All	Habitat and Natural Process Restoration (Freshwater Management)	Are shorebird populations impacted by decreased freshwater discharge/ salinity regimes in the estuary through changes in habitat and prey abundance? Changes in prey abundance and availability can affect body condition and survival.	Survival, Reproductive Success, Population Size	Difficult to predict future state of estuary communities. Uncertainity about how much of an impact freshwater management has on altering estuary habitat, prey abundance, and nutrient loads and how this impacts shorebird populations.	High	Unknown
All All	Habitat and Natural Process Restoration (Freshwater Management)	Blue-green algal blooms can lead to reduced or altered prey production, availability and abundance. For shorebirds, will resulting changes in prey lead to reduced body condition, fat gain, changes in habitat use and stopover patterns, consequently contributing to declines in shorebird reproductive success and survival?	Reproductive Success, Survival, Population Size	High uncertainty related to the role freshwater management plays in reproductive success and survival directly or indirectly (prey abundance, suboptimal habitat used, etc.) related to algal blooms. Limited data outside local mortality events.	High	Unknown
All All	Site/Area Management (Habitat Management)	Do activities such as beach driving reduce habitat use and quality for breeding and nonbreeding shorebirds?	Reproductive Success, Survival, Population Size	The degree of this effect is highly dependent upon extent, duration, frequency of beach driving, and site configuration. Even when public beach driving is eliminated there is often frequent driving for management and enforcement purposes. Ability to predict events and effects is poor. There is little research available that examines beach habitat quality and conditions once beach driving is removed.	High	High
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Disturbance)	Does the effect of human disturbance increase with proximity to breeding shorebirds, resulting in reduced reproductive success the closer disturbances occur?	Reproductive Success	Positive impacts to shorebird reproductive success associated with protection from disturbance with posting are well known. However, appropriate buffer distances are less understood for specific species in various habitats and under various relative disturbance thresholds.	High	High

Table 7.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Disturbance)	Do the impacts of human disturbance at key times during the nesting season have variable influence on reproductive success based on the stage of breeding (nest initiation, incubation, brood rearing) and corresponding time during nesting season (early, mid, late)?	Reproductive Success	There is limited research to identify points during the breeding season where disturbance has the most influence on reproductive success incorporating other site-specific variables (e.g. predation, presence of predators).	High	High
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Disturbance)	Does human presence lead to declines in reproductive success and survival?	Reproductive Success, Survival, Population Size	Recent research found the presence of people reduced fledgling survival of Piping Plovers on northern Atlantic breeding grounds. There is limited to no work in the GoM that has quantified and evaluated impacts of human presence on reproductive success and survival and how impacts vary in the GoM.	High	High
All Wintering, Migratory	Site/Area Management (Disturbance)	What is the influence of anthropogenic disturbance, predation/ disturbance pressures in the GoM on body condition, survival, and emigration rates?	Survival, Population Size	If and at what point and how do habitat alteration, predation or disturbance pressures negatively impact birds and how likely are birds to move to new habitats despite the potential benefits/consequences of moving?	High	High
All Wintering, Migratory	Site/Area Management (Disturbance)	Do anthropogenic activities during the winter reduce prey availability and foraging success, resulting in reduced body condition and survival for shorebirds?	Survival, Population Size	Degree of this effect is highly dependent upon extent, duration, and scale of anthropogenic activities. To what extent do activities impact body condition and survival?	High	Unknown
All Wintering, Migratory	Site/Area Management (Disturbance)	Does human disturbance on beaches during the winter reduce prey availability and foraging success for migratory shorebird species, leading to reductions in body condition and subsequent delays in departure ultimately resulting in lower reproductive success on their breeding grounds?	Reproductive Success	Degree of this effect is highly dependent upon extent, duration, and frequency of disturbance events. May be interactive with other unknown stressors on the breeding grounds.	High	Unknown
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Site/Area Management (Disturbance)	Do protection measures at nesting and brood-rearing locations increase reproductive success?	Reproductive Success	Increases in nesting populations have been documented following implementation of protection measures at nesting sites across the GoM.	Low	High

Shorebirds

Table 7.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Invasive/ Problematic Species Control (Predator Management)	Targeting problematic individual predators will increase the efficacy of predation management and limit potential negative impacts to other coastal dependent nesting species (i.e. beach mice) and increase reproductive success at nesting sites.	Reproductive Success, Survival	Will targeting problematic individual predators increase the efficacy of predation management and limit potential negative impacts to other coastal dependent nesting species (e.g., beach mice) and increase reproductive success at nesting sites?	High	High
All Wintering, Migratory	Invasive/ Problematic Species Control (Predator Management)	Does removal of predators improve survival for wintering and migratory shorebirds?	Survival	It is known that nonbreeding shorebirds select roosting locations that are far from habitat features that may be attractive to mammalian and avian predators (ex. woody vegetation, perches, etc.). When shorebirds are pushed out of preferred (safe) areas (i.e. high tide roosts subjected to overwash, etc.), to what degree are they susceptible to predation and reduced survival?	High	High
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Invasive/ Problematic Species Control (Predator Management)	Does removal of predators improve survival and reproductive success for breeding shorebirds?	Survival, Reproductive Success	The influence of predator pressures on shorebird reproductive success has been well documented in literature, however predation rates on solitary nesting shorebirds poorly understood and documented.	High	High
Buff-breasted Sandpiper, Long-billed Curlew Migratory	Site/Area Management (Contaminants)	Does the presence of pesticides and other contaminants at key stopover locations result in decreased reproductive success and survival? How much of a role does decreased prey abundance and availablilty play?	Reproductive Success, Survival, Population Size	Direct mortality has been observed, risks associated with new classes of pesticides are not known. Exposure to other classes of toxins are unknown.	High	High

[a]Categories follow the classification scheme and nomenclature presented by Salafsky et al. (2008) and Conservation Measures Partnership (2016).
[b]Based on expert opinion using two levels of classification (high level of uncertainty or low level of uncertainty) based on anecdotal observations and published literature.
[c]Based on expert opinion using three levels of classification (high, low, and unknown) per the potential positive or negative impact on a population. Where high represents the likelihood of a major impact; low represents a minor impact; and unknown represents unknown consequences.
[d]To facilitate decision making, we utilized a scoring rubric that contrasted the degree of uncertainty against the presumed population effect size, where High-High=1 (highest priority); High-Unknown=2; Low-Unknown=2; Low-High=3; High-Low=4; and Low-Low=5 (lowest priority). Here, we only present questions that scored a 1, 2, or 3.

Sustainable agriculture is a management action that can influence populations of shorebirds in the GoM during migration (e.g., Buff-breasted Sandpiper, Long-billed Curlew). There is uncertainty related to direct (i.e., mortality) and indirect (i.e., prey density, body condition) impacts to shorebirds (Figure 7.2, Appendix 7). Exposure to new classes of pesticides, as well as other classes of toxins have unknown, but potentially harmful effects (Tang et al. 2015). Duration and extent of exposure could impact reproductive success and survival.

Priority Ecological Processes

The occurrence of large-scale natural and anthropogenic ecosystem perturbations underscores the value of long-term monitoring data. The influences of demographic and environmental processes are routinely incorporated in population viability models and applied to species management (Bennett et al. 2009). Understanding changes in populations that arise from natural fluctuation in physical or climatic patterns will allow for predictions of population fluctuations in the absence of management actions. Understanding those relationships and how they affect demography of shorebirds is of high priority to the GoMAMN value model.

Shorebird population status and trends are driven by a suite of ecological processes in coastal, freshwater, and estuarine habitats that vary in spatial and temporal scale and can have disparate affects at distinct lifecycle stages. The GoMAMN value model prioritizes reduction of uncertainty about ecological processes that typically drive avian populations. The GoMAMN identified the most important ecological processes and mechanisms of action by shorebird species or suite of species (Table 7.3). The highest priority ecological processes for shorebirds in the GoM include: 1) habitat succession and transition, 2) hurricanes, severe weather events, and 3) sea-level rise, climate change, seasonal weather. These priority ecological processes affect the greatest number of shorebird species of conservation concern, impact large geographic areas, and have components of high uncertainty (Table 7.3). In addition, hydrological processes (nutrient loads), and natural disturbance regimes (red tide) are high priority ecological processes, but impact to species is less known and they tend to occur across smaller spatial scales. It is important to understand the seasonality of ecological processes because a process impacting a system or species during the breeding season (e.g., storm event causing reproductive failure) could result in a positive impact (e.g., accretion of habitat) for important nonbreeding shorebird species. Uncertainty about how a process impacts a system or species may also vary spatially, especially at larger scales (e.g., habitat availability, predator presence).

Habitat succession and transition, part of formation of biophysical habitats (Bennett et al. 2009), are ongoing processes across the full extent of the GoM region that have high effect size on some shorebirds, ultimately influencing everything from prey and predation, to body condition, time of departure, survival, and reproductive success. For example, the beach/dune habitat (Appendix 2) is highly dynamic and is shaped over time by wind, water, and other climatic forces. This habitat is typically comprised of a series of multiple dune ridges and pockets that differ in size, vegetation cover, and composition. It is this variation in the dune features that create the opportunities for diverse coastal-dependent wildlife, such as shorebirds. For example, Snowy and Wilson's Plovers are primarily limited to the early successional beach/dune habitat, where habitat is open and sparsely vegetated, for nesting and foraging (Page et al. 2009, Burger 2018). Additionally, the locations of plover brood-rearing areas are related to prey availability, but survival of the broods relates not only to prey, but to predator activity and physical features of the habitat such as dunes and vegetation (Pruner 2010). The preferred early successional habitat is typically maintained by tidal overwash and hurricanes. Naturally occurring plants like sea oats (*Uniola paniculata*) and bitter panicum (*Panicum amarum*) are dune engineers; they capture and stabilize moving sand and facilitate natural beach/dune habitat succession. In the absence of tidal or storm activity, the beach/dune habitat can become quickly over-vegetated for early-successional species and can contribute to a decline in reproductive success, habitat availability, and survival through increased predation rates. However, there is uncertainty in the relationship between predators and dune succession. Mammalian predators generally show a strong response to an increase in vegetation structure (Thompson and Gese 2007) and predators such as ghost crabs occur at higher densities as vegetation increases across the landscape (Pruner et al. 2015). Habitat succession likely improves connectivity between primary and secondary dunes and scrub/shrub habitats creating corridors and habitat favored by predators. Shorebird foraging habitat is also influenced by beach/dune succession where established dunes may prevent regularly occurring tidal overwash, thus reducing the occurrence of and formation of tidal ephemeral pools and flats. These types of foraging habitats are critical for Piping Plovers that use the GoM during migration and winter. Piping Plovers exhibit high winter site fidelity and often remain site-faithful even after conditions become unsuitable, resulting in reduced body condition and survival (Gibson et al. 2018).

Hurricanes and severe weather are natural disturbance regimes (Bennett et al. 2009) that can create or destroy habitats and indirectly or directly impact shorebirds. We are using the term 'hurricane' to include all tropical cyclone activity:

Table 7.3. *Uncertainties related to how ecological processes impact populations of shorebirds in the northern Gulf of Mexico.*

Species Season(s)	Ecological Process Category[a]	Question	End Point To Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Snowy Plover, Wilson's Plover Breeding	Formation of Biophysical Habitats	Does habitat succession and transition within the beach/dune system impact reproductive success and survival via loss or gain of nesting habitat?	Reproductive Success, Survival	For these species we know early successional habitat is preferred. Some information exists on transitional states, reproductive success and survival. Preliminary work suggests dune succession leads to increased predation rates at the local scale, leading to reduced reproductive success and survival. Population level impacts unknown.	High	High
Piping Plover Wintering, Migratory	Formation of Biophysical Habitats	Does change in habitat over time, through natural habitat succesion, lead to loss of foraging habitat availability and subsequently to declines in overwinter survival and population size?	Reproductive Success, Survival, Population Size	Piping Plovers have very high winter site fidelity. What is the rate of emmigration to new wintering areas due to habitat succession and what are the potential impacts of staying vs. emmigrating (body condition, survival, time of departure, reproductive success)?	High	High
All All	Natural Disturbance Regimes	When key stopover, wintering, and breeding habitats are lost and shorebirds are forced to shift to new habitats, does it result in survival and population declines?	Reproductive Success, Survival, Population Size	Degree of impact of habitat loss due to hurricanes and severe weather events on survival, reproductive success, and population trends.	High	High
All All	Hydrological Processes	Does the occurrence of blue-green algal (Cyanobacteria) blooms lead to declines in shorebird reproductive success and survival?	Reproductive Success, Survival	Impacts to shorebirds have not been studied and the risks of cyanotoxins to natural resources remain relatively unknown. There is a potential to impact shorebirds year-round. The seasonality of occurrence will impact the direction of overall influence and the spatial scale. Degree and direction of this effect is highly dependent upon extent, duration, and frequency of blue-green algal blooms.	High	Unknown
All All	Natural Disturbance Regimes	What is the extent of the impact of red tide on shorebird survival, reproductive success and populations?	Reproductive Success, Survival, Population Size	Red tide is a frequently cited conservation threat to shorebirds but little is known. It is unclear why some shorebird species are impacted more than others and which environmental factors to consider. Very little work has been completed on survival and reproductive success of impacted birds as well as tracking birds in the area that emmigrated or were documented as not impacted.	High	Unknown

Table 7.3 (continued).

Species Season(s)	Ecological Process Category[a]	Question	End Point To Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
American Oyster-catcher, Snowy Plover, Wilson's Plover Breeding	Climatic Processes	Does sea level rise impact reproductive success, survival, and populations via loss or gain of nesting habitat?	Reproductive Success, Survival, Population Size	Uncertainty in response of shorebirds to SLR, most models predict population declines. Also expected gains as the beach migrates.	High	High
All All	Climatic Processes	Sea level rise and changes in seasonal weather patterns will likely influence prey base, roosting and foraging habitat availability and connectivity. Will changes result in a decline in body condition and fat gain influencing survival, time of departure, reproductive success and population size?	Reproductive Success, Survival, Population Size	We know that body condition and time of departure can influence reproductive success and survival. No information available on how SLR, climate change, and seasonal weather will change prey base as well as foraging and roosting habitat availability and connectivity and the resulting body condition, time of departure, reproductive success, and survival.	High	High

[a]Categories follow the classification scheme and nomenclature presented by Bennet et al. (2009).
[b]Based on expert opinion using two levels of classification (high level of uncertainty or low level of uncertainty) based on anecdotal observations and published literature.
[c]Based on expert opinion using three levels of classification (high, low, and unknown) per the potential positive or negative impact on a population. Where high represents the likelihood of a major impact; low represents a minor impact; and unknown represents unknown consequences.
[d]To facilitate decision making, we utilized a scoring rubric that contrasted the degree of uncertainty against the presumed population effect size, where High-High=1 (highest priority); High-Unknown=2; Low-Unknown=2; Low-High=3; High-Low=4; and Low-Low=5 (lowest priority). Here, we only present questions that scored a 1, 2, or 3.

hurricanes, tropical storms, and tropical depressions, that differ based on maximum obtained wind speed. Hurricanes modify the beach profile by redistributing sand from the dunes to new forefront areas and creating ephemeral pools and large overwash fans that significantly increase nesting, brood-rearing, and roosting habitats for shorebirds (Leatherman 1979, Otvos 2004). Conversely, hurricanes and severe storms can alter biotic structure, wetland hydrology, geomorphology, and nutrient cycles in estuaries, which affect the availability and suitability of nesting and foraging habitats (Michener et al. 1997). Snowy Plovers, for example, were found to nest in higher densities in locations that had been impacted by hurricanes the previous year (Convertino et al. 2011). However, uncertainty exists in whether hurricanes would continue to provide the positive population-level benefits if they occurred frequently, at greater intensities, and during critical periods of the breeding season resulting in reduced annual recruitment. Future climate change scenarios depict more frequent and stronger hurricane events which may result in reduced habitat availability through localized losses of beach and estuary habitat (Bender et al. 2010, Geselbracht et al. 2015). Given the site-faithful nature of breeding and non-breeding shorebirds, there is uncertainty related to the impacts of habitat loss and suitability and the potential for subsequent declines in shorebird populations.

There is a great deal of uncertainty surrounding the response of shorebirds to climatic processes such as sea-level rise, climate change, and seasonal weather. Most climate change models predict a decline in population size for most species (Galbraith et al. 2002, Aiello-Lammens et al. 2011, Iwamura et al. 2013) and increased habitat fragmentation and loss which can result in a considerable reduction in both foraging and breeding areas for shorebirds (Chu-Agor et al. 2012). Large-scale changes to weather patterns, such as increased frequency of severe or unseasonable weather, also may have effects on reproductive success, survival, and movement patterns (Colwell 2010). There is much uncertainty associated with how and at what rate sea-level rise, climate change, and seasonal weather will impact the shorebird prey base and foraging, roosting, and nesting habitat availability and connectivity. There is also uncertainty in the response of shorebirds to changing conditions and if, when, and at what rate changing conditions will impact survival and reproductive success of shorebirds.

Red tide is a natural disturbance regime (Bennett et al. 2009) that can impact shorebirds. Red tide is a frequently cited conservation threat to shorebirds, but little is known about how or to what extent shorebirds are affected. It is unclear why some shorebird species (e.g., Red Knot, Sanderling, and Ruddy Turnstone) seem more susceptible to negative effects than others and which environmental factors contribute to the degree of impacts. Mortality of affected shorebirds is often documented; however, very little work has been completed on survival and reproductive success of exposed birds, as well as shorebirds that either emigrated out of the impacted area or avoided the impacted area.

High-water events can contribute to concentrations of nutrients in a system and the occurrence of blue-green bacteria (cyanobacteria). Direct or indirect impacts to shorebirds have not been studied and the risks of cyanotoxins to natural resources remain relatively unknown. There is potential for blue-green algal blooms to impact shorebirds year-round across the GoM. The seasonality of occurrence will impact the direction of the overall influence and the spatial scale of potential impacts. Degree and direction of this effect is highly dependent upon extent, duration, and frequency of blue-green algal blooms.

SUMMARY & MONITORING RECOMMENDATIONS

Monitoring plays a critical role in natural resource management to inform the decision-making process, and monitoring design should be driven by the decision context and associated uncertainties (Lyons et al. 2008). Lack of knowledge may limit the ability to identify, implement, and assess the most effective management and restoration strategies. Investments in monitoring will be required to maximize the effectiveness of management and restoration actions (Schulte 2016). Status and trend assessments focusing on system-state variables (e.g. population size, reproductive metrics, survival, movement patterns) at appropriate temporal and spatial scales will enhance the understanding of mechanisms underlying population dynamics and trends in the GoM. Monitoring should enable the evaluation of management performance and impacts of ecological processes and identify background variation. Conservation planning for the GoM will benefit from clear articulation of fundamental monitoring objectives.

Monitoring priorities:

★ Establish standardized baseline monitoring of breeding shorebirds to facilitate status and trend assessments across the GoM that can be used as a state-dependent variable to assess geographical movements, impacts of anthropogenic and natural perturbations (e.g. oil spills, hurricanes), changes in habitat, and/or impacts of management and restoration actions.

★ Establish or expand on existing studies designed to monitor changes in reproductive success during both stages of breeding (i.e., nest and chick survival) in response to management and restoration actions, changes in habitat and impacts of anthropogenic and natural perturbations (e.g. oil spills, hurricanes).

★ Establish baseline monitoring of migratory and wintering shorebirds to facilitate status and trend assessments that can be used as a region-wide variable to assess habitat use, habitat loss, changes in habitat, overwinter survival, and/or effects of management and restoration actions.

★ Establish monitoring of shorebirds at stopover and wintering sites to facilitate the identification of critical habitats and locations. Monitoring strategies should include coverage of habitat adjacent to known stopover sites to document shifts in habitat use.

★ Develop a better understanding of the ecology of shorebirds during migration through the GoM to predict the potential population-level effects of continued habitat loss and change in the GoM.

★ Establish or expand on existing studies designed to increase the knowledge of the effects of predation, predator presence, and effectiveness of targeted predation management in an adaptive management framework on demographics of breeding and nonbreeding shorebirds. Monitoring strategies should include the assessment of predator presence and predation frequency in relation to vegetation structure.

★ Establish or expand on existing studies designed to determine the effect of anthropogenic disturbance during different life stages (i.e., nesting, brood-rearing, non-nesting) on shorebird demographics with a focus on understanding the impacts of human activities and identification of important site-specific variables.

★ Evaluate and assess the impacts of incompatible beach management activities (e.g., beach nourishment, revegetation, etc.) on breeding and nonbreeding shorebird movement patterns, reproductive success, and survival.

- ★ Establish or expand on existing studies designed to monitor change and loss of coastal habitat through management/restoration, vegetation succession, or ecological processes, focusing on shorebird foraging, roosting, and breeding habitats to determine impacts to shorebird survival, reproductive success, and population size.
- ★ Evaluate the importance of site fidelity in breeding and nonbreeding shorebirds and incorporate site specific variables to determine rates of mortality and emigration.
- ★ Establish a monitoring program that allows rapid assessment of the effects of natural or man-made perturbations including episodic coastal oiling, red tide, or similar events on shorebird survival and health. This program may extend to tracking of survival of impacted birds as well as the tracking of birds in the area that were not impacted.

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Mixed species shorebird flock, including the American Oystercatcher (*Haematopus palliatus*). Photo credit: Janell Brush

LITERATURE CITED

Aiello-Lammens, M. E., Ma. L. Chu-Agor, M. Convertino, R. A. Fischer, I. Linkov, H. R. Akcakaya. 2011. The impact of sea-level rise on Snowy Plovers in Florida: Integrating geomorphological, habitat, and metapopulation models. Global Change Biology 17:3644-3654.

Alber, M. 2002. A conceptual model of estuarine freshwater inflow management. Estuaries 25:1246-1261.

American Oystercatcher Working Group, E. Nol, R. C. Humphrey. 2012. American Oystercatcher (Haematopus palliates). In A. Poole (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

Angelstam, P. 1986. Predation on ground-nesting birds' nests in relation to predator densities and habitat edge. Oikos 47:365-373.

Atlantic Flyway Shorebird Initiative (AFSI): A Business Plan. 2015. Retrieved on September 2, 2018, from http://www.nfwf.org/amoy/Documents/afsi_biz_plan.pdf.

Baker, A. J., P. M. Gonzalez, T. Piersma, L. J. Niles, I. L. S. do Nascimento, P. W. Atkinson, N. A. Clark, C. D. T. Minton, M. K. Peck, G. Aarts. 2004. Rapid population decline in Red Knots: Fitness consequences of decreased refueling rates and late arrival in Delaware Bay. Proceedings of the Royal Society of London B 271:875-882.

Baker, A., P. Gonzalez, R. I. G. Morrison, B. A. Harrington. 2013. Red Knot (Calidris cantus), In A. Poole (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

Beale, C., P. Monaghan. 2004. Behavioral responses to human disturbance: A matter of choice? Animal Behaviour 68:1065-1069.

Bender, M. A., T. R. Knutson, R. E. Tuleya, J. J. Sirutis, G. A. Vecchi. 2010. Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. Science 327:454.

Bennett, A.F., A. Haslem, D.C. Cheal, M.F. Clarke, R.N. Jones, J.D. Koehn, P.S. Lake, L.F. Lumsden, I.D. Lunt, B.G. Mackey, R. Mac Nally, P.W. Menkhorst, T.R. New, G.R. Newell, T. O'Hara, G.P. Quinn, J.Q. Radford, D. Robinson, J.E.M. Watson, A.L. Yen. 2009. Ecological processes: A key element in strategies for nature conservation. Ecological Management and Restoration 10:192-199.

Benson, T. J., J. D. Brown, J. C. Bednarz. 2010. Identifying predators clarifies predictors of nest success in a temperate passerine. Journal of Animal Ecology 79:225-234.

Blumstein, D. T., E. F. Juricic, P. A. Zollner, A. C. Garity. 2005. Inter-specific variation in avian responses to human disturbance. Journal of Applied Ecology 42:943-953.

Brown, S., B. Harrington, R. Gill (Eds.). 2001. The United States Shorebird Conservation Plan, Second edition. Manomet Center for Conservation Sciences, Manomet, Massachusetts, USA.

Brush, J. M., A. C. Schwarzer, P. C. Frederick. 2017. Importance and function of foraging and roost habitat for wintering American Oystercatchers. Estuaries and Coasts 40:286-295.

Burger, J. 1986. The effect of human activity on shorebirds in two coastal bays in northeastern United States. Environmental Conservation 13:123-130.

Burger, J., C. Jeitner, K. Clark, L. J. Niles. 2004. The effect of human activities on migrant shorebirds: Successful adaptive management. Environmental Conservation 31(4):283-288.

Burger, J., L. Niles, R. Porter, A. Dey, S. Koch, C. Gordon. 2012. Migration and over-wintering of Red Knots (*Calidris cantus rufa*) along the Atlantic Coast of the United States. Condor 114:302-313.

Burger, J. 2017. Avian resources of the northern Gulf of Mexico. In C.H. Ward (Ed.), Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill. Springer, New York. pp 1353-1488.

Burger, J. 2018. Birdlife of the Gulf of Mexico. Texas A&M University Press. College Station, Texas, USA.

Chalfoun, A. D., M. J. Ratnaswamy, F. R. Thompson III. 2002. Songbird nest predators in forest-pasture edge and forest interior in a fragmented landscape. Ecological Applications 12:858-867.

Chu-Agor, M. L., R. Muñoz-Carpena, G. A. Kiker, M. E. Aiello-Lammens, H. R. Akcakaya, M. Convertino, I. Linkov. 2012. Simulating the fate of Florida Snowy Plovers with sea-level rise: Exploring research and management priorities with a global uncertainty and sensitivity analysis perspective. Ecological Modelling 224(1):33-47.

Colwell, M. A., C. B. Millett, J. J. Meyer, J. N. Hall, S. J. Hurley, S. E. McAllister, A. N. Transou, R. R. LeValley. 2005. Snowy Plover reproductive success in beach and river habitats. Journal of Field Ornithology 76(4):373-382.

Colwell, M. A. 2010. Shorebird Ecology: Conservation and Management. University of California Press, Berkeley, California, USA.

Conklin, J. R., M. A. Colwell, N. W. Fox-Fernandez. 2008. High variation in roost use by Dunlin wintering in California: Implications for habitat limitation. Bird Conservation International 18:275-291.

Conservation Measures Partnership. 2016. Classification of Conservation Actions and Threats, Version 2.0. Retrieved from http://cmp-openstandards.org/tools/threats-and-actions-taxonomies/.

Convertino, M., J. B. Elsner, R. Muñoz-Carpena, G. A. Kiker, C. J. Martinez, R. A. Fisher, I. Linkov. 2011. Do tropical cyclones shape shorebird habitat patterns? Biogeoclimatology of Snowy Plovers in Florida. PLoS ONE 6(1):e15683.

Deepwater Horizon Natural Resource Damage Assessment Trustees (DHNRDAT). 2016. Deepwater Horizon oil spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Retrieved on March 30, 2019, from https://www.gulfspillrestoration.noaa.gov/sites/default/files/wp-content/uploads/Chapter-4_Injury_to_Natural_Resources_508.pdf.

Dugan, J. E., D. M. Hubbard, M. D. McCrary, M. O. Pierson. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuarine Coastal and Shelf Sciences 58S:133-148.

Dugger, B. D., K. M. Dugger. 2002. Long-billed Curlew (*Numenius americanus*). In A. Poole, F. Gill (Eds.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

DeRose-Wilson, A., K. L. Hunt, J. D. Monk, D. H. Catlin, S. M. Karpanty, J. D. Fraser. In press. Piping plover chick survival negatively correlated with beach recreation. Journal of Wildlife Management.

Elliott-Smith, E., S. M. Haig, B. M. Powers. 2009. Data from the 2006 International Piping Plover Census: U.S. Geological Survey Data Series 426. Reston, Virginia, USA.

Elliott-Smith, E., M. Bidwell, A. E. Holland, S. M. Haig. 2015. Data from the 2011 International Piping Plover Census: U.S. Geological Survey Data Series 922. Reston, Virginia, USA.

Ens, B. J., M. Kersten, A. Brenninkmeijer, J. B. Hulscher. 1992. Territory quality, parental effort, and reproductive success of Oystercatchers (*Haematopus ostralegus*). Journal of Animal Ecology 61:703-715.

Ferland, C.L., S.M. Haig. 2002. 2001 International Piping Plover Census. U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon, USA.

Flemer, D. A., M. A. Champ. 2006. What is the future fate of estuaries given nutrient over-enrichment, freshwater diversion and low flows? Marine Pollution Bulletin 52:247-258.

Fournier A. M. V, R. R. Wilson, J. E. Lyons, J. Gleason, E. Adams, L. Barnhill, J. Brush, F. Chavez-Ramirez, R. Cooper, S. DeMaso, M. Driscoll, M. Eaton, P. Frederick, M Just., M. Seymour, J. Tirpack, M. Woodrey. (in press). Structured decision making and optimal bird monitoring in the Northern Gulf of Mexico. U.S. Geological Survey, Open File Report.

Franks, S., D. B. Lank, W. H. Wilson Jr. 2014. Western Sandpiper (*Calidris mauri*). In A. Poole (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology. Ithaca, New York, USA.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, G. Page. 2002. Global climate change and sea-level rise: Potential losses of intertidal habitat for shorebirds. Waterbirds 25:173-183.

Geselbracht, L. L., K. Freeman, A. P. Birch, J. Brenner, D. R Gordon. 2015. Modeled sea-level rise impacts on coastal ecosystems at six major estuaries on Florida's Gulf Coast: Implications for adaptation planning. PLoS ONE 10(7):e0132079.

Gibson, D., M. K. Chaplin, K. L. Hunt, M. J. Friedrich, C. E. Weithman, L. M. Addison, V. Cavalieri, S. Coleman, F. J. Cuthbert, J. D. Fraser, W. Golder, D. Hoffman, S. M. Karpanty, A. Van Zoeren, and D. H. Catlin. 2018. Impacts of anthropogenic disturbance on body condition, survival, and site fidelity of nonbreeding Piping Plovers. The Condor 120:566-580.

Gill, J. A., K. Norris, W. J. Sutherland. 2001. Why behavioral responses may not reflect the population consequences of human disturbance. Biological Conservation 97(2):265-268.

Gratto-Trevor, C. L. 2000. Marbled Godwit (*Limosa fedoa*). In A. Poole, F. Gill (Eds.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

Gratto-Trevor, C. Amirault-Langlais, D. Catlin, F. Cuthbert, J. Fraser, S. Maddock, E. Roche, F. Shaffer. 2012. Connectivity in piping plovers: Do breeding populations have distinct winter distributions? Journal of Wildlife Management 76(2):348-355.

Henkel, J. R., C. M. Taylor. 2015. Migration strategy predicts stopover ecology in shorebirds on the northern Gulf of Mexico. Animal Migration 2:63-75.

Henkel, J. R. B. Sigel, C. M. Taylor. 2014. Oiling rates and condition indices of shorebird communities in the northern Gulf of Mexico following the Deepwater Horizon oil spill. Journal of Field Ornithology 85:408-420.

Hill, D., D. Hockin, D. Price, G. Tucker, R. Morris, J. Treweek. 1997. Bird disturbance: Improving the quality and utility of disturbance research. Journal of Applied Ecology 34:275-288.

Hood, S. L. 2006. Nesting ecology of snowy and Wilson's plovers in the lower Laguna Madre region of Texas. Thesis, Mississippi State University. 78 p.

Hunt, K. L., J. D. Fraser, S. M. Karpanty, D. H. Catlin. 2017. Body condition of Piping Plovers (*Charadrius melodus*) and prey abundance on flood-created habitat on the Missouri River, USA. The Wilson Journal of Ornithology 129(4):754-764.

Iwamura, T., H. P. Possingham, I. Chades, C. Minton, N. J. Murray, D. I. Rogers, E. A. Treml, R. A. Fuller. 2013. Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations. Proceedings of the Royal Society B 280:20130325.

Kersten, M., T. Piersma. 1987. High levels of energy expenditure in shorebirds: Metabolic adaptations to an energetically expensive way of life. Ardea 75:175-187.

Koch, S. L., P. W. C. Paton. 2014. Assessing anthropogenic disturbances to develop buffer zones for shorebirds using a stopover site. Journal of Wildlife Management 78:58-67.

Krapu, G. L., J. L. Eldridge, C. L. Gratto-Trevor, D. A. Buhl. 2006. Fat dynamics in arctic-nesting sandpipers during spring and mid-continental North America. Auk 123:323-334.

Leatherman, S. 1979. Beach and dune interactions during storm conditions. Journal of Engineering Geology and Hydrogeology 12:281-290.

Livingston, R. J., Z. Niu, F. G. Lewis III, G. C. Woodsum. 1997. Freshwater input to a gulf estuary: Long-term control of trophic organization. Ecological Applications 7:277-299.

Lyons, J. E., M. C. Runge, H. P. Lakowski, W. L. Kendall. 2008. Monitoring in the context of structured decision-making and adaptive management. Journal of Wildlife Management 72:1683-1692.

Maslo, B., T. A. Schlacher, M. A. Weston, C. M. Huijbers, C. Anderson, B. L. Gilby, A. D. Olds, R. M. Connolly, D. S. Schoeman. 2016. Regional drivers of clutch loss reveal important trade-offs for beach-nesting birds. Journal of Life and Environmental Sciences PeerJ.

McCarty, J. P., L. L. Wolfenbarger, C. D. Laredo, P. Pyle, R. B. Lanctot. 2017. Buff-breasted Sandpiper (*Calidris subruficollis*). In R. Rodewald (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

McGowan, C. P., J. E. Hines, J. D. Nichols, J. E. Lyons, D. R. Smith, K. S. Kalasz, L. J. Niles, A. D. Dey, N. A. Clark, P. W. Atkinson, C. D. T. Minton, W. Kendall. 2011. Demographic consequences of migratory stopover: Linking Red Knot survival to horseshoe crab spawning abundance. Ecosphere 2:1-22.

Michener, W. K., E. R. Blood, K. L. Bildstein, M. M. Brinson, L. R. Gardner. 1997. Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. Ecological Applications 7:770-801.

Newstead, D. J., L. J. Niles, R. R. Porter, A. D. Dey, J. Burger, O. N. Fitzsimmons. 2013. Geolocation reveals mid-continent migratory routes and Texas wintering areas of Red Knots (*Calidris canutus rufa*). Wader Study Group Bulletin 120(1):53-59.

Newstead, D. J. 2014. Habitat use of North Padre Island and Laguna Madre habitats by Piping Plovers and Red Knots in the vicinity of current and proposed wind energy development. The Texas Endangered Species Program. Corpus Christi, Texas, USA.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21:668-673.

Niles, L., H. Sitters, A. Dey, Red Knot Status Assessment Group. 2010. The Red Knot (*Calidris canutus*) Conservation Plan for the Western Hemisphere, Version 1.1. Manomet Center for Conservation Sciences, Manomet, Massachusetts, USA.

Otvos, E. 2004. Beach aggradation following hurricane landfall: Impact comparisons from two contrasting hurricanes, northern Gulf of Mexico. Journal of Coastal Research 20:326-339.

Page, G. W., L. E. Stenzel, J. S. Warriner, J. C. Warriner, P. W. Paton. 2009. Snowy Plover (*Charadrius nivosus*). In A. Poole (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

Partners in Flight. 2017. Avian Conservation Assessment Database, version 2017. Retrieved on September 2, 2018 from http://pif.birdconservancy.org/ACAD.

Piersma, T., A. Lindstrom. 2004. Migrating shorebirds as integrative sentinels of global environmental change. Ibis 146(1):61-69.

Placyk, J. S., B. A. Harrington. 2004. Prey abundance and habitat use by migratory shorebirds at coastal stopover sites in Connecticut. Journal of Field Ornithology 75(3):223-231.

Plissner, J. H., S. M. Haig. 1997. 1996 International Piping Plover Census. U.S. Geological Survey, Biological Resources Division, Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon, USA.

Powell, A. N., C. L. Collier. 2000. Habitat use and reproductive success of western Snowy Plovers at new nesting areas created for California least terns. Journal of Wildlife Management 64:24-33.

Pruner, R. A. 2010. Conservation and management of the Snowy Plover along the Florida Gulf Coast: Habitat selection, reproductive performance, and the effects of anthropogenic disturbance. Thesis, University of Florida, Gainesville, Florida, USA.

Pruner, R. A, M. J. Friel, J. E. Bente. 2015. Shorebird research and management at Florida Panhandle state parks. Department of Environmental Protection, Florida Park Service. Panama City, Florida, USA.

Rehfisch, M. M., H. Q. P. Crick. 2003. Predicting the impact of climatic change on Arctic-breeding waders. Wader Study Group Bulletin 100:86-95.

Rogers, D. I., P. F. Battley, T. Piersma, J. A. Van Gils, K. G. Rogers. 2006. High-tide habitat choice: Insights from modelling roost selection by shorebirds around a tropical bay. Animal Behaviour 72(3):563-575.

Ruhlen, T. D., S. Abbot, L. E. Stenzel, G. W. Page. 2003. Evidence that human disturbance reduces Snowy Plover chick survival. Journal of Field Ornithology 74(3):300-304.

Russell, R.W. 2005. Interactions between migrating birds and offshore oil and gas platforms in the Northern Gulf of Mexico: Final Report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2005-009. 348 pp.

Salafsky, N., D. Salzer, A. J. Stattersfield, C. Hilton-Taylor, R. Neugarten, S. H. M. Butchart, B. Collen, N. Cox, L. L. Master, S. O'Connor, D. Wilkie. 2008. A standard lexicon for biodiversity conservation: Unified classifications of threats and actions: Conservation Biology 22(4):897-911.

Schlacher, T. A., T. Nielsen, M. A. Weston. 2013. Human recreation alters behavior profiles of non-breeding birds on open-coast sandy shores. Estuarine, Coastal, and Shelf Science 118:31-42.

Schulte, S., S. Brown, D. Reynolds, American Oystercatcher Working Group. 2010. Version 1.0. American Oystercatcher Conservation Plan for the United States Atlantic and Gulf Coasts. Manomet, Massachusetts, USA.

Schulte, S. A. 2016. Florida Beach-Nesting Bird Plan. Manomet, Massachusetts, USA.

Schwarzer, A.C. 2011. Demographic rates and energetic of Red Knots wintering in Florida. Thesis, University of Florida, Gainesville, Florida, USA.

Sherfy, M. H., R. L. Kirkpatrick, K. D Richkus. 2000. Benthos core sampling and chironomid vertical distribution: implications for assessing shorebird food availability. Wildlife Society Bulletin 28(1):124-130.

Sherry, T. W., R. T. Holmes. 1996. Winter habitat quality, population limitation, and conservation of neotropical - nearctic migrant birds. Ecology 77:36-48.

Smith, R. K., A. S. Pullin, G. B. Stewart, W. J. Sutherland. 2010. Effectiveness of predator removal for enhancing bird populations. Conservation Biology 24(3):820-829.

Smith, R. K., A. S. Pullin, G. B. Stewart, W. J. Sutherland. 2011. Is nest predator exclusion an effective strategy for enhancing bird populations? Biological Conservation 144:1-10.

Stillman, R., J. Goss-Custard. 2002. Seasonal changes in the response of oystercatchers (*Haematopus ostralegus*) to human disturbance. Journal of Avian Biology 33:358-365.

Stenzel, L. E., G. W. Page, J. C. Warriner, J. S. Warriner, D. E. George, C. R. Eyster, B. A. Ramer, K. K. Neuman, B. K. Sandercock. 2007. Survival and natal dispersal of juvenile Snowy Plovers (*Charadrius alexandrinus*) in central coastal California. Auk 124:1023-1036.

Tang, Z., Q. Huang, Z. Nie, Y. Yang. 2015. Pollution threatens migratory shorebirds. Science 352(6):1176-1177.

Thibault, J. M. 2008. Breeding and foraging ecology of American Oystercatchers in the Cape Romain region, South Carolina. Thesis, Clemson University, Clemson, South Carolina, USA.

Thomas, K., R. G. Kvitek, C. Bretz. 2003. Effects of human activity on the foraging behavior of Sanderlings (*Caldris alba*). Biological Conservation 109:67-71.

Thompson, C. M., E. M. Gese. 2007. Food web and intraguild predation: Community interactions of a native mesocarnivore. Ecology 88(2):334-346.

U.S. Fish and Wildlife Service. 1996. Piping Plover (*Charadrius melodus*), Atlantic Coast population revised recovery plan. Hadley, Massachusetts, USA.

U.S. Fish and Wildlife Service. 2009. Piping Plover (*Charadrius melodus*), 5-year review: Summary and evaluation. Hadley, Massachusetts, USA.

Van Gils, J. A., T. Piersma, A. Dekinga, B. Spanns, C. Kraan. 2006. Shellfish dredging pushes a flexible avian top predator out of a marine protected area. PloS Biology 4(12):e376.

Virzi T., J. L. Lockwood. 2010. Conservation of American Oystercatchers in New Jersey. The State University of New Jersey, Rutgers. New Brunswick, New Jersey, USA.

Warnock, N. D., R. E. Gill. 1996. Dunlin (*Calidris alpina*). In P. Rodewald (Ed.), The Birds of North America, Version 2.0. Cornell Lab of Ornithology, Ithaca, New York, USA.

Warriner, J. S., J. C. Warriner, G. W. Page, L. E. Stenzel. 1986. Mating system and reproductive success of a small population of polygamous Snowy Plovers. Wilson Bulletin 98:15-37.

Webber, A. F., J. A. Heath, R. A. Fischer. 2013. Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during the breeding season. Ecology and Evolution 3(4):853-863.

Weston, M. A., G. C. Ehmke, G. S. Maguire. 2011. Nest return times in response to static versus mobile human disturbance. Journal of Wildlife Management 75(1):252-255.

Williams, B. K., R. C. Szaro, C. D. Shapiro. 2009. Adaptive management: The U.S. Department of the Interior technical guide. Adaptive Management Working Group. U.S. Department of the Interior, Washington, D.C., USA.

Williams, B. K. 2011. Adaptive management of natural resources-framework and issues. Journal of Environmental Management 92:1346-1353.

Withers, K. 2002. Shorebird use of coastal wetland and barrier island habitat in the Gulf of Mexico. The Scientific World Journal 2:514-536.

Wolff, W. J. 1969. Distribution of non-breeding waders in an estuarine area in relation to the distribution of their food organisms. Ardea 57:1-28.

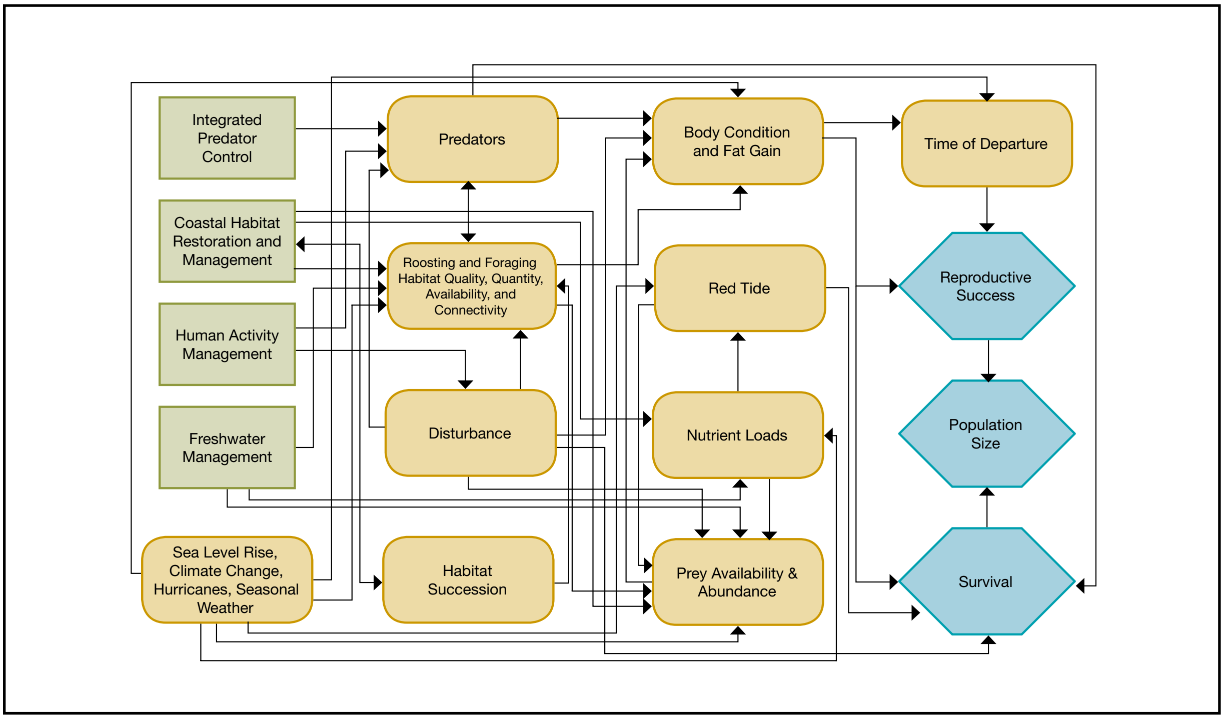
Yalden, P. E., D. W. Yalden. 1990. Recreational disturbance of breeding Golden Plovers (*Pluvialis apricarius*). Biological Conservation 51:243-262.

Yasue, M. 2006. Environmental factors and spatial scale influence shorebirds' responses to human disturbance. Biological Conservation 128:47-54.

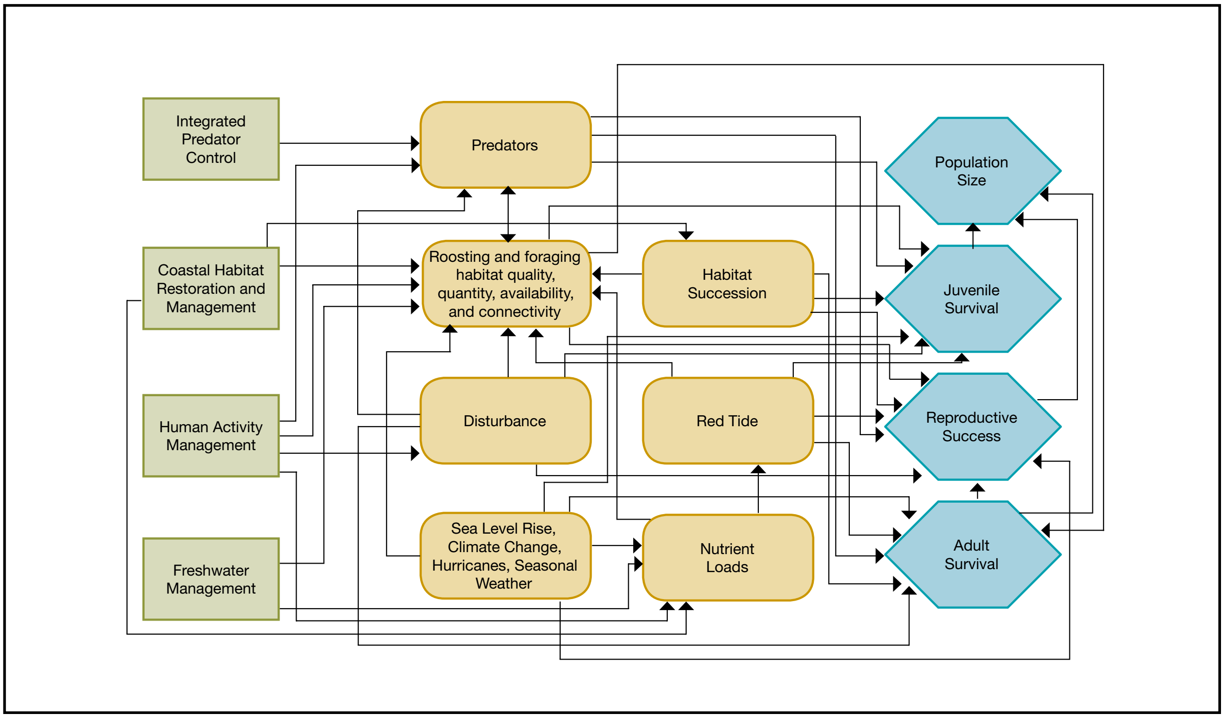
Zdravkovic, M. G., C. A. Corbat, P. W. Bergstrom. 2018. Wilson's Plover (*Charadrius wilsonia*). In P. Rodewald (Ed.), The Birds of North America, Version 1.1. Cornell Lab of Ornithology, Ithaca, New York, USA.

APPENDIX 7

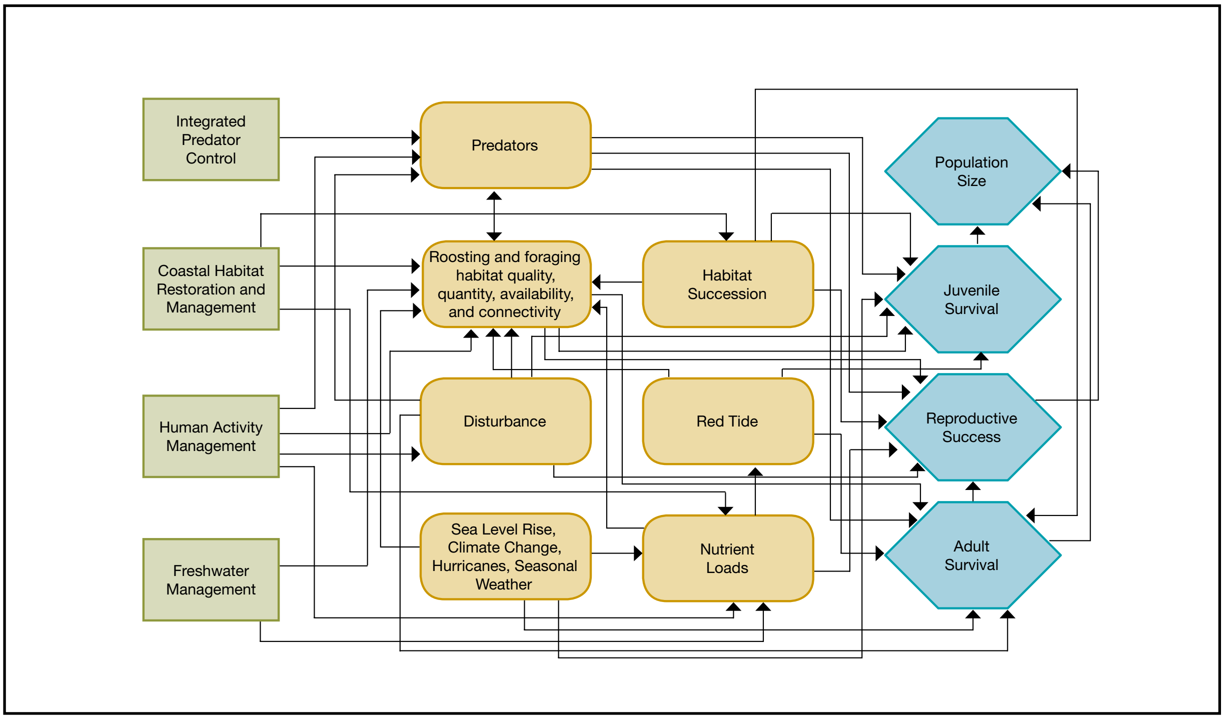
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of shorebirds.



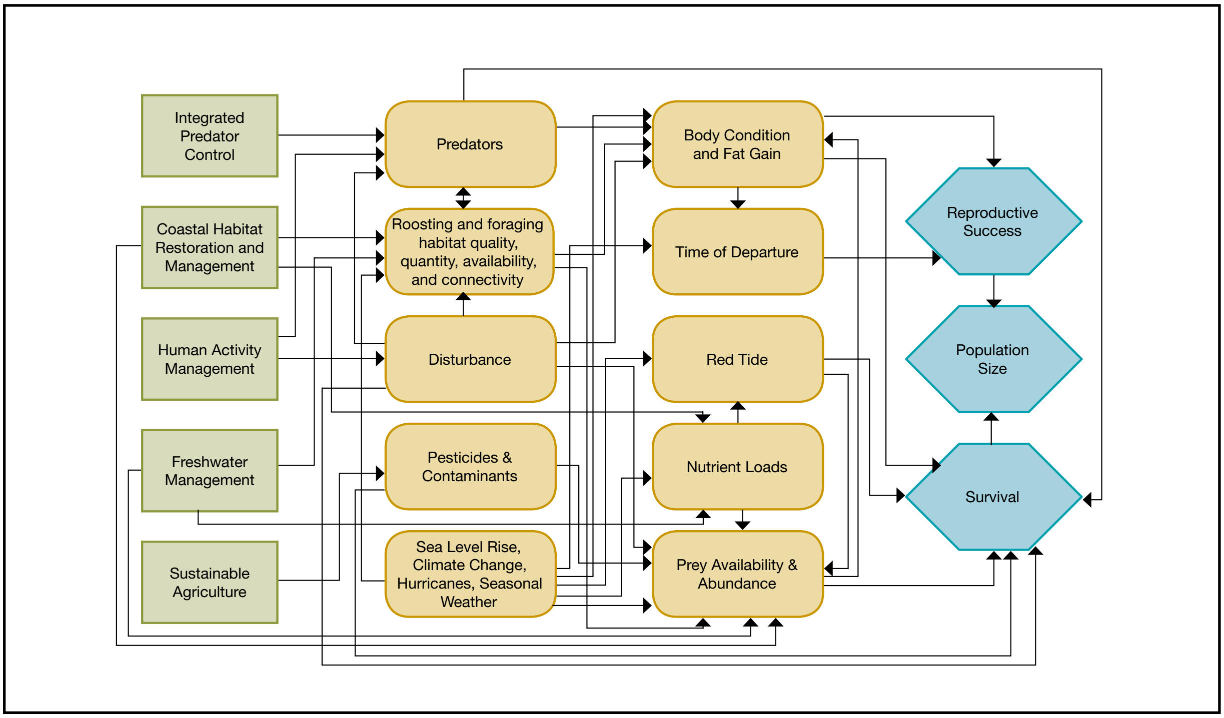
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the **Piping Plover** (Charadrius melodus) within the Gulf of Mexico Region.*



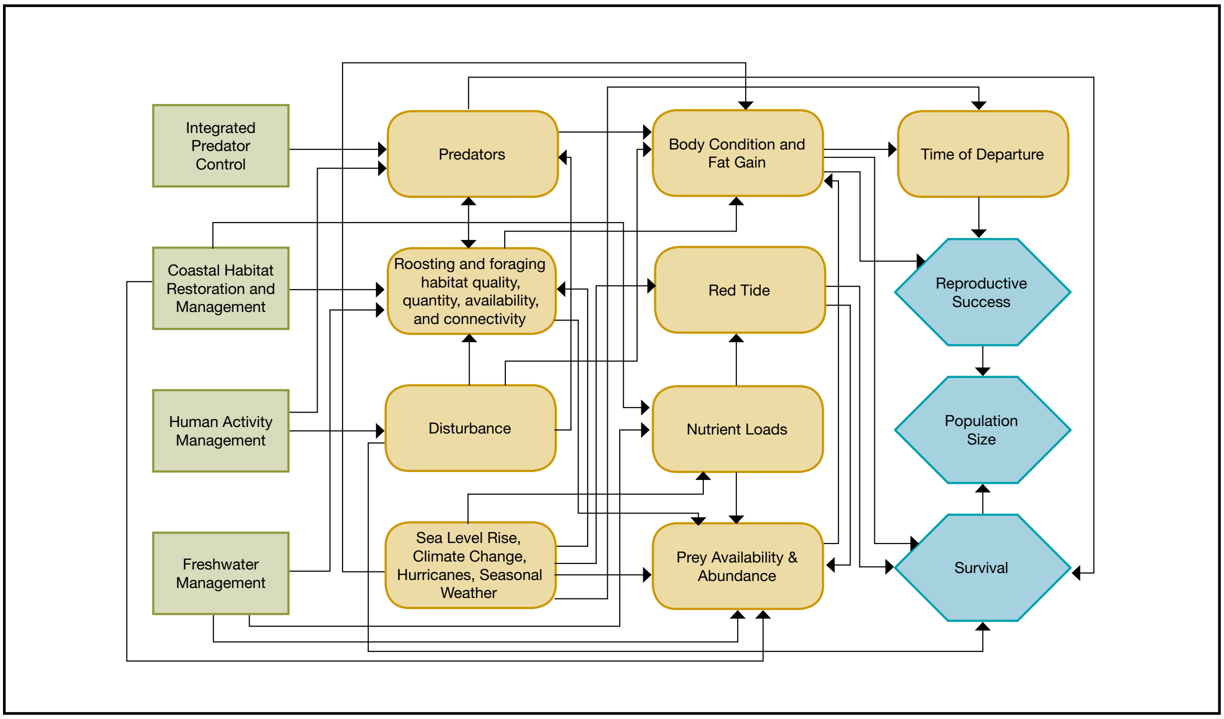
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Wilson's Plover*** *(Charadrius wilsonia) within the Gulf of Mexico Region.*



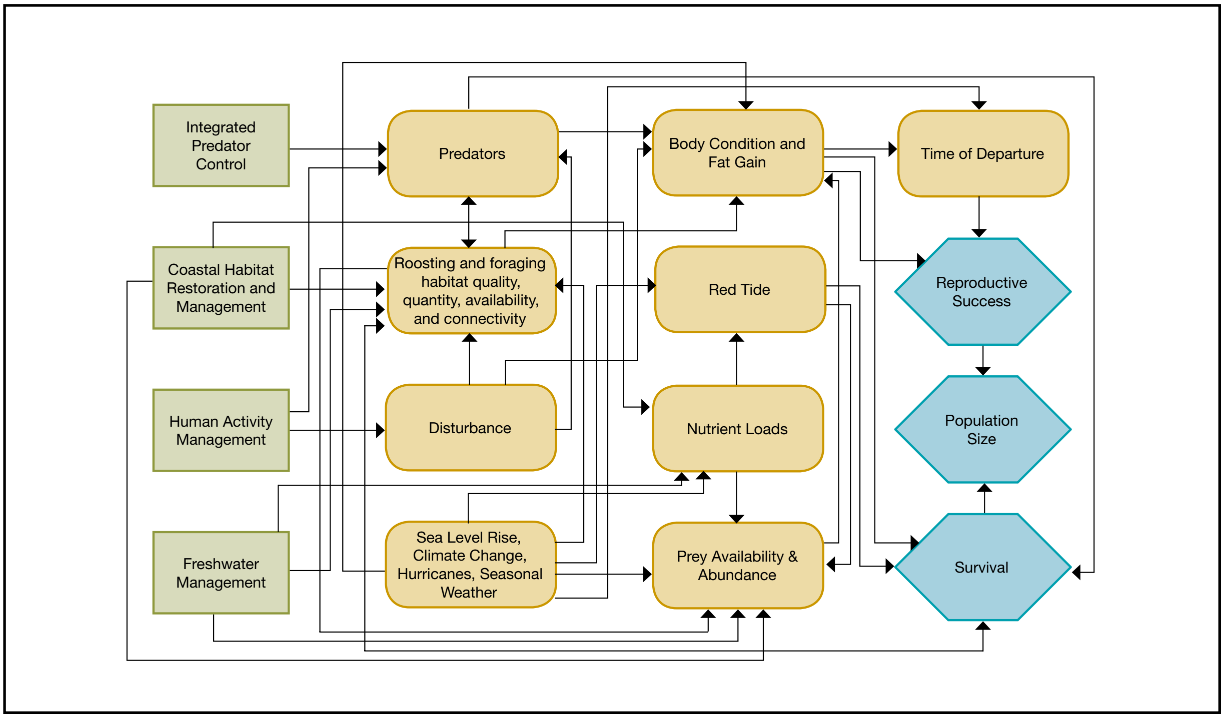
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Snowy Plover*** *(Charadrius nivosus) within the Gulf of Mexico Region.*



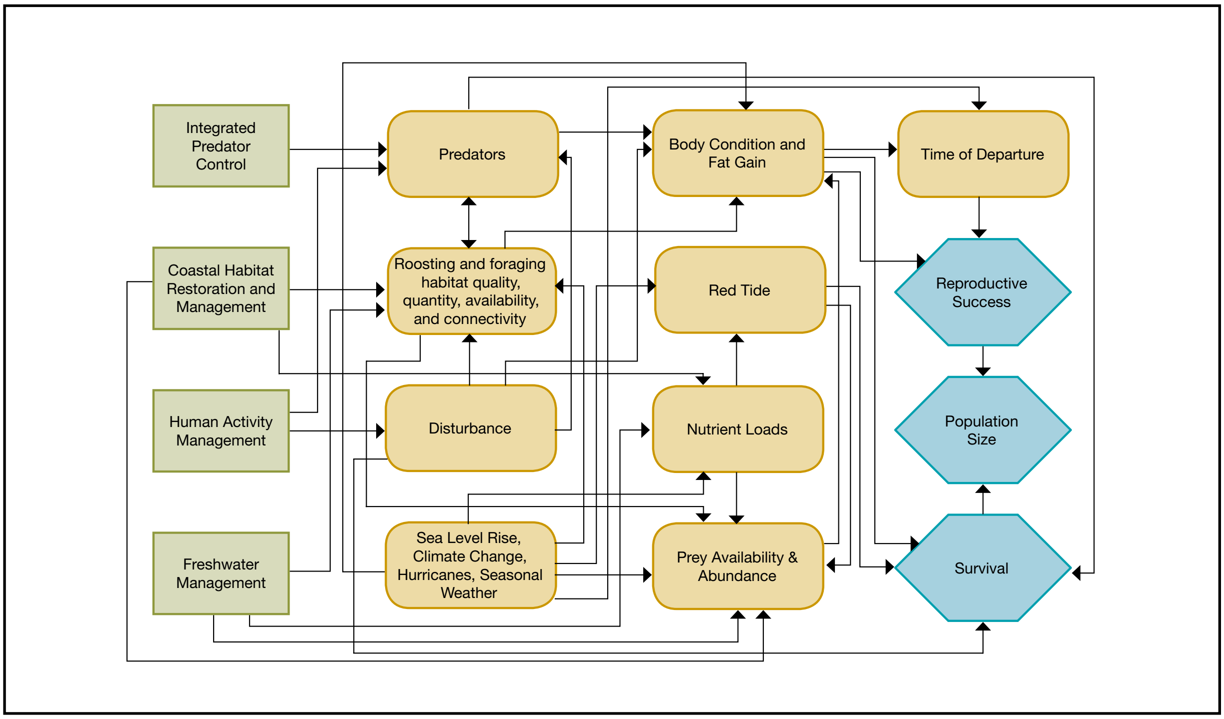
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Long-billed Curlew*** *(Numenius americanus) within the Gulf of Mexico Region.*



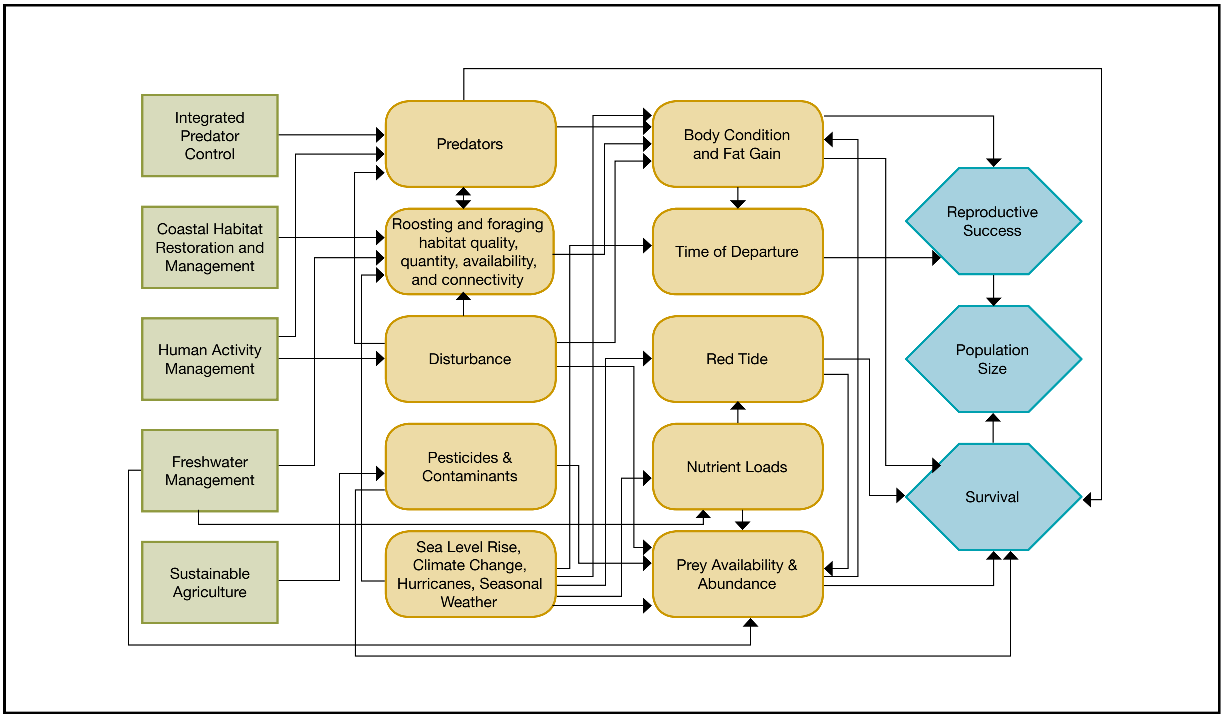
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Marbled Godwit*** *(Limosa fedoa) within the Gulf of Mexico Region.*



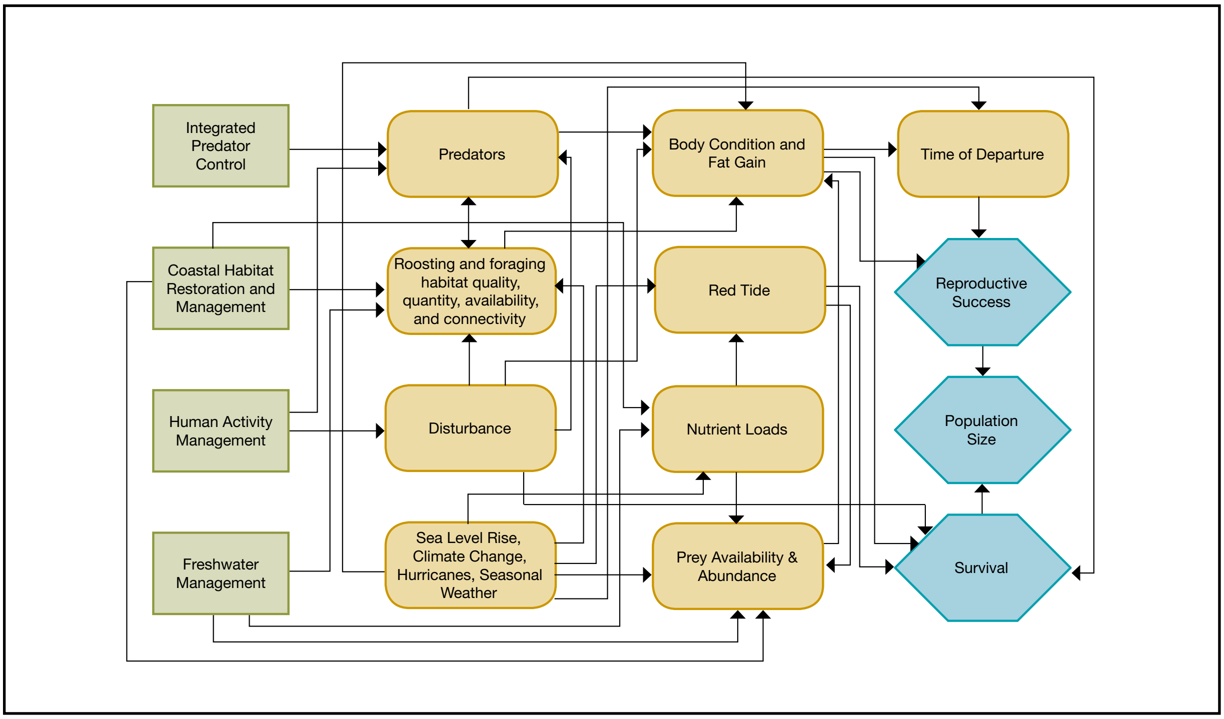
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Red Knot*** *(Calidris canutus) within the Gulf of Mexico Region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Dunlin*** *(Calidris alpina) within the Gulf of Mexico Region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Buff-breasted Sandpiper*** *(Calidris subruficollis) within the Gulf of Mexico Region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Western Sandpiper*** *(Calidris mauri) within the Gulf of Mexico Region.*