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*Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico*

# GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SEABIRDS


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Brown Pelican (*Pelecanus occidentalis*) returns to its nest. Photo credit: S. Desaivre


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*Chapter 6*

# GOMAMN STRATEGIC MONITORING GUIDELINES: SEABIRDS

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

THE TERM 'SEABIRD' IS GENERALLY APPLIED TO AVIAN species that forage in the marine environment over open water. Globally this includes all species from the orders Sphenisciformes (penguins) and Procellariiformes (albatrosses, petrels, storm-petrels, fulmars, and shearwaters), most species from the order Pelecaniformes (tropicbirds, pelicans, boobies, frigatebirds, and cormorants), and some species from the order Charadriiformes (alcids, gulls, terns, skuas, and skimmers). There are 65 seabird genera and approximately 222 wholly marine and 72 partially marine species (Gaston 2004). Seabird biology and natural history are thoroughly reviewed by Furness and Monaghan (1987), Schreiber and Burger (2001), and Gaston (2004). A comprehensive table of life history parameters for all seabirds also appears in Schreiber and Burger (2001). Examples of existing monitoring guidelines for seabirds include but are not limited to those by Walsh et al. (1995) for Britain and Ireland, and Haynes-Sutton et al. (2014) for Caribbean islands.

The goal of this chapter is to provide a framework for monitoring seabirds in the northern Gulf of Mexico. The framework relies upon designating several seabird species as priorities for monitoring (Table 6.1), and assessing the mechanisms and extent to which various management actions (Table 6.2) and ecological processes (Table 6.3) influence these species in the Gulf of Mexico. For both management actions and ecological processes, we also rank the magnitude of uncertainty and effect sizes of the action or process on seabird species of interest. Using influence diagrams (IDs), we describe how life history parameters of seabirds are affected by ecological processes and subsequently how those processes are influenced by selected management actions and other anthropogenic and natural changes to the ecosystem (Figure 6.1, Appendix 6 [note that the number of management actions and ecological processes are constrained by design for each species' influence diagram and therefore, for some species, a management action or ecological process of interest may not be included]). We populated each of these tables and figures by compiling life history and ecology data (reviewed throughout the chapter) and by eliciting expert opinion from seabird scientists familiar with the relevant taxa and ecosystems.

For the purposes of articulating monitoring plans for seabirds in the Gulf of Mexico (hereafter GoM or Gulf) we delineate between nearshore and pelagic systems. The nearshore zone includes beaches, wetlands, coastal or barrier islands, and waters that are influenced by a combination of riverine, estuarine, or coastal processes (Table 6.1). Pelicans, gulls, and terns tend to be more common in these coastal habitats and forage here during both the breeding and non-breeding seasons. The pelagic zone includes waters influenced by oceanographic processes (Table 6.1). Shearwaters, petrels, pelagic terns, and boobies are more common in pelagic zones, foraging over open water and typically occurring in coastal habitats only when attending nests. Nearshore and pelagic systems also may include species that breed in freshwater systems, but that are found during nonbreeding periods in marine systems (e.g., *Gavia* spp.). Although these categories present some ambiguities and are not strictly defined, they are consistent with designations of marine ecoregions (Spalding et al. 2007) and clearly link to habitat use and ecological processes (Jodice and Suryan 2010, Jodice et al. 2013).

The life history and behavioral attributes of seabirds are relevant to population monitoring and are subsequently referenced throughout this chapter. Briefly, seabirds tend to be colonial breeders with moderate to protracted breeding seasons (e.g., 40 days in Least Terns [*Sternula antillarum*], 220 days in Magnificent Frigatebirds [*Fregata magnificens*]). The age at first breeding ranges from 2 years (e.g., some gulls or terns) to ≥ 7 years (e.g., frigatebirds). Seabirds are central-place foragers during the breeding season (i.e., commute to and from a nest site to provision young), and parental investment is high, often extending into the post-fledging period (Guo et al. 2010, Watson et al. 2012). Foraging ranges during the breeding season vary among species, ranging from 10s–100s of km, and migratory strategies range from partial migration to trans-ocean basin migration. In the non-breeding season foraging ranges are more dynamic and can lack the central tendency present during the breeding season.

The study area for seabirds in the Gulf of Mexico is comprised of a diverse suite of habitats within the nearshore and

**Table 6.1.** *Seabird 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 | Mar-May | June-Aug | Sep-Nov | Dec-Feb | Landcover Association(s)[a] | Trend Score | Continental Concern Score |
|---|---|---|---|---|---|---|---|---|
| Sooty Tern[b] | *Onychoprion fuscatus* | X | X | X | X | Beach/Dune, Estuarine-Open Water, Marine-Nearshore, Marine-Offshore, Marine-Oceanic | 3 | 9 |
| Least Tern[b] | *Sternula antillarum* | X | X | X | | Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Coastal, Beach/Dune | 4 | 14 |
| Gull-billed Tern[b] | *Gelochelidon nilotica* | X | X | X | X | Estuarine-Coastal, Estuarine-Coastal Riverine Coastal, Beach/Dune | 4 | 13 |
| Black Tern[c, d] | *Chlidonias niger* | X | X | X | | Marine-Offshore, Marine-Oceanic; Marine-Nearshore | 5 | 12 |
| Royal Tern[b] | *Thalasseus maximus* | X | X | X | X | Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine Open Water, Marine-Nearshore, Beach/Dune | 2 | 11 |
| Sandwich Tern[b] | *Thalasseus sandvicensis* | X | X | X | X | Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine Open Water, Beach/Dune | 2 | 11 |
| Black Skimmer[b] | *Rynchops niger* | X | X | X | X | Estuarine-Coastal | 5 | 14 |
| Common Loon[d] | *Gavia immer* | X | | X | X | Lacustrine/Riverine, Estuarine-Open Water, Marine-Nearshore | 1 | 9 |
| Audubon's Shearwater[d] | *Puffinus lherminieri* | X | X | X | X | Marine-Offshore, Marine-Oceanic | 4 | 14 |
| Band-rumped Storm-Petrel[d] | *Oceanodroma castro* | X | X | X | X | Marine-Offshore, Marine-Oceanic | 4 | 17 |
| Black-capped Petrel[d, e, f] | *Pherodroma hasitata* | X | X | X | | Marine-Offshore, Marine-Oceanic | 5 | 20 |
| Magnificent Frigatebird[b] | *Fregata magnificens* | X | X | X | X | Marine-Nearshore, Marine-Offshore | 4 | 16 |
| Masked Booby[b] | *Sula dactylatra* | X | X | X | X | Marine-Nearshore, Marine-Offshore, Marine-Oceanic | 3 | 12 |
| Northern Gannet[d] | *Morus bassanus* | X | | X | X | Estuarine-Open Water, Marine-Nearshore, Marine-Offshore | 1 | 10 |
| Brown Pelican[b] | *Pelecanus occidentalis* | X | X | X | X | Estuarine-Coastal, Estuarine-Open Water, Estuarine-Tidal Riverine Open Water, Marine-Nearshore, Marine-Offshore | 1 | 10 |

[a] See Chapter 1 and Appendix 2 for full description of landcover associations.
[b] Occurs in the Gulf of Mexico during both the breeding and non-breeding seasons for that species.
[c] This species is not included in the GoMAMN Birds of Conservation Concern list, but is considered important given the duration the species spends in the GoM and its broad distribution, as well as its ecological importance and/or potential for use as an indicator species (Caro 2010).
[d] Occurs in the Gulf of Mexico during the nonbreeding season for that species.
[e] Threatened and Endangered Federally listed species, candidate species, or species Under Review.
[f] IUCN International Union for Conservation of Nature- per the IUCN RedList this species is considered Endangered (https://www.iucnredlist.org/species/22698092/132624510). Further, it is Proposed Threatened (with 4d) under ESA (https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B0AS).

Seabirds

Masked Booby (*Sula dactylatra*) nesting area, Hospital Kay, Dry Tortugas National Park, Florida. Photo credit: P. Jodice

pelagic habitat categories that are used here. These habitats occur across a range of political and jurisdictional boundaries including state waters, federal waters, and the U.S. Exclusive Economic Zone (EEZ) (Figure 1.2). This vast study area is generally characterized by a complex coastal system of bays, estuaries, beaches, tidal marshes, and islands where changes to all these habitats occur rapidly due to freshwater inputs and erosion. The climate and conditions at breeding and loafing (i.e., coastal) habitats in the Gulf range from subtropical to temperate, and from xeric to mesic. The pelagic zone is dominated by the Loop Current, which varies in location among seasons and years (Schmitz et al. 2005). Cold core and warm core eddies are common attributes of the Loop Current (Schmitz et al. 2005, Oey et al. 2005) and their location, duration, and intensity can all affect the distribution and abundance of seabirds in pelagic waters (Haney 1986, Ribic et al. 1997, Hyrenbach et al. 2006). Among this diversity, marine habitats are also undergoing change due to anthropogenic stressors. The Gulf coastal zone is characterized by rapid population growth and land conversion/development (Ordonoz et al. 2014, Martinuzzi et al. 2015). Nearshore and pelagic waters of the northern Gulf also support substantial oil and gas activities in the western and central regions, while the waters and coast of the eastern region are currently less developed.

In general, seabirds have been studied sporadically and often in a temporally or spatially restricted manner within the northern Gulf, with most of the focus on colonies and coastal waters. For example, the distribution and abundance of both nearshore species off-colony and pelagic species at-sea are poorly understood in the Gulf of Mexico (Burger 2017, 2018). Basic inventories for seabirds in the Gulf are dated (e.g., Clapp et al. 1982, 1983) and at-sea surveys that have been conducted are restricted to a very few efforts that can be characterized as being both spatially and temporally limited (e.g., Fritts and Reynolds 1981, Ribic et al. 1997, Davis et al. 2000, Haney 2011). The distribution of breeding sites (i.e., colonies) for most seabirds in the study area is documented, although the availability of measures of population size are variable among species and states (see Breeding Season below). Research efforts on colonies also have been limited, with Brown Pelicans (*Pelecanus occidentalis*) receiving the most attention.

## Breeding Season

**BREEDING DISTRIBUTION:** Species that most commonly inhabit nearshore waters represent two orders (Pelecaniformes, Charadriiformes) and three families (Pelecanidae, Laridae, Rynchopidae) and nest in each state within the northern Gulf: one gull, five terns, one pelican, and one skimmer. These include Brown Pelican, Laughing Gull (*Larus atricilla*), Royal Tern (*Thalasseus maximus*), Sandwich Tern (T*halasseus sandvicensis*), Gull-billed Tern (*Gelochelidon nilotica*), Caspian Tern (*Hydroprogne caspia*), Least Tern, and Black Skimmer (*Rynchops niger*). Among these species, nesting occurs across a range of habitats including barrier islands, dredge spoil islands, estuarine islands, marshes, and beaches (Table 6.2). Although some of these species are at population levels that have warranted some level of "listing," none are considered globally important, nor does the region support, for example, the entire U.S. population of any of these species (Hunter et al. 2006). Because many of these species breed in mixed colonies or on the same island, monitoring and conservation efforts often may be targeted at suites of breeding seabirds. An extreme example of this is the Sandwich/Royal tern breeding association in which Sandwich Terns breed within Royal Tern colonies almost exclusively (Shealer et al. 2016). Forster's Tern (*Sterna forsteri*) also breed at more than one location in the study area, but not within each state (colonies primarily in Louisiana and Texas). Lastly, several nearshore species breed at one or few locations in the northern Gulf including White Pelican (*Pelecanus erythrorhynchos*) in Texas, Herring Gull (*Larus argentatus*) in Texas, Common Tern (*Sterna hirundo*) in Alabama, and Roseate Tern (*Sterna dougallii*) in the Florida Keys.

Seabirds that are more common in pelagic zones (e.g., shearwaters, petrels, boobies) do not breed in Alabama, Mississippi, or Louisiana. Certain species do nest in the western extent of the Florida Keys and southernmost Texas. Sooty Terns (*Onychoprion fuscatus*) breed in the Florida Keys and at several sites in Texas. The Florida Keys also support small breeding numbers of Brown Noddy (*Anous stolidus*), Bridled Tern (*Onychoprion anaethetus*), Magnificent Frigatebird, and Masked Booby (*Sula dactylatra*). The Gulf coast of Mexico also supports breeding populations of many nearshore and pelagic seabirds although data are not readily available or accessible. For example, Alacranes Arecife National Park, located on the Campeche Bank, supports breeding populations of Bridled, Sooty, Royal, and Sandwich terns; Brown Booby (*Sula leucogaster*), Masked Booby, and Red-footed Booby (*Sula sula*); and Magnificent Frigatebirds (Tunnell and Chapman 2000). Many pelagic and nearshore species of interest to GoMAMN also breed in adjacent areas of the western Caribbean and may inhabit Gulf waters during their breeding season. Of interest are breeding sites on Cuba, Cay Sal Bank (Bahamas), and Hispaniola (Bradley and Norton 2009).

**BREEDING PHENOLOGY:** For nearshore species that breed throughout the northern Gulf, the timing of the breeding season is comparable to many temperate breeders in North America. Nest initiation typically begins in March–June (depending on the species) and chicks fledge during the summer months. Nearshore seabirds in the northern Gulf are colonial, although to date there is not a current colony register or atlas for seabirds at the regional level that is regularly updated. Colibri and Ford (2015) did, however, collect nest count data on colonial waterbirds in the Gulf coast region from Vermillion Bay, Louisiana, to Appalachicola Bay, Florida, during May and June 2010–2013. Furthermore, breeding bird atlases for each of the states provide some data and information on breeding locations and numbers.

For some pelagic species the breeding seasons are more variable in timing and synchrony compared to those of nearshore species. For example, Black-capped Petrels (*Pterodroma hasitata*) in the Dominican Republic return to nesting areas as early as late autumn and fledge chicks typically prior to the core of the hurricane season (Jodice et al. 2015). In contrast, Audubon's Shearwaters (*Puffinus lherminieri*) breeding in the Caribbean initiate nesting as early as January and fledge chicks by mid-summer. Other tropical species such as boobies demonstrate asynchronous breeding and on any given colony, pairs may be found at all stages of the breeding cycle at any time of year. Therefore, the design of monitoring efforts in the Gulf of Mexico and subsequent data interpretation would benefit from consideration of these variable breeding cycles.

**HABITAT USE DURING BREEDING:** Habitat use of seabirds during the breeding season includes individual nest sites, colonies, chick-rearing areas, loafing areas, and foraging areas. These areas may be spatially dispersed across 10s of m (e.g., distance of nest sites to loafing areas) to >100 km (e.g., distance of nest sites to foraging areas). Seabirds, therefore, cross a distinct terrestrial/marine ecological boundary on a regular basis to forage, and often cross jurisdictional boundaries on a near-daily basis (e.g., state lands, state waters, federal waters; Jodice and Suryan 2010, Harrison et al. 2018). Habitats used for breeding by seabirds may be occupied for substantial periods of time (e.g., 4 months in Brown Pelicans, ≥6 months in many pelagic species), but use areas may shift as the breeding cycle progresses. For example, pelican chicks (altricial) may remain nest bound (e.g., shrub-nesting individuals) or chicks may crèche and move about the colony after 3–4 weeks (ground-nesting individuals). Closer to and soon after fledging, young-of-year pelicans also may occupy loafing sites often in the intertidal zone of the colony island (Ferguson 2012). Similarly, precocial chicks of terns, gulls, and skimmers may occupy areas nearby or distant from nests during the chick-rearing period. For example, Royal and Sandwich terns often move chicks out of nesting areas soon after hatching, and chicks will form large crèches that frequently move between the intertidal zone and dune on island beaches, complicating efforts to restrict human access to sensitive sites (Ferguson 2012). Parental foraging occurs off-colony for all seabirds in the study area and foraging distance may range from localized (100s of m to 10s of km) to distant (50–150 km) depending on the species, although detailed data are lacking for most species (Walter et al. 2014, Lamb 2016, Lamb et al. 2017c). Therefore, with respect to monitoring and conservation, habitat use during the breeding season is both focused on core locations (i.e., colonies), but also sites that are dispersed, shifting, and ephemeral (e.g., loafing and foraging sites).

### Nonbreeding Season

As with breeding seasons, defining nonbreeding and migration seasons for seabirds in the Gulf is complex and dependent on taxa. Here, we discuss the nonbreeding season considering not only those species that breed within the Gulf, but also those that migrate to or through the Gulf and those that use these waters consistently during winter. Currently, many data gaps exist regarding ecology of seabirds in the Gulf during the nonbreeding season.

**GULF RESIDENTS:** The timing of breeding and nonbreeding seasons for nearshore seabirds that breed within the northern Gulf and winter throughout the Gulf matches that for most other avian taxa that breed in the region. The breeding season begins in March–May for most of these species and ends in July–August. To date, however, data on migratory patterns and wintering locations are lacking for most species within this group of seabirds. Migration tracks are available for Brown Pelicans and Black Skimmers, and we review those here as examples of the range in migratory strategies possible for nearshore seabirds in the northern Gulf.

Brown Pelicans nest throughout the Gulf states from Corpus Christi Bay, Texas through SW Florida (Shields 2014, Visser et al. 2005). Band return data suggest that the potential range for migration endpoints are extensive (e.g., Schreiber and Mock 1988, Stefan 2008). Since 2010 multiple studies have deployed satellite tags on Brown Pelicans and therefore, our understanding of migration paths and endpoints have improved (Selman et al. 2012, Walter 2012, King et al. 2013, Lamb 2016). Among breeding adults tagged in Texas, Louisiana, and NW Florida, Lamb et al. (2017c) found three classes of migratory strategy; 1) resident, traveling <200 km from breeding site, 2) short-distance, traveling 200–800 km from nesting sites, and 3) long-distance, traveling 1000–2500 km from breeding sites. That study also documented easterly movements from Texas to Louisiana, trans-Gulf migrations from the Louisiana Delta to the Yucatan Peninsula, crossings of the Florida Straits to Cuba, overland crossings of Cuba, and overland crossings of the Tehuantepec Isthmus in Mexico to the Pacific (Lamb et al. 2018). Drivers of these varied migration strategies are not entirely clear, although Lamb et al. (2017c) did find a positive relationship between colony size and both migration distance and proportion of migrants, and that females were more likely than males to migrate long distances.

Black Skimmers also commonly nest throughout the Gulf states from South Padre Island, Texas, through SW Florida (Gochfeld and Burger 1994) and their annual range includes the entire U.S. Gulf coast. Black Skimmers do not appear to persist at the same site throughout the annual cycle, however, and specific migration paths or endpoints for breeding populations are not well documented. Following the DWH oil spill, black skimmers were captured and outfitted with VHF ($n$ = 40) and satellite tags ($n$ = 12) between 20 July 2010 and 11 January 2011 along the Louisiana coast (Eggert et al. 2011). Because individuals were captured post-breeding, no information on breeding location or breeding activity was available. Tracking continued through the winter months. Approximately 55% of tagged skimmers remained within 200 km of their capture site in the northern Gulf while approximately 20% moved 800–1200 km from the capture site to areas near Cedar Key, Florida, and along the central and southern Texas coast. Furthermore, two skimmers equipped with satellite tags were tracked to Mexico, each ca. 900 km from the capture location. One individual was located just south of the Texas border and the other on the eastern end of the Yucatan Peninsula. Migration routes for these two individuals included a coastal route to the location in NE Mexico, and a trans-Gulf route to the Yucatan Peninsula. Despite lacking a breeding colony of origin, these tracking data still clearly demonstrate a varied migration strategy in skimmers within the Gulf with the ability to cross over the pelagic waters of the Gulf.

These two data sets demonstrate a varied migration strategy with numerous pathways and destinations. Such varied migration strategies create a diverse and complex portfolio of risk to both anthropogenic and natural stressors for nearshore seabirds (Lamb 2016) and can complicate the design and interpretation of monitoring data. Lacking an explicit understanding of migration strategy, inferences from monitoring data would be limited and would not be as geographically specific as needed. For example, if monitoring data within a specific region of the Gulf coast demonstrated a decline in wintering Royal Terns over time, or if a spill event resulted in high mortality to wintering Royal Terns, it would not be entirely clear what breeding population was being affected given the current lack of detailed migration data.

**GULF MIGRANTS:** Migrants to and through the Gulf include nearshore and pelagic seabirds (e.g. Northern Gannets; (*Morus bassanus*), as well as species that breed in freshwater systems (e.g., Common Loons (*Gavia immer*), White Pelicans, and several terns and gulls). Jodice (1992) reported that Common Loons were frequently encountered during aerial surveys in the Florida Big Bend and in bays and estuaries of the Florida Panhandle. Satellite tracking studies of Common Loons have demonstrated that loons wintering in the Gulf migrate from the upper Midwest of the U.S. and Saskatchewan, but not the northeastern U.S. (Kenow et al. 2009, Paruk et al. 2014, Paruk et al. 2015). White Pelicans that occur in the Gulf are primarily migratory individuals, wintering in estuaries, coastal bays, and in nearshore environments (Clapp et al. 1982, King and Michot 2002, Anderson and Anderson 2005, King et al. 2016). Bonaparte's Gull (*Chroicocephalus philadelphia*), Franklin's Gull (*Leucophaeus pipixcan*), Herring Gull, Ring-billed Gull (*Larus delawarensis*), Common Tern, and Forster's Tern (*Sterna forsteri*) all breed outside of the Gulf, but migrate to the Gulf, although data gaps still exist regarding ecology during the nonbreeding season. Ring-billed Gull and Bonaparte's Gull appear to winter throughout the northern Gulf coast (Pollet et al. 2012, Burger and Gochfeld 2002) while Franklin's Gull appears to be more restricted to the western Gulf (Burger and Gochfeld 2009). Common Terns (Nisbet et al. 2017) occur throughout the northern Gulf during the nonbreeding season. Forster's Terns (McNicholl et al. 2001) breed in northern wetlands and marshes along the Gulf coast, and winter throughout the region being locally

Audubon's Shearwater (*Puffinus lherminieri*), Gulf of Mexico. Photo credit: Christopher Haney

abundant near Gulf coast breeding sites. Least Terns migrate through the region to Mexico and to Central and South America (Thompson et al. 1997). Least Terns along the Gulf Coast may include local breeders and breeding birds from interior populations (USFWS 2013).

Black Terns (*Chlidonias niger*) also migrate to and through the Gulf from northern prairie breeding areas (Heath et al. 2009). The species is considered as a monitoring target in these monitoring guidelines. Black Terns are locally abundant along the Gulf coast during migration and appear to be widespread and locally abundant in nearshore shelf waters east and west of the Mississippi River in May–October (GoMMAPPS unpublished data). Flock sizes range from several birds up to several hundred birds (GoMMAPPS unpublished data). Black Terns also were ranked 11th among birds injured during the Deepwater Horizon Oil Spill and are a priority for restoration efforts post-spill (DHNRDAT 2016, 2017).

Northern Gannets are also a priority species for monitoring that breeds outside of the Gulf. Gannets breed at only six colonies in North America, all of which are in eastern Canada (Mowbray 2002). Gannets migrate to the Gulf in late summer/early fall and depart the Gulf in early spring (Montevecchi et al. 2012a, 2012b). Approximately 25% of the North American Northern Gannet population occupies the Gulf during winter, and many immature gannets remain in the Gulf for most of the year (Fifield et al. 2014). Aerial and vessel surveys commonly record gannets in nearshore and pelagic waters, often foraging at the mouths of major bays (Jodice 1992, Ribic et al. 1997, Haney 2011). Recent research, however, has demonstrated that gannets also use wintering areas and migration corridors throughout coastal Louisiana, an area not previously considered significant winter habitat (Fifield et al. 2014). Gannets were one of the most injured bird species following the Deepwater Horizon Oil Spill (Haney et al. 2014, DHNRDAT 2016), and because they can be linked to a few closely-monitored colony sites within a small geographic area, this species offers a unique opportunity to integrate conservation and monitoring efforts (DHNRDAT 2017).

Migration patterns among seabirds that breed outside of the Gulf and often occupy waters beyond the coastal or nearshore zone are also varied and data gaps are common, thus complicating the development of monitoring plans and restoration efforts. For example, Audubon's Shearwaters, a priority species for Gulf monitoring, breed throughout the Caribbean and Bahamas and have a compressed nonbreeding season due to their extended breeding season (Lee 2000). Shearwaters have been observed during vessel-based surveys in the Gulf from May through August (GoMMAPPS unpublished data). Tracking data (geolocator) from an adult shearwater breeding on Cay Sal Bank indicated that the individual occurred in the Gulf between late July and early January in two consecutive years (Jodice unpublished data). Currently, the breeding locations of shearwaters wintering in the Gulf are unclear, further complicating the interpretation of monitoring data or the design of restoration efforts. Even less systematic are the breeding cycles of asynchronous breeders like Masked Boobies (a priority monitoring species in the Gulf), which may breed year-round, and therefore, nonbreeding birds may occur in the Gulf throughout the year.

The Band-rumped Storm-Petrel (*Oceanodroma castro*) is also a high priority species in the Gulf, although the species has been understudied and understanding of its ecology, distribution, and abundance in the Gulf is limited. The taxonomy of the species is currently under review (Smith et al. 2007). Band-rumped Storm-Petrels breed on the Azores and have both a summer and winter breeding population (Slotterback 2002). In 1998, an individual banded in the Azores was recovered along the Florida panhandle (Woolfenden et al. 2001). In the Atlantic Gulf Stream, the species occurs in proximity to dynamic upwelling zones (Haney 1985). Pelagic survey data from the Gulf suggest Band-rumped Storm-Petrels are present throughout much of the year (excluding winter months- Ribic et al. 1997, Haney 2011, GoMMAPPS unpublished data).

## CONSERVATION CHALLENGES AND INFORMATION NEEDS

### Primary Threats and Conservation Challenges

Approximately 30% of the 350 species considered as seabirds globally are classified as Globally Threatened, and 10% as Near Threatened (Croxall et al. 2012, based on IUCN RedList). Pelagic species are more often categorized as threatened compared to nearshore species. Globally, 50–70% of seabirds are experiencing population declines (Croxall et al. 2012, Paleczny et al. 2015). Within the western North Atlantic, the Jamaica Petrel (*Pterodroma caribbaea*) is likely extinct (Douglas 2000), and Black-capped Petrel and Cahow (*Pterodroma cahow*) are Threatened and Endangered, respectively. Because of the diversity of seabirds and the spatial extent of threats they experience given their wide-ranging movements, the U.S. is considered a high priority for seabird conservation efforts (Croxall et al. 2012).

Seabirds use terrestrial, coastal, estuarine, and offshore habitats daily and can therefore be exposed to conservation threats that occur within each of these habitats (Jodice and Suryan 2010). Seabirds present a conservation challenge in the Gulf of Mexico that is both local in nature, as well as multi-jurisdictional and international. For example, individuals may occupy multiple jurisdictional zones during a relatively short period of time (e.g., days to weeks) and rely on food resources (e.g., marine forage fish) that are managed by multiple entities as well (e.g., state, federal, and international) (Einoder 2009, Cury et al. 2011, Harrison et al. 2018). Therefore, matching conservation threats to the spatial and temporal resolutions of the movements of the focal species is critical for monitoring and conservation planning (Jodice and Suryan 2010). Croxall et al. (2012) list ten primary threats for seabirds globally. For the purposes of our review it is relevant to consider where these threats are most likely to be active (at breeding sites, at sea, or both), and therefore, most likely to be addressed via management or monitoring (Table 6.2).

**CONSERVATION THREATS AT BREEDING SITES:** At breeding sites, primary threats include invasive species, problematic native species (e.g., range expanding species), human disturbance, and human development. All four of these threats can be accelerated or exacerbated, or are driven almost entirely by, anthropogenic influences. For breeding seabirds in the western North Atlantic, invasive and problematic native species act as a threat primarily via predation pressure, sublethal effects on body condition, habitat change, and competition (Figure 6.1, Appendix 6). For coastal breeding seabirds, invasive and problematic native mammals, birds, or reptiles often act as nest predators of eggs and small chicks (e.g., Brooks et al. 2013, Jodice et al. 2014). The opportunity for predation to occur can be enhanced when food conditions require parents to extend the duration of foraging trips. Many crevice or burrow nesting seabirds in the Caribbean experience such predation (Haynes-Sutton et al. 2014). Some invasive species can also lead to sublethal reductions in body condition to both nestlings or adults. For example, invasive red fire ants (*Solenopsis invicta*) can be common in sandy habitats (e.g., beach nesting areas) and infestations can lead to changes in blood chemistry and body condition (Jodice et al. 2007, Plentovich et al. 2009). Invasive, range-expanding, or problematic native species can also result in habitat changes to nesting sites. For example, invasive plants can create vegetation complexes or structures that are unsuitable or suboptimal for beach or marsh nesting species (Fisher and van der Wal 2007, Lamb et al. 2014). Range-expanding species (e.g., gulls) can also compete for nest sites or food (Quintana and Yorio 1998).

Human disturbance at nesting areas (Tables 6.2 and Appendix 6) can lead to mortality of eggs and chicks (Burger et al. 2010), reduced functional habitat, reduced access to habitat (e.g. disturbance to loafing areas; Ferguson 2012), and sublethal changes in body condition (Ellenberg et al. 2007). Egg harvesting from colonies in the Caribbean that support seabirds that occur in the Gulf has been occurring for decades (Haynes 1987) although the current extent and severity of this activity are not known. Many seabird nesting sites in the U.S. are afforded some formal or legal level of protection from human access, thus reducing the potential for direct mortality from trampling or collection. In contrast, protection may be diminished adjacent to nesting sites, but human activity there also can have a deleterious effect on reproductive success. Some seabirds may react to disturbance adjacent to a colony and reduce nest attendance, therefore subjecting eggs to predation or thermal stress. Outside of the U.S., however, legal protection is less consistent and not well documented. Disturbance can also act on two very different temporal scales, being either chronic or acute (Nisbet 2000, Viblanc et al. 2015). Chronic disturbance occurs when activity extends over longer periods of time and can result in either abandonment (of individual nests or entire colonies) or habituation (Nisbet 2000, Yorio et al. 2001, Watson et al. 2014). In contrast, acute disturbance occurs when single events result in parental abandonment and thus, nest loss.

Development of coastal habitats also can affect loafing and foraging sites, as well as breeding sites (Hunter et al. 2006). Due to the dynamic nature of coastal habitats, many nearshore seabirds are capable of shifting colony locations regularly (Jodice et al. 2007, Lopes et al. 2015). Thus, a decrease in habitat richness due to development (e.g., the number of available sites for nesting or loafing) may not be relevant until a current breeding site becomes unstable or suboptimal. In contrast, many pelagic species that breed outside the region, but occupy the Gulf at some point of the annual cycle show very high site fidelity, often using the same nest burrow or crevice for several years (Mackin 2016). Anthropogenic development of such habitat can result in colony displacement that is difficult to manage or mitigate.

**CONSERVATION THREATS AT SEA:** Primary threats to seabirds at-sea (i.e., during foraging and migration) include bycatch and overfishing (Croxall et al. 2012). Data gaps exist for each of these threats with respect to seabirds in the Gulf (Figure 6.1 and Appendix 6). Current evidence suggests that bycatch is not a primary conservation threat for most seabirds in the western North Atlantic (Moore et al. 2009, Winter et al. 2011). Incidence of bycatch can change, however, as fisheries develop or fishing pressure changes. Illegal take (direct and incidental) of seabirds associated with commercial and recreational fishing activity also occurs, although the extent and severity of the activity are not known.

Currently it does not appear that overfishing is leading to population-level effects on seabirds in the Gulf, although

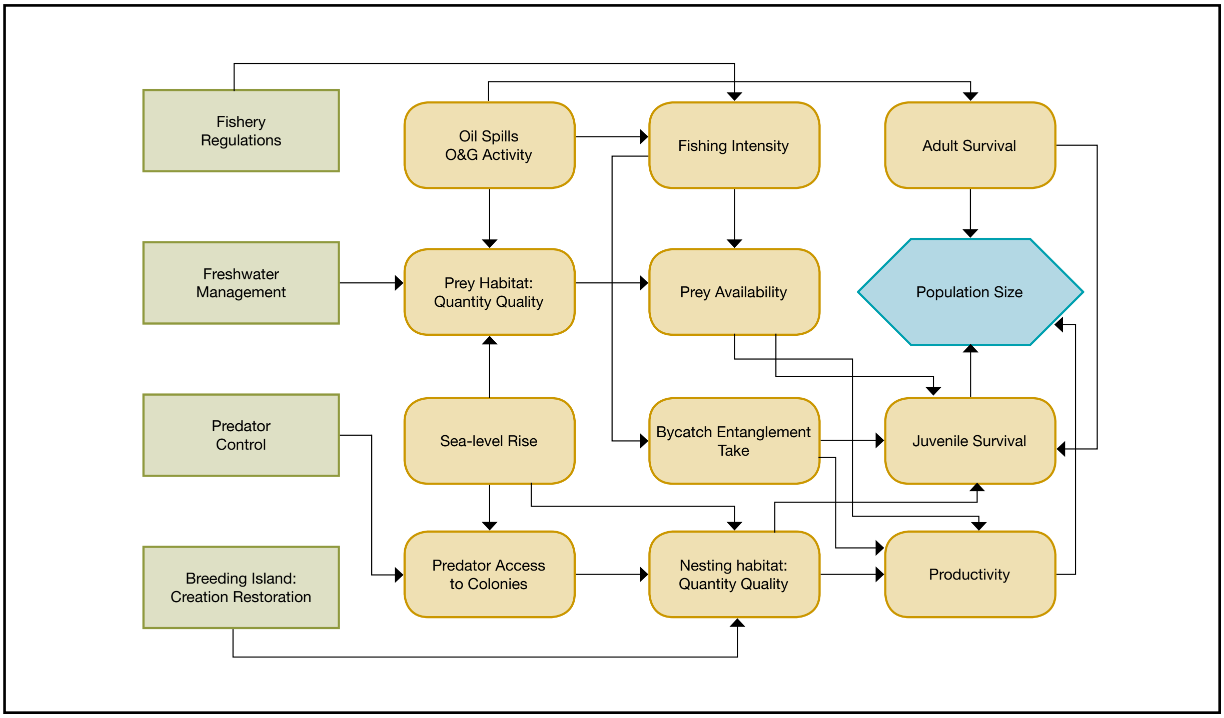


**Figure 6.1.** *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Brown Pelican*** *(Pelecanus occidentalis) within the Gulf of Mexico Region.*

data are lacking. Perhaps the fishery of most interest in this respect is Gulf menhaden (*Brevoortia patronus*), which is regulated through the Gulf States Marine Fisheries Commission in cooperation and oversight by National Oceanic and Atmospheric Administration under the Magnuson-Stevens Fishery Conservation and Management Act (MSA) (VanderKooy and Smith 2015). Menhaden appears to be the key forage fish for Brown Pelicans in the Gulf, and as such, any changes to its availability may have wide-ranging impacts on pelicans (Shields 2014, Lamb et al. 2017b). The extent to which menhaden occur in the diet of other seabirds is not well documented (but see Liechty et al. 2016).

**CONSERVATION THREATS AT BREEDING SITES AND AT SEA:** Climate change, various activities associated with energy production, and pollution also may affect seabirds both on the breeding grounds and at-sea (Table 6.3 and Appendix 6). Climate change, acting through sea-level rise, may impact availability, location, and quality of breeding habitat particularly through coastal erosion, subsidence, and island and/or beach overwash (Visser et al. 2005, Grémillet and Boulinier 2009). Foraging conditions also may be affected by climate change particularly if mismatches in timing or location occur between seabird breeding and forage fish availability, potentially resulting in trophic cascades (Suryan et al. 2006, Grémillet and Boulinier 2009). Similarly, oil and gas production activities can result in pollution events, both acute and chronic, that can be spatially and temporally localized or extensive (Gleason et al. 2016). Preliminary studies regarding the potential impacts of oil and gas platforms on bird flight through lighting and associated nocturnal circulation events suggest it may be detrimental to seabirds and other birds migrating through marine waters (Russel 2005, Ronconi et al. 2015). Other sources of pollution, such as contaminants and plastics acquired during foraging, are also well-documented as factors that adversely affect seabirds both on land and at sea (Van der Pol et al. 2012, Wilcox et al. 2015), although contaminant exposure appears to be less studied in tropical and sub-tropical seabirds compared to those at high latitudes.

## IDENTIFICATION OF PRIORITIES

Coordinated monitoring efforts have been consistently recognized as lacking for nearshore and pelagic seabirds in the Gulf of Mexico (Clapp and Buckley 1984) and globally (Croxall et al. 2012, Paleczny et al. 2015). A lack of monitoring has resulted in substantial data gaps for species, habitat (breeding, nonbreeding, and foraging), and prey status (Tables 6.1-6.3); relatively high levels of uncertainty with respect to ecological processes and management actions; and often unknown effect sizes for proposed management actions (Tables 6.2 and 6.3). Therefore, the development of effective monitoring plans rests upon identifying explicit priorities for improving our assessments of status and trends, improving our understanding of the effects of management actions, and improving the level of detail with which we can elucidate underlying ecological processes. Differences in monitoring methodologies, data streams, and scales of inference differ between seabirds at their breeding colonies and at-sea leading to challenges in integrating monitoring efforts. The occurrence of large-scale ecosystem perturbations, be they natural or anthropogenic, underscore the value that long-term monitoring data can provide for seabirds (Chambers et al. 2015, Mesquita et al. 2015, Haney et al. 2017).

### Priority Management Actions

Because seabirds have extensive home ranges and cross ecological and jurisdictional boundaries daily, they present a challenge to prioritizing management actions, identifying appropriate end-points for a specific action, and evaluating the effectiveness of actions (Jodice and Suryan 2010, Harrison et al. 2018). For example, to be effective, management actions should consider the colonial nature of most seabirds (i.e., populations are often clumped in space, and multiple species with slightly different requirements may occupy the same colony site), the transboundary nature of their daily movements (i.e., individuals occupy terrestrial and aquatic habitats that may be under different control mechanisms), the extended periods of time required for breeding to be completed (e.g., 4–7 months for some species), and the links between breeding sites and distant foraging areas that may occur in different ecological and/or jurisdictional systems. These issues, and others, may impact prioritization of management activities for seabirds in the Gulf. GoMAMN has outlined priorities for monitoring through the objectives hierarchy (Figure 2.2). Portions of the objectives hierarchy refer specifically to management actions (e.g., Walsh et al. 2015) and therefore, prioritize potential or proposed projects that: 1) affect many priority species, 2) have a large spatial scope, 3) reduce uncertainty about the impact of management action(s) on seabirds, 4) address management actions which are frequently used as part of Gulf of Mexico restoration activities e.g., (http://www.dwhprojecttracker.org/), and 5) answer questions about management action(s) using an adaptive management framework (e.g., Williams 2003, 2011; Walsh et al. 2015).

Our assessments resulted in similar management actions being identified as relevant for most priority seabirds in the Gulf, in part due to their colonial nesting habits (Table 6.1, Figure 6.1, Appendix 6). In general, management actions tend to focus either at the breeding sites (i.e., on-colony) or at-sea (i.e., off-colony). Management actions that occur on-colony are more likely to have lower uncertainty or be logistically less complex (and less expensive) to implement and monitor compared to those that would occur at-sea. For both nearshore and pelagic species, a portion of the annual cycle occurs outside of the northern Gulf and therefore, some management actions may be beyond the scope of control for management agencies within the GoMAMN study area.

Influence diagrams for nearshore seabirds identify five primary management actions that likely affect the status of nearshore seabirds: freshwater management, fisheries regulations, colony restoration/creation, predator control (to include invasive spp.), and limiting/eliminating human access/disturbance (Figures 6.1 and Appendix 6). Each of these management actions is likely to affect each of the priority nearshore seabirds (Table 6.1), although some species-specific and action-specific variation is anticipated. Management actions for pelagic seabirds are focused both at-sea and at-breeding colonies and include fishery regulations (at-sea), predator control (breeding), colony restoration/creation (breeding), and monitoring/management of Sargassum (at-sea). Because the pelagic seabird species of conservation concern do not breed in the northern Gulf of Mexico, some of the recommended management actions (e.g., predator control) would occur outside of our study area (e.g., DHNRDAT 2017: module 4). Nonetheless, we address these non-local activities because they may have an influence on focal species and their respective populations.

One class of management actions for seabirds (colony restoration/creation, predator control, and human access) focuses on improving the quantity or quality of terrestrial habitat used either for breeding or loafing, the latter of which encompasses both the breeding and nonbreeding seasons (Jones and Kress 2012) (Figure 6.1, Appendix 6). Of these, colony restoration/creation would appear to have the least uncertainty (see Jones and Kress 2012 for a thorough review) associated with the outcome combined with the greatest potential positive effects. Most of the uncertainty is associated with site location and subsequent settling behavior (i.e., successful reproduction and not simply occupancy) of seabirds related to a site, as well as potential delays or lag effects in immigration or occupancy, especially for newly created sites (Buckley and Buckley 1980). Location should be considered in relation to long-term colony persistence (i.e., coastal processes such as currents, deposition, and erosion) and inter-colony dynamics (i.e., distance among colonies and potential overlap of foraging areas). Colony establishment can be promoted via social attraction techniques. The creation or restoration of a colony site also has the potential to affect multiple avian taxa. For example, Gaillard Island (ca. 500 ha) was created in Mobile Bay, Alabama in 1979. It has since become the largest Brown Pelican colony in the northern Gulf and supports substantial breeding populations of several nearshore seabirds and wading birds (Robinson and Dindo 2011). Due to the specific priority species noted for pelagic seabirds and their breeding locations/habitats (i.e., many of these species do not breed in the same location), colony restoration and predator control are more likely to affect a small number of species or be single-species focused.

Bridled Tern (*Onychoprion anaethetus*) in Sargassum patch, Gulf of Mexico. Photo credit: Christopher Haney

The effectiveness of colony restoration/creation can be measured via a hierarchy of avian-focused performance metrics including but not limited to occupancy, abundance, nest counts, nest survival probabilities, and fecundity (Figure 6.1, Appendix 6). The exact choice of measures may, however, differ within and among species and locations depending upon life-history characteristics, logistics, or variability in environmental conditions. Regularly timed measures of reproductive success will provide the strongest data, although factors that are not local to the colony can also affect reproductive success and therefore should also be considered (e.g., foraging ranges of adults, diets). If measures of any of the performance metrics are considered in the low range of values for a given target species, then efforts to determine the underlying causal mechanisms should be pursued. For example, physical characteristics of nesting sites can influence flooding and predator access (e.g., elevation distance to mainland, indices of human activity, and beach

**Table 6.2.** *Uncertainties underpinning the relationship between management decisions and populations of seabirds in the northern Gulf of Mexico.*

| Species<br><br>Season(s) | Management Category[a] | Question(s) | End-point to measure mgmt. performance | Uncertainty Description | Uncertainty Category[b, d] | Effect Size[c, d] |
|---|---|---|---|---|---|---|
| Beach-nesting Seabirds<br><br>Breeding, Non-breeding | Habitat and Natural Process Restoration (Habitat Restoration) | Does island creation/ restoration improve habitat quality during breeding and nonbreeding seasons? | Nest counts, nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, abundance estimation (nonbreeding), residency time (nonbreeding) | Other on-site (e.g., nest predators) and off-site (e.g., prey availability) factors contribute to process uncertainty and partial observability affects status uncertainty differently depending on the monitoring end point | Low | High |
| Marsh-nesting Seabirds<br><br>Breeding, Non-breeding | Habitat and Natural Process Restoration (Habitat Restoration) | Does island creation/ restoration improve habitat quality during breeding and nonbreeding seasons? | Nest counts, nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, abundance estimation (nonbreeding), residency time (nonbreeding) | Other on-site (e.g., nest predators) and off-site (e.g., prey availability) factors contribute to process uncertainty and partial observability affects status uncertainty differently depending on the monitoring end point | Low | High |
| Breeding Seabirds<br><br>Breeding, Non-breeding | Habitat and Natural Process Restoration (Habitat Restoration) | Does island creation/ restoration improve habitat quality during breeding and nonbreeding seasons? | Nest counts, nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, abundance estimation (nonbreeding), residency time (nonbreeding) | Other on-site (e.g., nest predators) and off-site (e.g., prey availability) factors contribute to process uncertainty and partial observability affects status uncertainty differently depending on the monitoring end point | Low | High |
| Beach-nesting Seabirds<br><br>Breeding | Invasive/ Problematic Species Control (Predator Management) | Does predator control improve reproductive success? | Predators (species composition and abundance estimation), nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests | Other on-site (e.g., weather) and off-site factors (e.g., prey availability) contribute to process uncertainty;predation rates not well documented and strong spatial variation | Low | Unknown |
| Marsh-nesting Seabirds<br><br>Breeding | Invasive/ Problematic Species Control (Predator Management) | Does predator control improve reproductive success? | Predators (species composition and abundance estimation), nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests | Other on-site (e.g., weather) and off-site factors (e.g., prey availability) contribute to process uncertainty;predation rates not well documented and strong spatial variation | Low | Unknown |
| Nearshore Seabirds<br><br>Breeding, Non-breeding | Site/Area Management (Disturbance) | Does restricting or reducing human activity improve reproductive success (breeding) and use (nonbreeding)? | Nest attendance patterns, nest temperatures, indices of human activity, nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests | Other on-site (e.g., weather) and off-site factors (e.g., prey availability) contribute to process uncertainty;human activity is correlated with weather conditions and may lead to difficulties with observability | Low | Unknown |
| Nearshore Seabirds<br><br>Breeding, Non-breeding | Habitat and Natural Process Restoration (Freshwater Management) | Can freshwater management influence the amount of prey habitat and prey availability for seabirds? | Water chemistry, prey community structure | Reliance on estuarine resources varies among species and sites and diet not well documented, environmental variation in these processes will be large and difficult to observe the process | High | Unknown |

**Table 6.2 (continued).**

| Species<br>Season(s) | Management Category[a] | Question(s) | End-point to measure mgmt. performance | Uncertainty Description | Uncertainty Category[b, d] | Effect Size[c, d] |
|---|---|---|---|---|---|---|
| Audubon's Shear-water, Sooty Tern<br>Breeding, Non-breeding | Species Management (Habitat Management) | Does Sargassum harvest reduce prey availability, reduce adult survival, and/or reduce reproductive success? | Distribution and abundance of Sargassum | Abundance, distribution, and harvest (location, landings) of Sargassum poorly understood making the process difficult to observe; affects of Sargassum on prey habitat and seabird foraging not well documented- likely to vary among species | High | Unknown |
| Brown Pelican, Royal Tern, Sandwich Tern<br>Breeding, Non-breeding | Species Management (Fisheries Management) | Does commercial fishing activity affect seabird populations via direct harvesting of forage fish or via supplemental feeding from discarded bycatch? | Harvest:bycatch ratios, seabird diets, fisheries stock assessments, seabird entanglements in nets, seabird mortality from longline fisheries (where allowed) | Diet diversity is not well-documented over time, landings/bycatch not always well-documented and varies among sites | High | Unknown |

[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.



profile; Visser et al. 2005, Ferguson 2012). Infestation of nests by ectoparasites can result in sublethal effects on chicks (Eggert and Jodice 2008, Eggert et al. 2010). A high burden of ectoparasites in nests also may result in nest, sub-colony, or colony abandonment, and can result in unexplained shifts in breeding locations if not monitored (Ramos and Drummond 2017).

The reduction of both predator activity and human disturbance are aimed ultimately at increasing reproductive success (Figure 6.1 and Appendix 6), but may also be estimated indirectly via parental nest attendance patterns, adult behavior (e.g., vigilance and alert behaviors), and individual condition such as stress (Ellenberg et al. 2007, Sachs and Jodice 2009, Thibault et al. 2010, Viblanc et al. 2015). The reduction of both predator activity and human disturbance at breeding sites are also likely to have relatively low levels of uncertainty associated with the outcome, although important process uncertainties related to weather conditions and prey availability remain (Table 6.2). For example, neither are likely to be the sole process affecting reproductive success or survival, and therefore, even the total elimination of either or both may still not result in improvements to these metrics. The response to each management activity also may vary among species depending upon their sensitivity to the type of predation event (e.g., avian or mammalian) or type of disturbance (e.g., acute or chronic). Furthermore, predator activity and disturbance can also act synergistically, wherein disturbance may reduce attendance at nests thereby increasing potential for predation. These uncertainties may also contribute to effect sizes being less predictable with a high probability of among species or site variation.

Two management actions that are focused off-colony and that ultimately may affect prey availability are freshwater management and fisheries regulations (Figure 6.1, Appendix 6). Both are classified as having high levels of uncertainty with unknown effect sizes. It is unclear the extent to which prey communities may shift as salinity gradients shift (Ainley et al. 2005), and whether alternate prey of suitable quality would be available. Similarly, it is unclear how either competition for prey with fisheries (Tasker et al. 2000) or the addition of prey via discarding of bycatch will affect each of the priority species (Jodice et al. 2011). Both are complex processes influenced by a wide array of other factors (e.g., climate, interspecific competition for prey, dynamic oceanographic and coastal processes) that in and of themselves carry substantial variability and uncertainty. Sargassum management would potentially affect those species that specialize in foraging in Sargassum patches (e.g., Audubon's Shearwater), but also species that forage on fish that use Sargassum for habitat (e.g. SAFMC 2002, BOEM 2016). Management actions for Common Loons are unique, and represent their use of inland freshwater lakes outside the Gulf for breeding while using marine habitats in the Gulf as wintering habitat (DHNRDAT 2017: module 4).

Because both freshwater management and fisheries regulations affect prey availability, diet data can serve as a performance metric to establish the taxonomic depth and breadth of prey captures particularly during the chick-rearing period (Sydeman et al. 2001, Barrett et al. 2007, Jodice et al. 2006, Lamb et al. 2017b). Diet data can either be collected directly (e.g., regurgitates, fresh prey deliveries) or indirectly (e.g., fecal samples, stable isotope sampling). In addition to diet composition, efforts to explore the proximate composition, energy density, and contaminant burden of diet samples are also encouraged (Arcos et al. 2002, Jodice et al. 2006, Jodice et al. 2011, Lamb et al. 2017b). Such diet data can inform ecological processes or anthropogenic activities including, but not limited to, climate (Sydeman et al. 2001, Ancona et al. 2012), influence or use of freshwater systems (Hobson 1990), contamination (Arcos et al. 2002), fisheries activities (Votier et al. 2013, Gaglio et al. 2018), oil spills/pollution (Pritsos et al. 2017), or ocean circulation (Kai and Marsac 2010, Rayner et al. 2016).

All six species listed as priority nearshore seabirds (Table 6.1) breed in all five states of the GoMAMN region (Figure 1.2). Furthermore, it is not uncommon for these species to nest in similar or identical habitat, and therefore, to be co-located during the breeding season. The spatial scope for management actions for nearshore species also includes habitats off-colony in the nearshore or estuarine environment (e.g., foraging habitat). The lack of tracking data for each of these species (except Brown Pelicans) further limits our understanding of the spatial scope that is required for management activities for nearshore seabirds while foraging. In general, most of the pelagic species that occur in the Gulf appear to be wide-ranging or at least appear to have the potential to be wide-ranging. Further, pelagic seabirds are not likely to be distributed in fixed locations (e.g., at permanent habitat features), but rather use habitat in response to dynamic properties that vary in space and time such as ocean eddies or sea-surface temperature fronts (Weimerskirch et al. 2004, Hyrenbach et al. 2006). The exception to habitat use focusing on dynamic features are the association of seabirds with more permanent features such as sea mounts (e.g., DeSoto Canyon) or river mouths (e.g., Mississippi River plume) which tend to produce consistent zones of productivity, and hence increased local seabird abundance (GoMMAPPS unpublished data), although even these can vary in intensity, spatial extent, and timing throughout the annual cycle. Nonetheless, management actions and monitoring activities focused on pelagic seabirds often consider the dynamic nature of their habitat and the dynamic nature of the human activities (e.g., commercial fishing) that occur within those habitats.

## Priority Status and Trends Assessments

The assessment of the status and trends of seabird populations in the northern Gulf has been recognized as a critical need for at least three decades (Clapp and Buckley 1984, Burger 2018). Similarly, despite recent efforts to catalog and map seabird colonies in the Caribbean and southern Gulf (Bradley and Norton 2009), gaps exist with respect to trend assessment there as well. Data gaps in nearshore and pelagic systems preclude efficient and effective assessments of conservation threats in all habitat types used by seabirds. Such data gaps become particularly apparent when the system is stressed (e.g., oil spills, hurricanes) and assessments need to be made of damage or impacts to habitats and living marine resources including seabirds (DHNRDAT 16: Chapt. 4). Data gaps for seabirds reflect our objectives of: 1) increasing status and trend data (including life history parameters), 2) improving our understanding of the efficacy of management actions and restoration activities (Table 6.2), and 3) improving our understanding of ecological processes (Table 6.3) that affect seabirds in both coastal and pelagic habitats (Figure 6.1 and Appendix 6).

We have included the population status of each priority species, as well as other seabirds to be considered in monitoring programs (Table 6.1). These trends are from the Partners in Flight (2017) Species Assessment. Seabirds for which the population trend is highly uncertain or highly variable received a score of 3, species with a score <3 are of less concern, species with a score >3 are of higher concern. Of the 13 seabirds included in the GoMAMN birds of conservation Concern (Appendix 1), five received a PIF score <3 (Royal Tern, Sandwich Tern, Northern Gannet, Brown Pelican, Common Loon), two received a score of 3 (Masked Booby, Sooty Tern), and 6 received a score >3 (Gull-billed Tern, Audubon's Shearwater, Least Tern, Magnificent Frigatebird, and Band-rumped Storm-Petrel). Furthermore, the

Black-capped Petrel, an endemic seabird of the region and one classified as globally endangered (breeding population ca 2,500 pairs; Simons et al. 2013) received a PIF score of 5. For species which do not breed in the Gulf of Mexico, and for which the proportion of the population wintering in the Gulf of Mexico is unknown (i.e., all pelagic seabirds in our priority list), population level status and trends assessment specific to the Gulf of Mexico may not be available.

For seabirds that nest in the northern Gulf, the highest priority for addressing gaps in data for status and trends is the development of a registry or colony atlas that is region-wide and accessible to the broader avian conservation community (e.g. Ferguson et al. 2018). Although each state collects some level of data on abundance of breeding seabirds, the timing, frequency, type, and protocols associated with surveys are not consistent, inhibiting effective and efficient regional assessments. For example, infrequent or irregular colony surveys or surveys that are uncoordinated among states may fail to capture shifts in colony sizes among locations either within or among states, resulting in potentially misleading data (Jodice et al. 2007). Periodic assessments of variables beyond nest counts (e.g., productivity, provisioning rates, chick condition, nestling diets) also are lacking, and would greatly enhance our understanding of mechanisms underlying colony dynamics and hence population trends.

A robust monitoring program for nearshore species would also include year-round surveys of the nearshore zone to assess distribution and abundance of migrants, as well as use of sites that may not be a focus during the breeding season, and an assessment of foraging habitats and individual body condition. Given the extensive foraging and migration range of nearshore species in the region, it is critical to understand that declines observed at a colony may not be due to on-colony factors, but rather, may be a function of environmental conditions or threats experienced outside the Gulf. Similarly, many data sets exist that examine specific reproductive, behavioral, or physiological attributes of Gulf seabirds at breeding sites, but many such efforts are site- or taxonomic-specific and temporally limited.

Data focused on the distribution and abundance of seabirds at-sea are also sparse across the GoMAMN geography (Figure 1.2). Habitat use, foraging locations, and migratory routes are poorly understood, and therefore, associated threats are only generally described. As of 2017, data from only three survey efforts for seabirds are readily available for the Gulf (Fritts and Reynolds 1981, Ribic et al. 1997, Haney 2011), and the most spatially and temporally extensive of these occurred after the Deepwater Horizon Oil Spill (DHNRDAT 2016). Designing and implementing surveys for seabirds at-sea may benefit from coordination with existing monitoring efforts focused on marine mammals, sea turtles, or fisheries/oceanography. These benefits may include, but are not limited to logistics, but also ecological context as well. Although such efforts are focused on distribution and abundance specifically within the Gulf of Mexico, interpretation of trends in abundance may benefit from colony-based data at breeding sites (e.g., trends in reproductive success), while interpretation of trends in distribution may benefit from data focused on spatial and temporal patterns in dynamic oceanography.

For seabirds at-sea, a new monitoring program has been developed as of 2017. The Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS) includes nearshore (out to ca. 50 nm) aerial surveys and vessel-based surveys of the pelagic environment. The goal is to determine the distribution and abundance of seabirds, and to relate these response variables to the presence and status of oil and gas platforms, fisheries activities, habitat variables (e.g., SST, primary productivity, frontal boundaries), colony locations, and local and regional climate. GoMMAPPS will provide spatially and temporally more extensive survey data for seabirds than currently exists. Surveys are scheduled to be conducted from 2017–2019.

## Priority Ecological Processes

The ecosystems that seabirds occupy during both the breeding and nonbreeding seasons are highly dynamic both spatially and temporally, and the abiotic and biotic components of these ecosystems interact in complex ways. The trans-boundary nature of seabird movement patterns, at temporal scales ranging from daily to annual, also lead to numerous and complex abiotic and biotic interactions within these complex ecosystems. The complex interactions of these abiotic and biotic components are the foundations for ecological processes in the terrestrial and marine environments that ultimately may act as selective forces on species adaptations, but that proximally act as underlying mechanisms driving population dynamics (Newton 1998). Therefore, if a goal of management agencies is to enhance or maintain the viability of seabird populations in the northern Gulf, then the ecological processes that affect seabird populations needs to be clearly understood so that effective management actions (e.g., Kress1998) can be prioritized and implemented. To do so, the status and trends of seabird populations, as well as the effectiveness of management actions need to be fully understood, and these in turn require both long-term monitoring and directed research efforts (Lindenmayer and Likens 2010). Therefore, we review ecological processes that are likely to be underlying the population dynamics of seabirds in the northern Gulf in the context of informing the direction and focus of long-term monitoring plans.

The means by which ecological processes impact seabirds have been ranked using a combination of estimated effect sizes (Unknown, High, Low) and uncertainty (High, Low) (Table 6.3). Values from the objectives hierarchy (Figure 2.2) were used to prioritize ecological processes. By using values from the objectives hierarchy, questions which are relevant to priority species and which reduce uncertainty in understanding of how ecological processes influence population dynamics were prioritized (Figure 2.2). The seabird influence diagrams (Figure 6.1 and Appendix 6) were used to link ecological processes and management actions with population dynamics.

The ecological processes we identified as likely to affect seabird population dynamics fall into three broad categories; climatic processes, interaction with other organisms, and natural disturbance regimes (Bennet et al. 2009). Within these broad categories we identified more refined processes and these focus on the quantity and quality of habitat (breeding, nonbreeding, foraging) and prey, the influence of predation, and relationships between breeding phenology and annual climate patterns (Figure 6.1 and Appendix 6). Uncertainty is highest for processes related to climate and natural disturbances, primarily due to the unpredictable nature of both, and the lack of opportunities to examine how species respond to each. Similarly, effect sizes are highest for those processes which are most likely to operate at large spatial scales such as climate and natural disturbances.

In terrestrial ecosystems there is a great deal of complexity surrounding the predicted responses of seabirds to climate change and sea-level rise (Sandvik et al. 2012, Jenouvrier 2013, Reynolds et al. 2015, Kruger et al. 2018). Seabirds rely primarily on barrier, coastal, estuarine, and marsh islands for breeding in the northern Gulf. Activities at these sites include not only nesting, but also chick-rearing and loafing, and use areas often extend beyond just the physical limits of the colony (i.e., nest sites; Ferguson 2012). Seabirds also occupy coastal areas and islands during the nonbreeding season, using these sites for juvenile care, staging, molting, loafing, and as roost sites. Therefore, changes that may occur to the size, elevation, vegetation, or predator access to islands and coastal areas may have a proximate impact on the availability and/or quality of breeding and nonbreeding habitat, and ultimately on reproductive success, individual condition, and survival.

Climatic processes also may affect aquatic habitats occupied by seabirds. Climatic processes may result in changes in freshwater input from rivers, changes in salinity of estuaries, or changes in water temperature. These may subsequently affect fish/prey life histories, distribution, or abundance (Bachman and Rand 2008, Fodrie et al. 2010) and thereafter, foraging ranges and behavior, parental attendance patterns, and reproductive success of seabirds. In pelagic and coastal waters, climate change could lead to changes in dynamic oceanography (e.g., circulation patterns, upwelling), which may subsequently affect the underlying habitat to which seabirds respond while foraging (Bakun et al. 2015). Large-scale changes to weather patterns that result in more frequent and greater intensity of tropical storms and hurricanes also may have effects on behavior, movements, and reproductive success (Bugoni et al. 2007, Hass et al. 2012, Sherley et al. 2012, Descamps et al. 2015).

Two other ecological processes of note that may be affected by climate patterns in the pelagic zone include potential effects on prey availability for seabirds due to changes in the distribution and abundance patterns of Sargassum and of sub-surface predators. Sargassum serves as an important habitat (i.e., refugia) for forage fish that are a primary prey for some pelagic seabirds (e.g., Audubon's Shearwater, Sooty Tern; Moser and Lee 2012). Similarly, sub-surface predators such as tuna (*Thunnus* sp.) can serve to drive forage fish to the surface and thus, affect prey availability for seabirds (facilitated foraging; Miller et al. 2018). It is unclear how climate change, and subsequently changes in dynamic oceanographic processes such as currents, eddies, and upwellings, might therefore, impact either of these prey-related processes and subsequently, seabird foraging behavior, individual condition, and provisioning rates to chicks.

The behavior, population dynamics, and ultimately status and trends of seabirds are driven by a suite of complex ecological processes that are terrestrial, freshwater, and marine-based, and that vary in spatial and temporal scale from local to hemispheric. Linking ecological processes to seabird response variables can therefore be challenging, particularly if data are collected only at single sites or over short time intervals. The long-lived nature of seabirds, combined with their extensive spatial movements, suggests that monitoring efforts or study designs that incorporate longer time frames and multiple locations be prioritized over monitoring efforts focused only at single sites or for brief periods of time (e.g., Clutton-Brock and Sheldon 2010).

## SUMMARY & MONITORING RECOMMENDATIONS

Data gaps for seabirds in the Gulf of Mexico remain substantial with respect to long-term monitoring and research to inform monitoring (Burger 2017, 2018). In many cases, we recognize that the uncertainty associated with management activities or ecological processes is high and the likely effect sizes are unknown. Additionally, study designs that correctly disentangle process uncertainty from multiple sources are often logistically challenging or impossible to conduct in the field. The unique life-history characteristics of seabirds and the extensive variability that occurs in habitats and conditions

**Table 6.3.** *Uncertainties related to how ecological processes impact populations of seabirds in the northern Gulf of Mexico.*

| Species<br><br>Season(s) | Ecological Process Category[a] | Question | End point to measure | Uncertainty Description | Uncertainty Category[b, d] | Effect Size[c, d] |
|---|---|---|---|---|---|---|
| All Seabirds<br><br>Breeding, Non-breeding | Climatic Processes | Do climate, sea-level rise, and/or ocean acidification affect habitat quantity and quality for seabird prey, prey availability for seabirds, and ultimately reproductive success and/or individual survival? | Adult annual survival, nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, post-fledgling survival, abundance of prey available to seabirds | Sea-level rise regional variance not understood; plasticity in foraging behavior unknown | High | High |
| Nearshore Seabirds<br><br>Breeding, Non-breeding | Climatic Processes | How does sea-level rise influence the frequency and severity of flooding/ overwash events, habitat quality during breeding and nonbreeding seasons, and subsequent reproductive success and/or individual body condition? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, size-corrected body mass (or other energetic condition estimators), number & frequency of overwash events | Sea-level rise regional variance not understood; creation of new habitat from SLR not well understood | High | High |
| Pelagic Seabirds<br><br>Breeding | Climatic Processes | How does sea-level rise influence the frequency and severity of flooding/ overwash events, habitat quality during breeding season, and subsequent reproductive success? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, size-corrected body mass (or other energetic condition estimators), number & frequency of overwash events | Sea-level rise regional variance not understood; creation of new habitat from SLR not well understood | High | High |
| Nearshore Seabirds<br><br>Breeding | Climatic Processes | How does sea-level rise influence predator access to nest sites and colonies, and subsequent reproductive success? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests; species composition, occupancy, and abundance of predators at seabird colonies | Sea-level rise regional variance not understood; predator response to SLR not understood | High | Unknown |
| Pelagic Seabirds<br><br>Breeding | Climatic Processes | How does sea-level rise influence predator access to nest sites and colonies, and subsequent reproductive success? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests; species composition, occupancy, and abundance of predators at seabird colonies | Sea-level rise regional variance not understood; predator response to SLR not understood | High | Unknown |
| Nearshore Seabirds<br><br>Breeding | Interactions Between Organisms | How does avian and mammalian nest predation influence reproductive success and subsequent the colony and population dynamics of seabirds? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, annual variation in fecundity, true breeding colony abundance over multiple years | Predation rates are not understood across most species and geographies | Low | Unknown |
| Pelagic Seabirds<br><br>Breeding | Interactions Between Organisms | How does avian and mammalian nest predation influence reproductive success and subsequent the colony and population dynamics of seabirds? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, annual variation in fecundity, true breeding colony abundance over multiple years | Predation rates are not understood across most species and geographies | Low | Unknown |

## Table 6.3 (continued).

| Species<br><br>Season(s) | Ecological Process Category[a] | Question | End point to measure | Uncertainty Description | Uncertainty Category[b, d] | Effect Size[c, d] |
|---|---|---|---|---|---|---|
| Audubon's Shear-water, Sooty Tern<br><br>Breeding, Non-breeding | Climatic Processes | How will climate change affect Sargassum distribution and abundance, seabird foraging, and subsequent seabird survival and reproductive success? | True density of at-sea seabirds, density of prey available to seabirds, adult annual, annual fecundity estimates for marked individuals x species x colony | Climate change effects on Sargassum are unknown; factors that regulate distribution and abundance of Sargassum poorly understood | High | Unknown |
| Pelagic Seabirds<br><br>Breeding, Non-breeding | Climatic Processes | How will climate change affect tuna abundance and distribution, prey availability and foraging success for seabirds, and ultimately population demographics? | True density of at-sea seabirds, density of prey available to seabirds, adult annual, annual fecundity estimates for marked individuals x species x colony | Relationship between predatory fish and seabirds poorly understood in GoM | High | Unknown |
| Nearshore Seabirds<br><br>Breeding | Natural Disturbance Regimes | How does the timing and intensity of hurricanes affect seabird survival and reproductive success? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, adult annual survival, before & after effects of hurricanes on habitat quantity & quality | Extent to which frequency and intensity of hurricanes will vary with climate change poorly understood; direct and indirect effects of hurricanes on seabird behavior and survival poorly understood | High | High |
| Pelagic Seabirds<br><br>Breeding | Natural Disturbance Regimes | How does the timing and intensity of hurricanes affect seabird survival and reproductive success? | Nest success and/or daily survival rates of marked nests, daily survival rates of chicks in marked nests, adult annual survival, before & after effects of hurricanes on habitat quantity & quality | Extent to which frequency and intensity of hurricanes will vary with climate change poorly understood; direct and indirect effects of hurricanes on seabird behavior and survival poorly understood | High | High |
| All Seabirds<br><br>Breeding, Non-breeding | Not Defined[e] | How does contact with spilled oil and associated chemicals (e.g., dispersants) affect individual health, body condition, and annual survival? | Body condition index (or other energetic estimators), multi-faceted health assessment, adult annual survival | Long- and short-term survival poorly understood for most species; sublethal effects difficult to quantify | Low | High |
| All Seabirds<br><br>Breeding, Non-breeding | Not Defined[e] | How does contact with spilled oil and associated chemicals (e.g., dispersants) affect prey availability and quality, and subsequent individual health, body condition, and annual survival? | Body condition index (or other energetic estimators), multi-faceted health assessment, adult annual survival | Diet data generally known, but not detailed across all species and study area; effects of oiling on prey dynamics not well known | Low | 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.
[e]No category defined in Bennet et al. (2009).

across the GoMAMN geography (both within and between nearshore and pelagic systems) contribute to this pattern of high uncertainty and effects. To address these challenges, herein we present options for monitoring seabirds in the Gulf in the nearshore and pelagic systems. We provide guidelines that are appropriate across long time-frames and extensive spatial scales given the complexities associated with monitoring seabirds. At breeding sites, we review guidelines for monitoring colony status, reproductive success, and chick growth. We also review guidelines for monitoring individuals through tracking, as well as aerial and vessel surveys.

## Colony-based Studies

For seabirds that breed in the GoMAMN area, a spatial inventory of breeding sites (e.g., colony atlas) is a critical data component for long-term monitoring. Nest counts are a basic metric used to monitor colonial seabirds (Jodice et al. 2007, Seavy and Reynolds 2009, Porzig et al. 2011, Ferguson et al. 2018). Surveys can be direct observations/counts within colonies or via aerial photos taken from UAVs or planes (Schiavini and Yorio 1995, Laran et al. 2017, McClellan et al. 2016, Hodgson et al. 2016). Other unique approaches to monitor seabird colonies include using readily available satellite imagery in Google Earth (Hughes et al. 2011) and remotely sensed signatures of guano (Fretwell et al. 2015). Given the diversity of logistical issues/constraints associated with conducting nest counts (e.g., colony size/density, species composition on the colony, accessibility of colony, behavior of nesting birds in relation to researcher disturbance) it is unlikely that a single approach can be universally applied across all species throughout the entire region (but see Colibri and Ford 2015). Ideally, surveys should be synchronized among states (e.g., every year, every 3rd year) and conducted at the same point in the nesting cycle (e.g., during peak incubation for the target species). Seabirds that breed in the Gulf display various degrees of breeding synchrony within- and among-species, and therefore, survey design should consider the variability in synchrony. If nest counts are not viable, colony occupancy can be measured (presence/absence at a colony; e.g., MacKenzie et al. 2006, Jodice et al. 2013). Occupancy and nest count data cannot, however, distinguish between source, sink, and ecological trap habitats.

Productivity estimates provide a level of detail beyond that available from basic nest count surveys and would be an invaluable contribution to long-term monitoring strategies. Nest and fledging success can be reported as a measure of survival (≥1 egg/chick survives to hatch/fledge), daily survival rate (DSR, the probability that a clutch/individual/brood survives from one day to the next), or as a proportion (% eggs/chicks that hatch/fledge per nest/clutch). Each approach has its own inherent assumptions and analytical limitations (Shaffer 2004, Jones and Geupel 2007), and therefore, monitoring plans should consider and evaluate these prior to implementation. For example, measures of apparent success may be acceptable for species where detectability is high and nests are readily visited, but for most situations some method of estimating DSRs via regular nest visits is likely more appropriate (Jones and Geupel 2007). Ultimately, the method that provides the least biased estimate of the population parameter of interest (i.e., fecundity) is preferred. Daily survival rate is usually the least biased estimate, but these data can be difficult and expensive to collect. Tolerance for bias and uncertainty need to be assessed for each monitoring project to determine the best choice for that study. Remote cameras can be used to monitor individual nests and provide data useful for measuring nest success while also decreasing the potential for researcher disturbance at colonies. Cameras also have the potential to yield other nest-based data such as parental attendance or cause-specific nest failure (Danielsen and Bengston 2009, Gladbach et al. 2009, Jodice et al. 2015). Loss of productivity during incubation tends to be due to either partial or total clutch loss through predation or total clutch loss through flooding, and identifying cause-specific egg loss can often lead to management actions that can improve overall reproductive success (Dinsmore 2008, Brooks et al. 2013, Brooks et al. 2014). Individual monitoring of chick survival can be challenging given that seabirds breeding in the region are both altricial, with extended fledging periods (e.g., Brown Pelicans, ≥10 weeks) and precocial, with chicks that vacate nest sites soon after hatching (e.g., Black Skimmers and terns). Nest-bound chicks (e.g., shrub nesting pelicans) may be monitored via remote cameras, but precocial chicks that leave the nest (i.e., Black Skimmers, terns) are not amenable to this approach. Band-resighting (i.e., color bands or color bands with alphanumeric codes) or telemetry are more likely to result in survival data of sufficient quality to estimate productivity although each requires considerable field time (Brooks et al. 2013, Walter et al. 2013). An abbreviated time-frame also may be established to estimate fledgling survival in pelicans to reduce the duration of monitoring activities within a season (e.g., survival to 50 days; Eggert and Jodice 2008, Lamb 2016). Fledging success can also be measured at the population level by deriving adult:hatch year ratios at colonies near the termination of the breeding season. While this metric quantifies long-term hatch year survival and can be a robust estimate of productivity, the scope of inference is limited due to the population-level scale of the measurement.

Chick growth rates can provide further detail for long-term monitoring strategies. Chick growth can be measured repeatedly on the same individuals to provide growth curves that can be assessed, for example, in relation to environmental stressors or diet (Eggert and Jodice 2008, Eggert et al. 2010, Jodice et al. 2008). A single measure of chick size when collected on many chicks at once can also be used to make comparisons among colonies or across time and space (Benson et al. 2003). Recently, approaches that rely on physiological parameters, such as the measure of corticosterone in chick feathers, have been used to compare reproductive success among colonies (Lamb et al. 2016b). Feather corticosterone shows promise as a noninvasive sampling technique that can be collected during a single visit and that can be correlated with body condition or fledging success (Patterson et al. 2015, Lamb et al. 2016b).

One of the most important data gaps for seabirds in the region is the lack of measures of adult survival, particularly for females. Seabirds are long lived (commonly >20 years) and adult survival rates tend to be drivers of population dynamics and recovery (Weimerskirch 2001, Sandvik et al. 2005, Champagnon et al. 2018). Long-term banding data provide some insights into survival (e.g., Schreiber and Mock 1988), but analysis of banding and band-resight data are not published or readily accessible for most of the focal species' (aside from some datasets residing at the USGS Bird Banding Lab). The extensive spatial distribution of colonies throughout the region, the remoteness of some colonies, and the apparent ability of individuals to move among colonies within or between years also makes the detailed estimation of adult survival via band-resighting challenging, requiring a long-term commitment of resources, and a well-planned study (Aubry et al. 2011, Walter et al. 2013). Delayed maturity results in a multi-year state of non-residency and multiple transition probabilities amongst classes (e.g., Cooke et al. 1995) that also complicates band-resight studies, particularly if marking studies are short-term and local in nature. Therefore, measures of juvenile survival are also difficult to obtain and generally lacking for seabirds in this region. For pelagic seabirds, estimates of age- and sex-specific survival, although generally lacking, are likely not an efficient endpoint for monitoring in the GoMAMN geography. Any such efforts would best be conducted at breeding sites for those species (e.g. Mackin 2016). The seabird colonies in the southern Gulf also provide a unique opportunity to pursue such efforts. For example, several species of interest nest at Arecife Alacranes National Park in Mexico (Tunnell and Chapman 2000) and may provide opportunities for long-term monitoring.

## Individual Tracking Studies: Movement & Habitat Use

Habitat is an important component of the objectives hierarchy, influence diagrams, and ecological processes in these monitoring guidelines. For seabirds, habitat use is most often determined from tracking data or survey data and the pursuit of such studies would be a valuable contribution to long-term monitoring. Tracking data from seabirds provides details on residency time in specific habitats, patterns of movements among habitats, explicit links between colonies and foraging or wintering sites, inter- and intra-individual variability in habitat use, and in some cases behavior (Wakefield et al. 2009, Camphuysen et al. 2012, Jodice et al. 2015, Poli et al. 2017, Lamb et al. 2017b, 2017c). Individual tracking data are also appropriate for investigating ranges at multiple time scales (e.g., daily, seasonally, annually). Recent tracking data from Brown Pelicans has demonstrated, however, that movement patterns of breeding birds may differ among colonies in the study area, due to either foraging conditions, colony size, or individual-bird attributes (Lamb et al. 2017 b,c). Therefore, caution is warranted when extrapolating habitat use to the broader target population if movement data are only available from a single colony.

Given the range of tracking devices available and their accompanying range in spatial and temporal resolution with respect to data acquisition, it is advisable that programs that intend to deploy tracking devices have *a priori* identified clear and explicit questions of interest (Wakefield et al. 2009). To date, tracking studies conducted on the priority seabirds identified by the GoMAMN have been limited to a few species. This list primarily includes Brown Pelican (King et al. 2013, Walter et al. 2013, Lamb et al. 2017b, Lamb et al. 2017c), Masked Booby (Poli et al. 2017), Sooty Tern (Huang et al. 2017), Northern Gannet (Fifield et al. 2014), and Black Skimmer (Eggert et al. 2011, Newstead et al. in prep.). One primary concern is to ensure that the tags chosen are capable of withstanding salt water, force from plunge dives, or pressure from water depth. Tag mass and size is an important consideration, as is the shape and design of the tag (Barron et al. 2010, Wilson et al. 2012). The former can affect flight costs or energy expenditure, while the latter can affect diving and swimming efficiency (i.e., aero- and hydro-dynamic considerations), as well as prey-capture. Harnesses from Teflon ribbon have successfully been used to deploy tags on Brown Pelicans and Black Skimmers in the Gulf (Evers et al. 2011, Walter et al. 2013, Lamb et al. 2017a) and would likely be effective for large terns and gulls (Putz et al. 2007, Gilg et al. 2016). Implanted transmitters have been used successfully with Common Loons (Kenow et al. 2009). Smaller-bodied seabirds may be more amenable to attachment of transmitter packages via tape, leg bands, or suturing. The attachment technique also affects the longevity of the attachment and thus, the transmitter package, which may last days/weeks (e.g., tape; Weimerskirch et al. 2006, Poli et al. 2017), months (e.g., suturing; Reid et al. 2014, Jodice et al. 2015), or ≥1 year (e.g., harness or implant; Kenow et al. 2009, Lamb et al. 2017a).

## At-Sea Surveys

The continuation and expansion of at-sea surveys is warranted to expand the temporal and spatial scope of available seabird data in the Gulf. Reviews of vessel-based and aerial survey techniques for seabirds can be found in Tasker et al. (1984), Clarke et al. (2003), Camphuysen et al. (2004), Spear et al. (2004), and Buckland et al. (2012). The use of both vessel and aerial surveys can provide complementary data that will enhance interpretation of abundance and distribution data. The typical objective of at-sea surveys is to estimate the abundance, density, or occupancy of a target species or species group over space and time (e.g., Ribic et al. 1997, Bolduc and Fifield 2017, Winship et al. 2018). The Bureau of Ocean Energy Management (BOEM) has a series of guidelines that have been developed in the context of monitoring renewable energy development (https://www.boem.gov/Avian-Survey-Guidelines/) and GoMAMN guidelines are strongly informed by BOEM's suggestions. The distribution of seabirds in pelagic systems is characterized by a high degree of spatial and temporal variation because of the dynamic nature of oceanographic habitat leading to substantial variance in survey counts within areas between days, weeks, and years (Kinlan et al. 2012, Winship et al. 2018). Seabird locations are often not, therefore, static or location-based (i.e., linked to a specific set of geographic coordinates), but rather are better characterized as dynamic and linked to habitat variables that shift locations, intensity, and duration in time and space (Scales et al. 2015). The design of long-term monitoring plans will benefit from considering intra- and inter-annual variation in distribution, and from including measures of dynamic oceanographic variables to elucidate seabird distribution. Given this, we suggest that surveys be conducted regularly throughout the annual cycle (e.g., seasonally) for a minimum of three years regardless of the platform chosen. Marine conditions also change among years (e.g., El Niño) and over longer time periods (e.g., Pacific Decadal Oscillation) due to global climate patterns or global climate change, thus revisiting surveys every decade may be required to update spatial density estimates.

Parallel or 'sawtooth' transect lines are useful for covering a large area in an efficient manner and line spacing may vary based on the objectives and hypotheses. We recognize, however, that often seabird surveys are using vessels of opportunity and therefore, seabird observers may be constrained with regards to survey design. Surveys often use some aspect of distance sampling (Buckland et al. 2012) to quantify the probability that an animal is detected as a function of the distance between the individual being observed and the observer. Detection rates also may be influenced by behavioral traits (of each species) including flight height, dive frequency, and dive duration. While on transect, the use of a survey application package on a laptop (e.g., SEEBIRD; Ballance and Force 2016), a mobile application developed for mobile devices for recording seabirds (SEASCRIBE; Gilbert et al. 2016), or a GPS that consistently tracks the position of the moving vessel is recommended. All birds should be identified to species as often as possible and data on non-avian species should also be recorded assuming it does not interfere with the recording of seabird data (e.g., in the Gulf consider recording marine mammals, sea turtles, flying fish, predatory fish, and Sargassum patches).

Data from aerial surveys may be collected by human observers or via digital recordings (Buckland et al. 2012). Both typically use transects perpendicular to the coastline over the study area, though consideration of logistics, safety issues, no-fly zones, and weather/glare also will influence survey design. Randomization can be used to focus the surveys on areas or conditions of interest. For example, GoMMAPPS is using a survey lay-out based on a global system of hexagonal grids (White et al. 1992) and Generalized Random Tesselation Stratified (GRTS) sample selection (Stevens and Olsen 2004). Human-observer surveys typically use strip transects with distance sampling across the strips to account for detection probability (Eberhardt 1978, Burnham et al. 1980). As with vessel-based surveys, sea state and weather conditions are recorded as they affect detection probabilities of birds. Identification to the level of species can sometimes be difficult in these surveys, and often a more coarse-grained identification scheme is adopted (e.g. large tern v. small tern). Digital aerial surveys often fly at 450–1000m ASL and 220–350 km/hr. Flight details may vary with the quality of camera systems and required resolution at ground level.

Surveys conducted in pelagic waters for seabirds are typically transect-based and result in detection-corrected density estimates (Tasker et al. 1984, Laran et al. 2015, Bolduc and Fifield 2017). Pelagic seabirds tend to be sparse and clumped in the Gulf, however, making density estimation challenging in some cases. As such, occupancy-based modeling (MacKenzie et al. 2006) may provide a less sensitive, but still relevant means by which to assess basic measures of abundance (Kinlan et al. 2016). Other community-based metrics of occurrence also may be relevant for spatial and temporal comparisons including species diversity and species richness (Goyert et al. 2016). Survey data may be well-suited for developing habitat-use models that are spatially and temporally specific (e.g., focused on a specific area at a specific time), and therefore, can address the response of seabirds to specific management actions or threats (e.g., Bradbury et al. 2014).

## Conclusion

Seabirds present a suite of unique challenges for monitoring and research. Their extensive daily and annual movements and use of marine, estuarine, freshwater, and terrestrial habitats expose them to a wide variety of ecological processes, management actions, and conservation threats that influence their condition, fecundity, survival, and ultimately population dynamics. In the northern Gulf they have, as a group, been relatively understudied and therefore, data gaps are substantial. Therefore, the uncertainty associated with conservation threats, management actions, and ecological processes is often high, and the predicted effect sizes often unknown. Moreover, the spatial and temporal scope of their movements can make process uncertainty difficult to quantify. Environmental conditions and events can interact to affect seabird populations without clear experiments that can be designed to isolate the role of each individual process. Our review of the status and trends of seabirds in the region, and of management actions (Table 6.2) and ecological processes (Table 6.3) likely to affect their status, suggest that priorities for monitoring should consider the development of a regularly updated seabird colony atlas, efforts to improve data streams on reproductive performance and survival from colonies of consistent activity that represent considerable portions of regional fecundity, and implementing and/or expanding surveys for seabirds at-sea and of individual tracking. Data from these efforts would reduce data gaps and uncertainty with respect to effects of management actions and ecological processes, inform conservation decision-making, and increase the success of restoration activities. Efforts to expand seabird monitoring to the southern Gulf and Caribbean, both areas that interconnect seabirds with the northern Gulf, would further reduce identified uncertainties.

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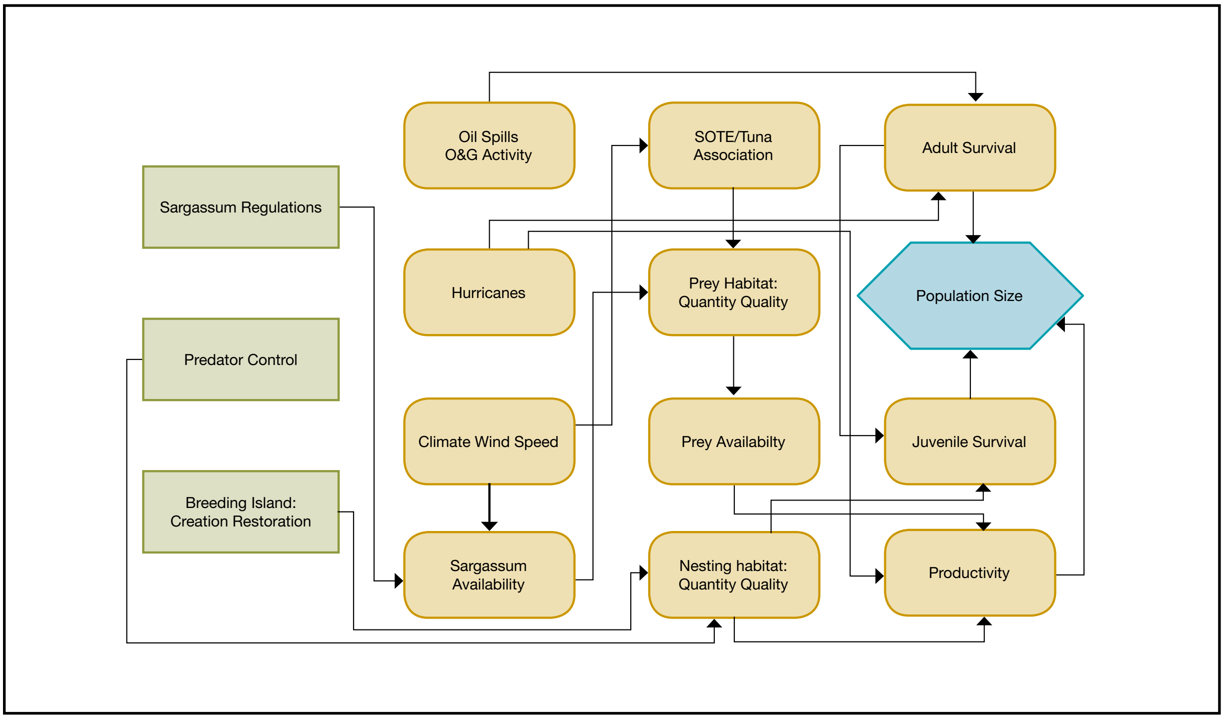
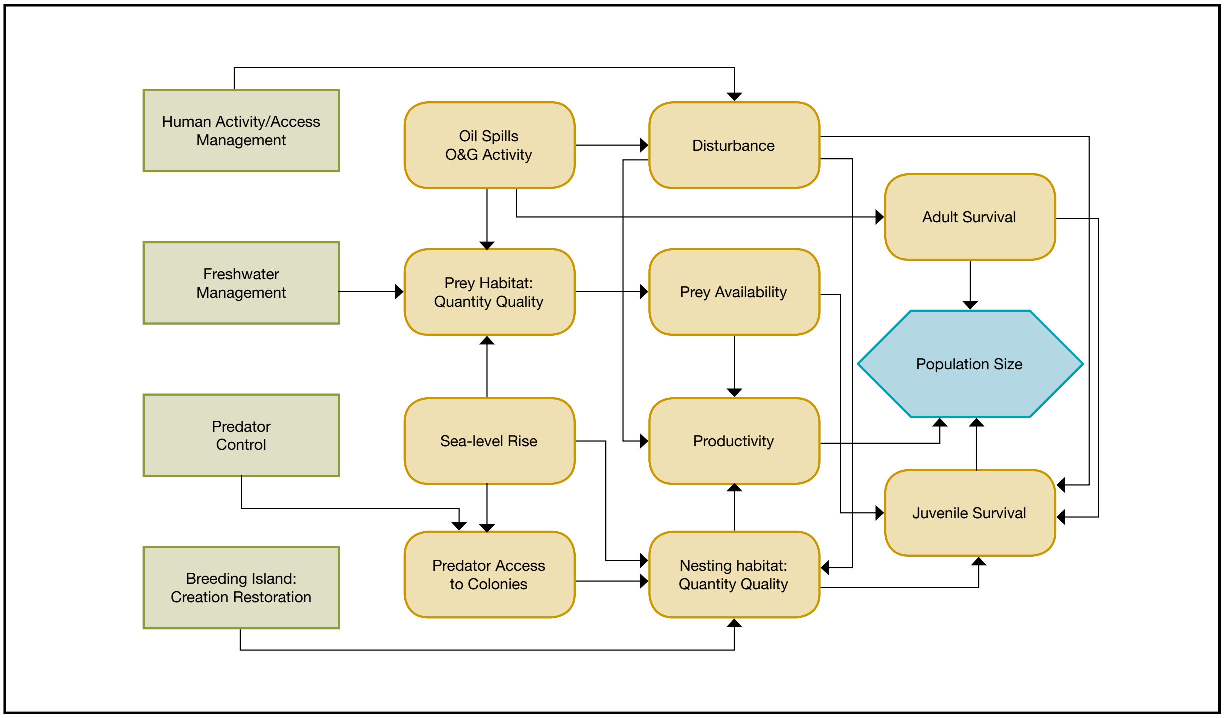
# APPENDIX 6

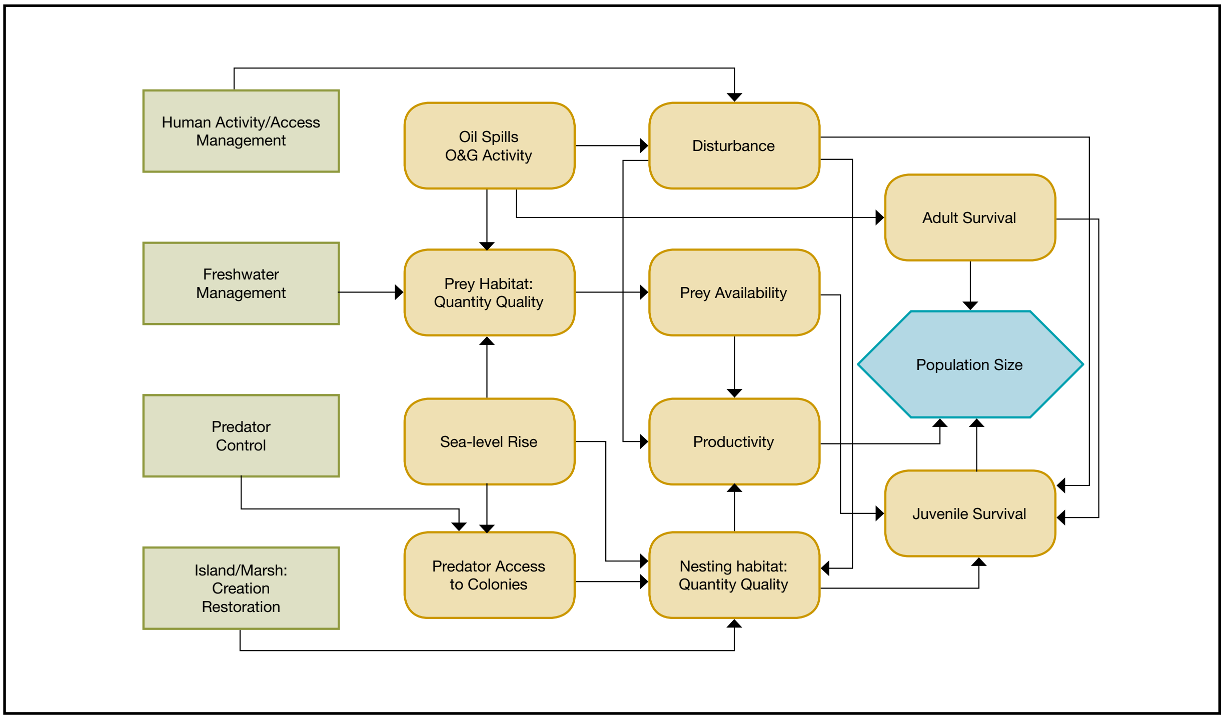
*Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of seabirds.*



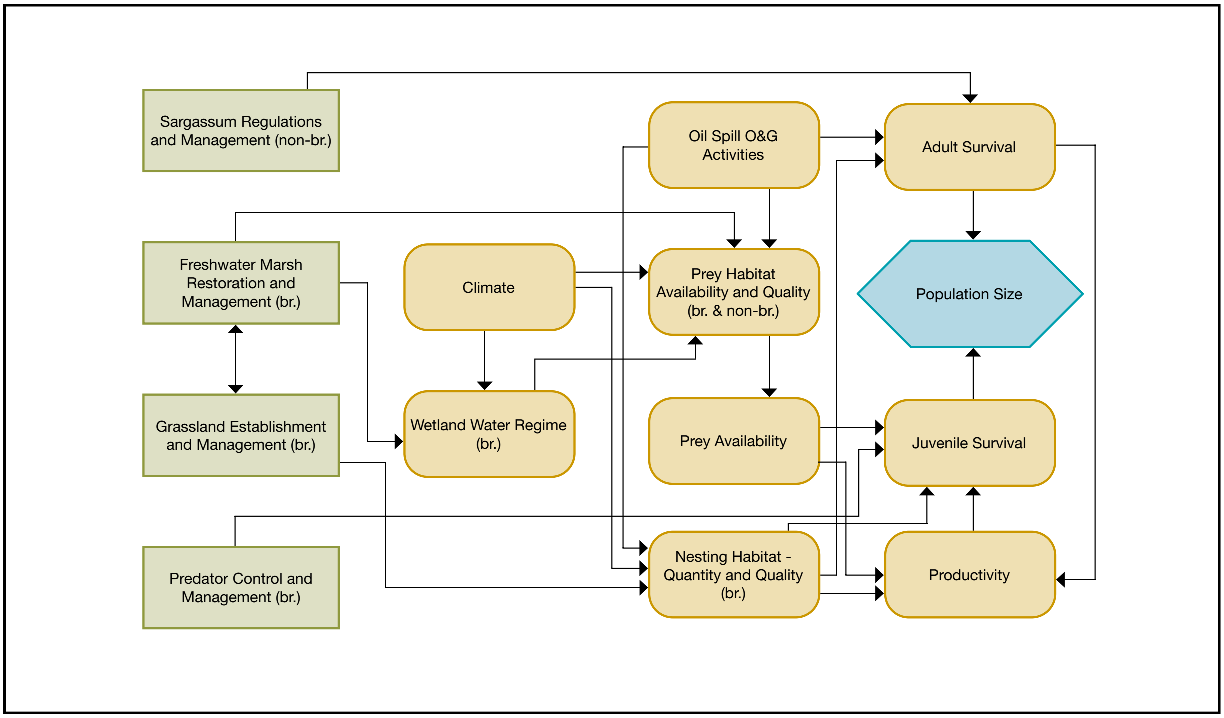

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Sooty Tern*** *(Onychoprion fuscatus) within the Gulf of Mexico Region.*



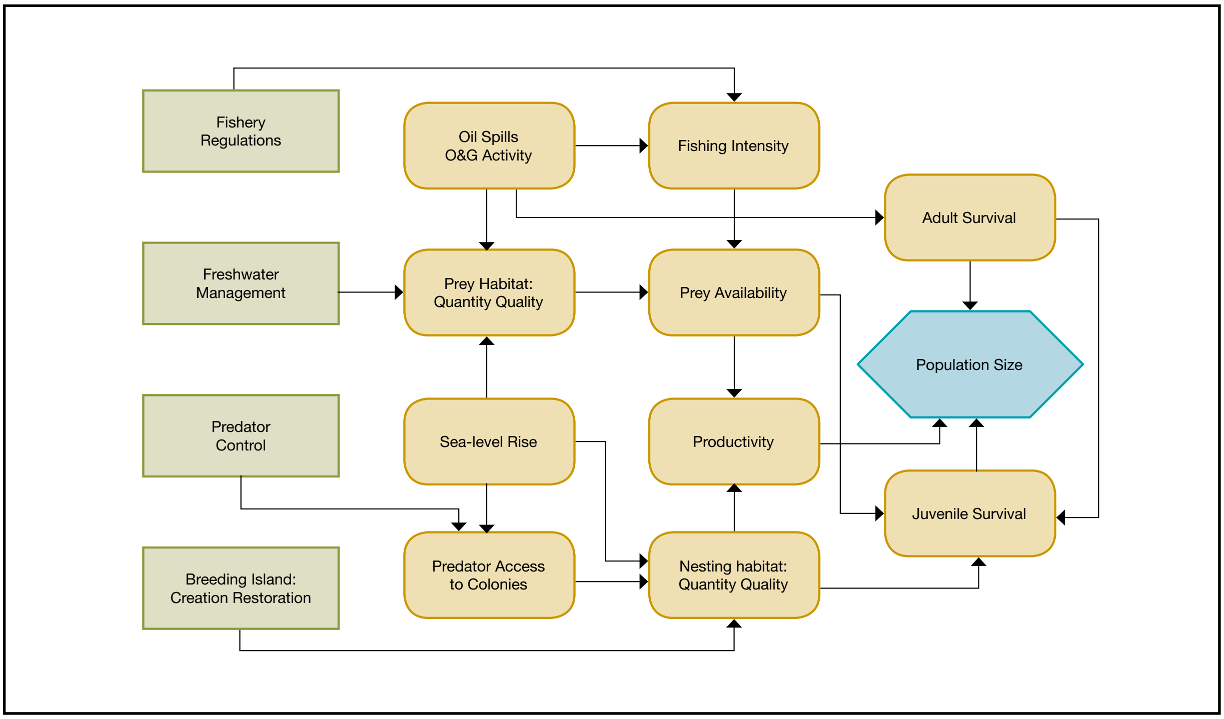

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Least Tern*** *(Sternula antillarum) within the Gulf of Mexico Region.*



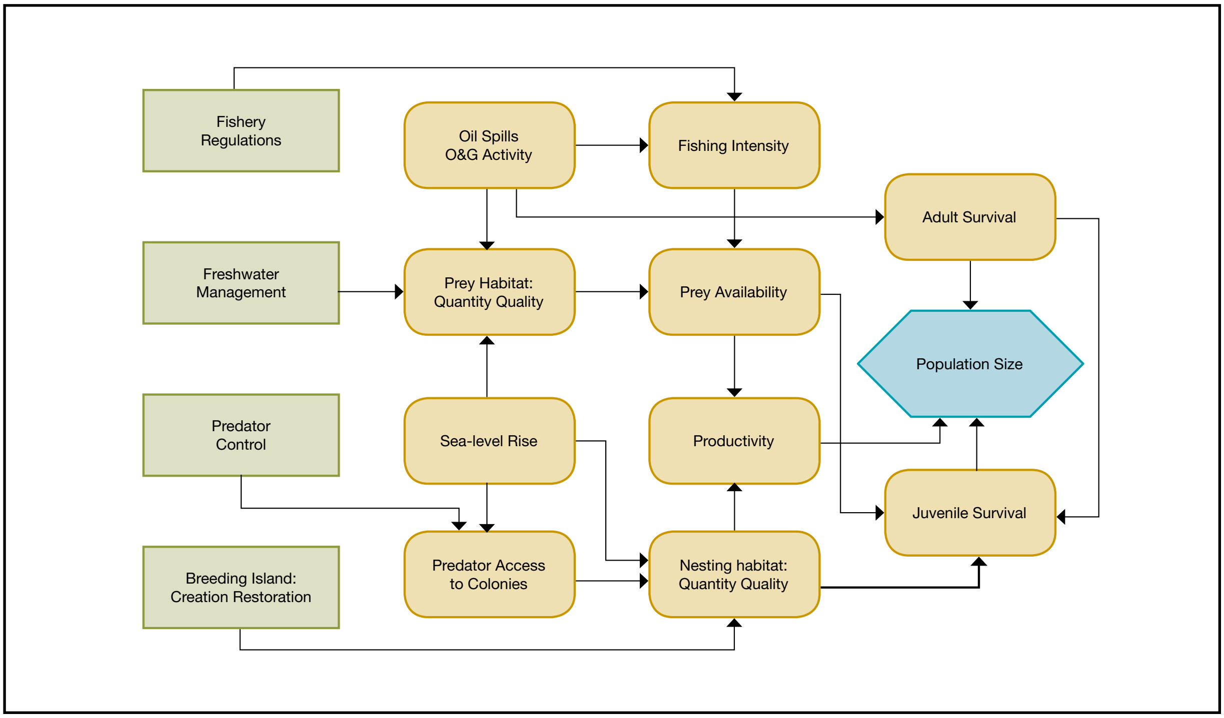

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Gull-billed Tern*** *(Gelochelidon nilotica) within the Gulf of Mexico Region.*



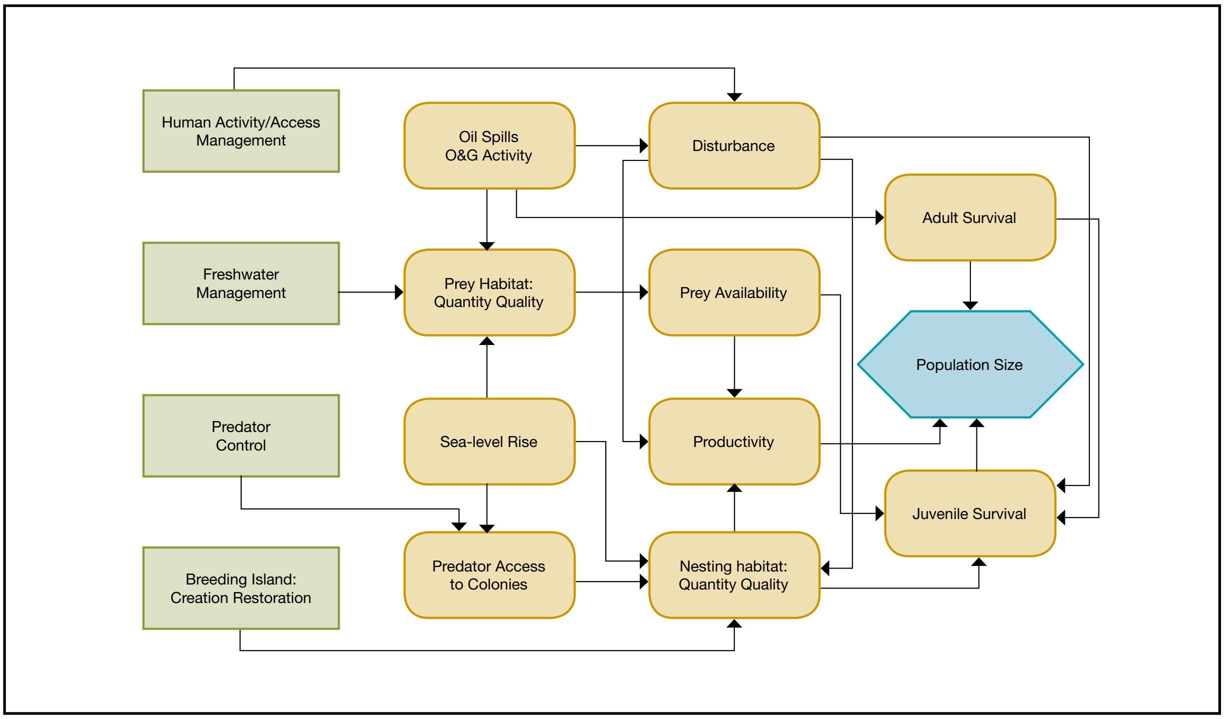

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Black Tern** (Chlidonias niger) within the Gulf of Mexico Region.*



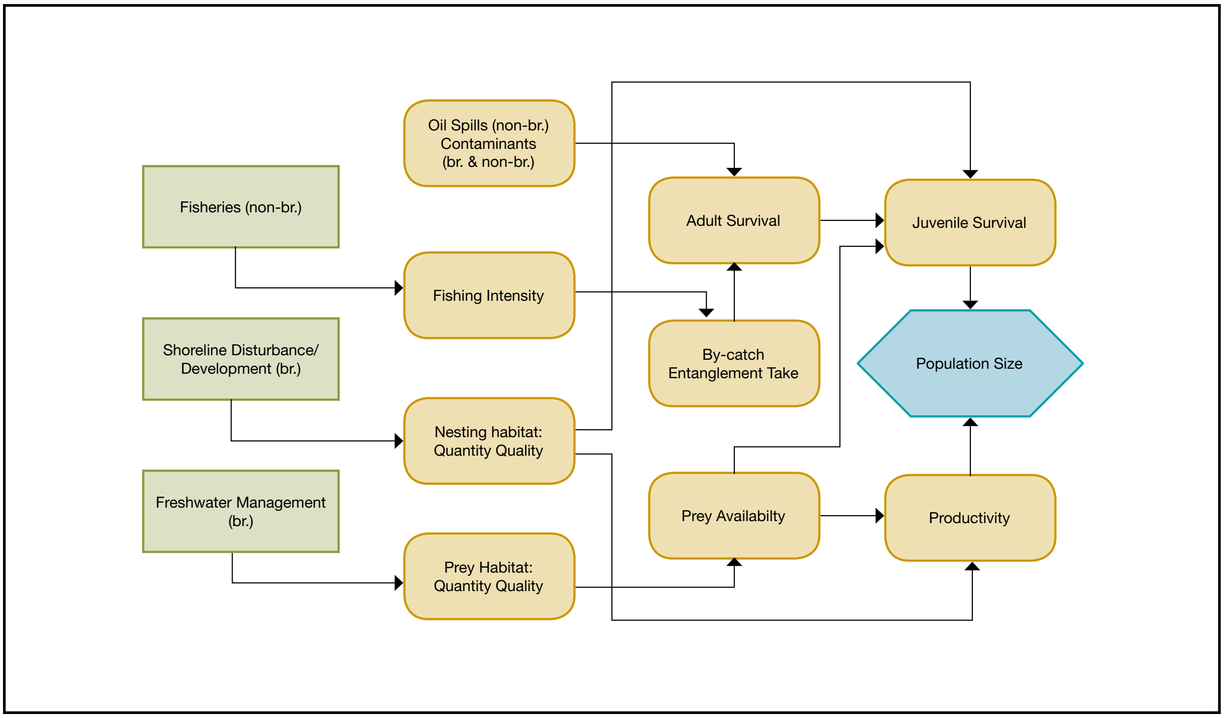

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Royal Tern** (Thalasseus maximus) within the Gulf of Mexico Region.*



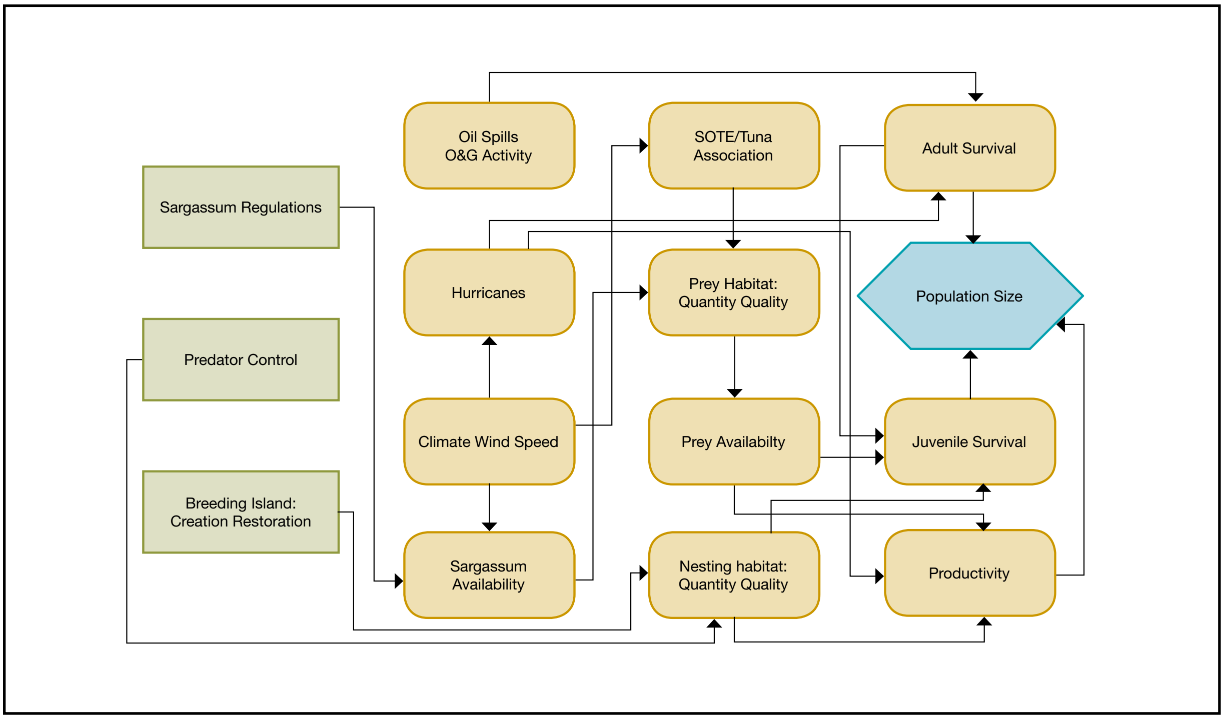

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Sandwich Tern** (Thalasseus sandvicensis) within the Gulf of Mexico Region.*



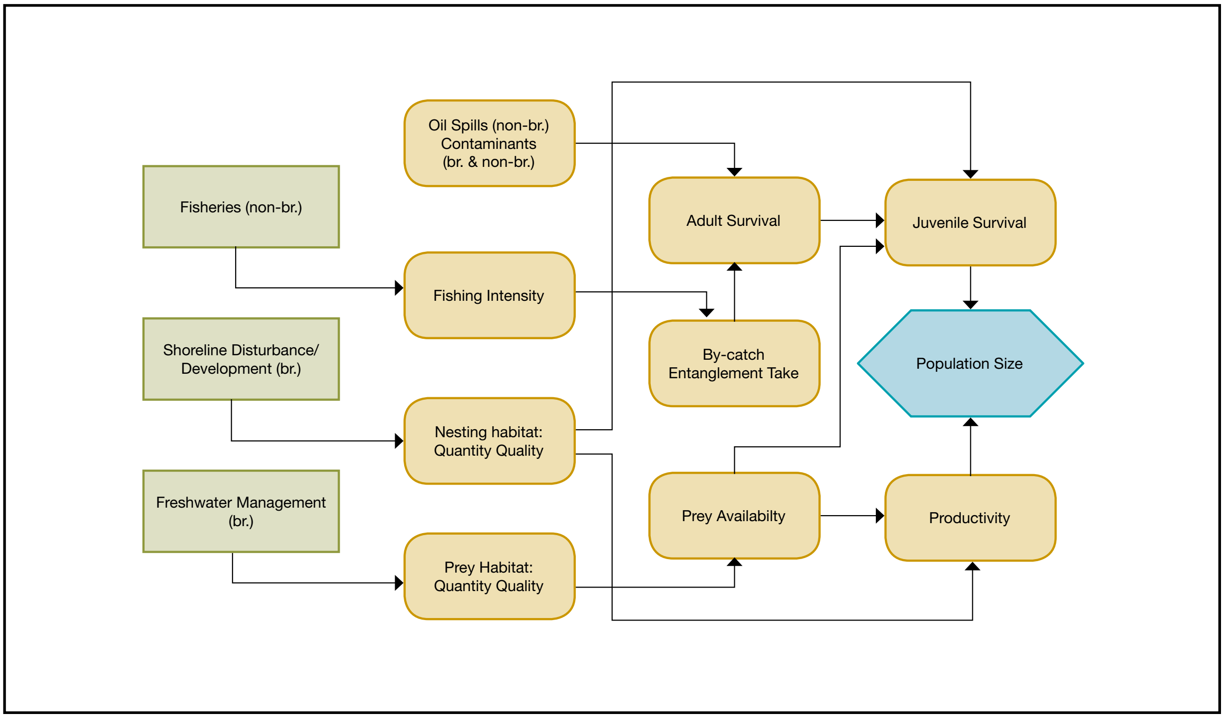

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Black Skimmer** (Rynchops niger) within the Gulf of Mexico Region.*



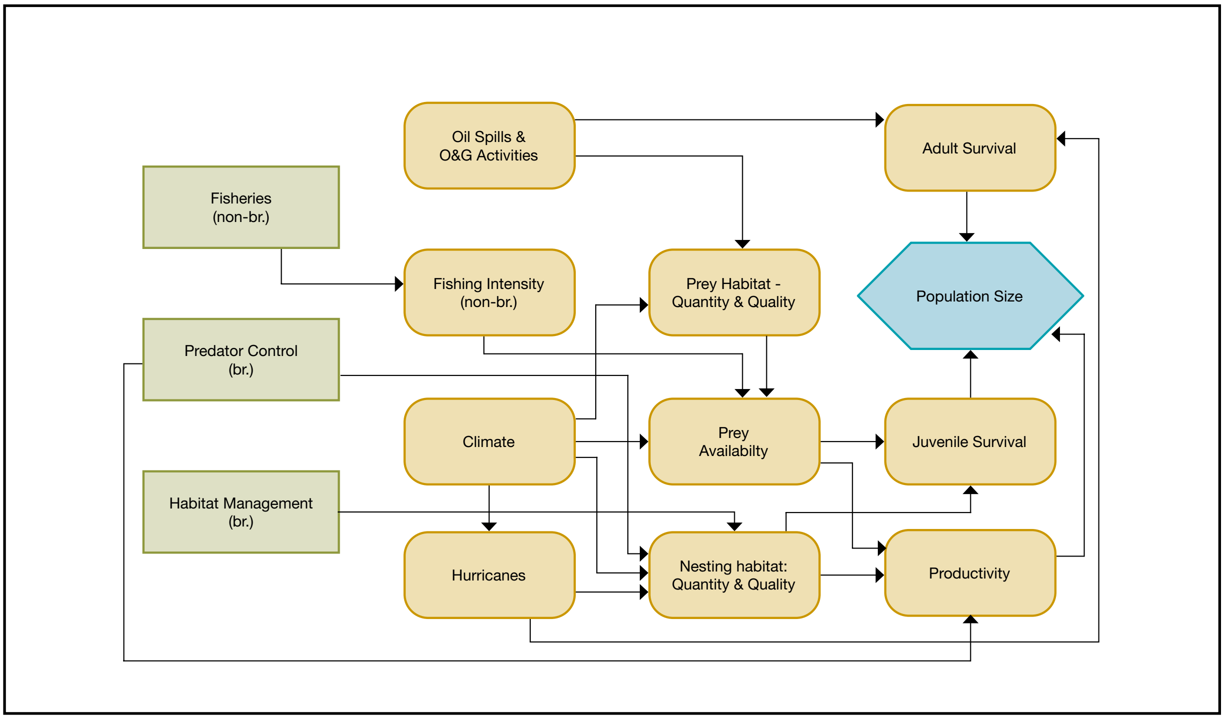

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Common Loon** (Gavia immer) within the Gulf of Mexico Region.*



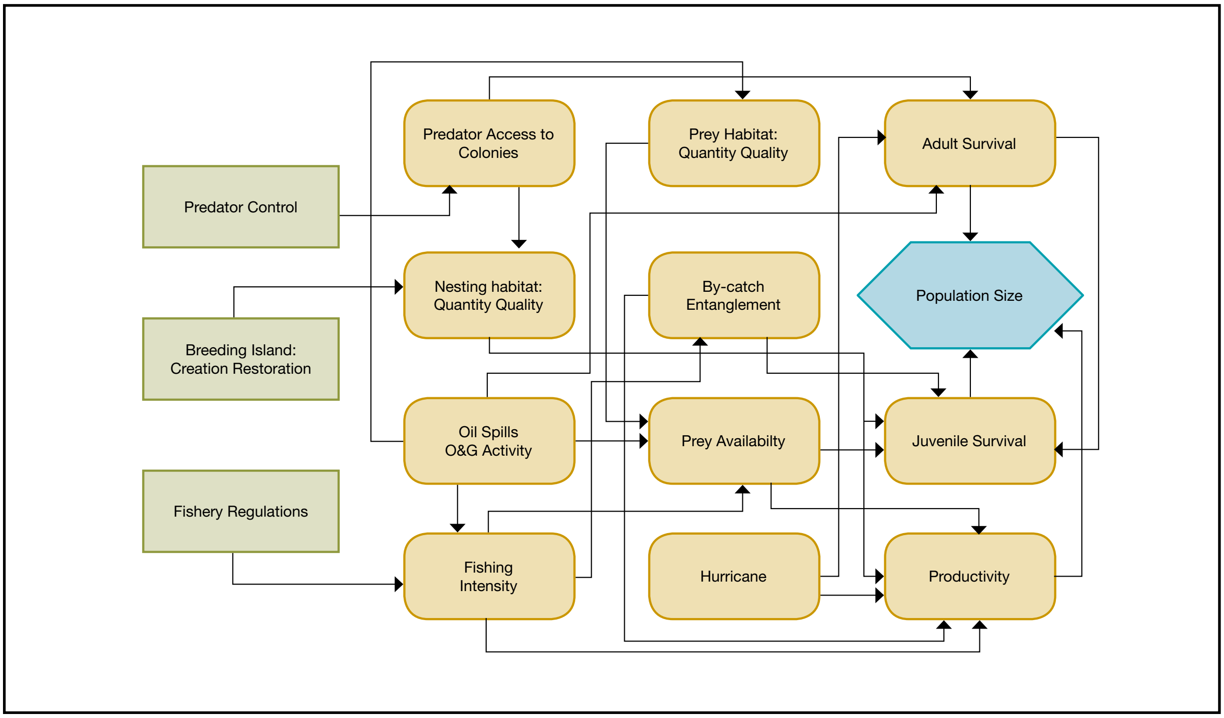

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Audubon's Shearwater** (Puffinus lherminieri) within the Gulf of Mexico Region.*



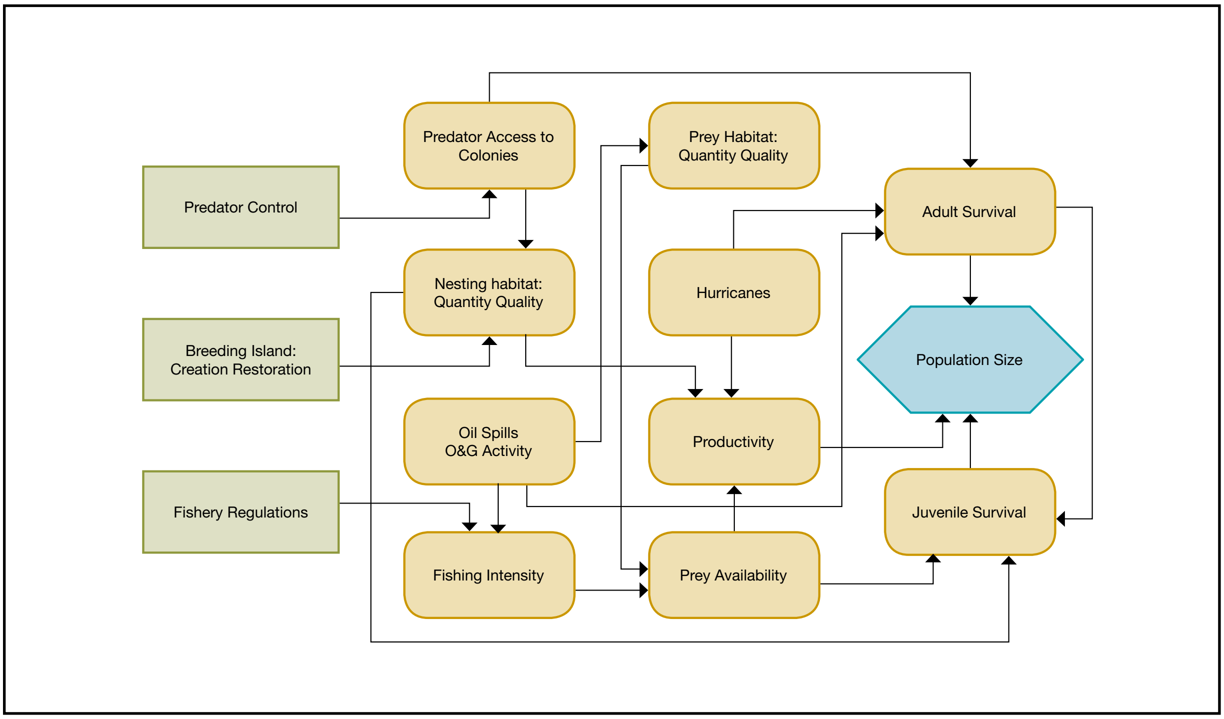

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Band-rumped Storm-Petrel*** *(Oceanodroma castro) within the Gulf of Mexico Region.*



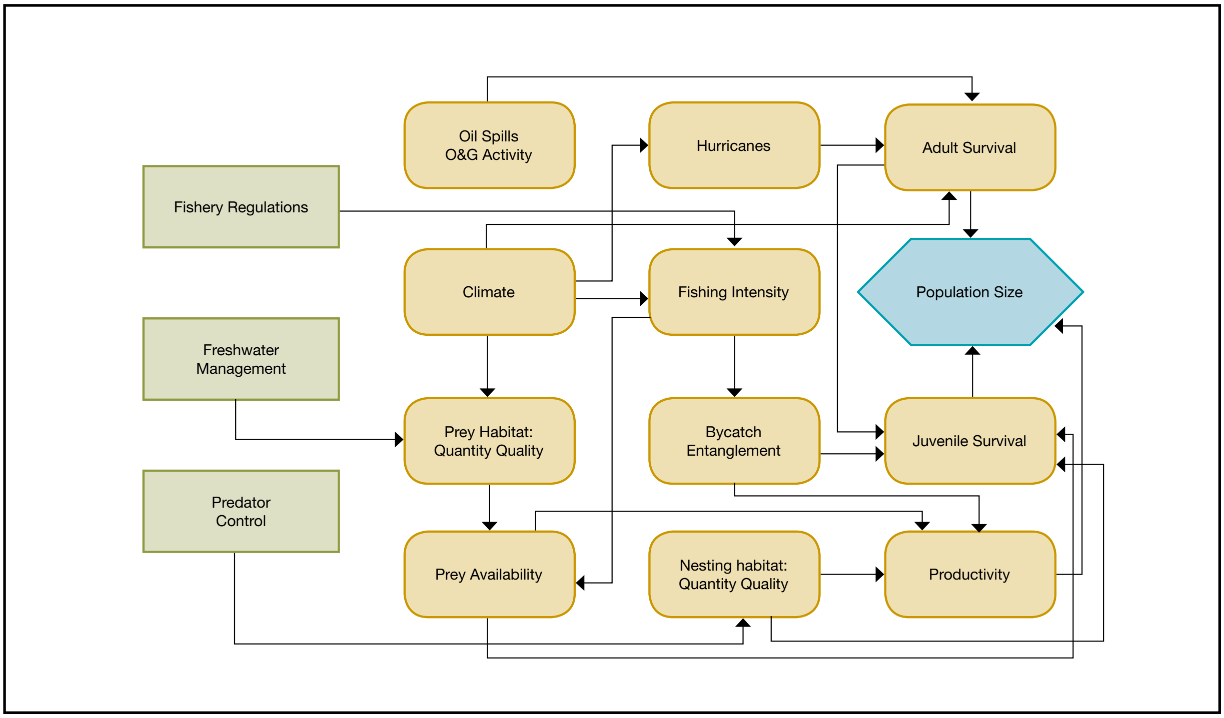

*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Black-capped Petrel*** *(Pterodroma hasitata) within the Gulf of Mexico Region.*




*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Magnificent Frigatebird*** *(Fregata magnificens) within the Gulf of Mexico Region.*




*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Masked Booby*** *(Sula dactylatra) within the Gulf of Mexico Region.*




*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Northern Gannet*** *(Morus bassanus) within the Gulf of Mexico Region.*

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