Strategic Bird Monitoring Guidelines
for the Northern Gulf of Mexico

GoMAMN | Gulf of Mexico Avian Monitoring Network

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Strategic Bird Monitoring Guidelines
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Editors:
R. Randy Wilson
U.S. Fish and Wildlife Service, Migratory Bird Program, Southeast Region

Auriel M. V. Fournier
Mississippi State University; Forbes Biological Station-Bellrose Waterfowl Research Center, Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign

Jeffrey S. Gleason
U.S. Fish and Wildlife Service, Migratory Bird Program-Gulf Restoration Office, Southeast Region

James E. Lyons
U.S. Geological Survey, Patuxent Wildlife Research Center

Mark S. Woodrey
Mississippi State University, Coastal Research and Extension Center; Grand Bay National Estuarine Research Reserve

The Gulf of Mexico Avian Monitoring Network is a self-directed, non-regulatory network of conservation professionals. Partners within the Network share information and expertise to facilitate and coordinate development of monitoring plans that address contemporary and future needs of bird populations and their habitats across the northern Gulf of Mexico region.

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Preface

Under the auspices of the RESTORE Act of 2012 and the Deepwater Horizon Oil Spill: Final Programmatic Damage Assessment and Restoration Plan, the conservation objective in the northern Gulf of Mexico is to enhance and conserve habitat to support and sustain healthy populations of natural resources, including migratory birds. Billions of migratory birds representing >500 species use the northern Gulf of Mexico for all or part of their annual life-cycle, thereby underpinning the importance of the Gulf region in supporting not only local, but also continental and international populations of birds. However, birds and their habitats continue to be vulnerable to a variety of system stressors such as urban and industrial development, offshore energy development, contaminants (e.g., point and non-point sources), altered hydrological processes, natural disturbance events (e.g., hurricanes), and climate change (e.g., sea-level rise). The large-scale restoration work underway in the northern Gulf of Mexico presents many opportunities to mitigate these threats and advance bird-habitat conservation. However, to capitalize on these opportunities, decision makers and practitioners need information related to avian ecology and guidance for developing monitoring strategies that will establish baselines, evaluate management effectiveness, and increase our understanding of how ecological processes influence bird responses to habitat restoration practices.

Monitoring data are most valuable to decision makers when collected in a cost-efficient and scientifically robust manner that facilitates learning and is relevant to stakeholder needs and values. To that end, the Gulf of Mexico Avian Monitoring Network hosted a series of workshops and used the principles of structured decision making to identify core values and objectives supporting stakeholder data needs. Throughout these workshops, stakeholders agreed that bird-monitoring efforts should address three fundamental objectives: 1) maximize the relevancy of monitoring data, 2) maximize the scientific rigor underpinning monitoring, and 3) maximize integration of monitoring efforts. Relevancy speaks to the desire for status and trend assessments, greater understanding of management effectiveness, and greater understanding of how ecological processes affect birds and their habitats. Further, species experts subsequently used these core values and fundamental objectives in concert with conceptual models (i.e., influence diagrams) to identify key monitoring needs and uncertainties underpinning our ability to advance restoration and conservation actions. Collectively, these fundamental objectives and conceptual models reflect, "what matters" about the design and implementation of future bird monitoring activities.

This document summarizes the stakeholder workshops and subsequent discussions. To facilitate readability and transfer of information, the document includes a number of topical chapters that collectively represents Strategic Bird Monitoring Guidelines for the northern Gulf of Mexico. Specifically, the guidelines contain: 1) an overview of core-values and fundamental bird monitoring objectives, 2) an overview of threats, challenges, conceptual models for priority species, and associated uncertainties for seven taxonomic groups (i.e., landbirds, marsh birds, raptors, seabirds, shorebirds, wading birds, and waterfowl), 3) an overview of avian health and physiological stressors, and 4) an overview of integration and data management challenges. Each chapter also identifies priority-monitoring activities and puts forth recommendations to facilitate decision-making and advance bird conservation across the northern Gulf of Mexico.

To our knowledge, these Strategic Bird Monitoring Guidelines represent the first comprehensive, Gulf-wide monitoring framework for any living marine resources in the northern Gulf of Mexico. However, for it to be fully successful, the bird monitoring community of practice must collaborate and integrate monitoring efforts with other monitoring communities of practice. For example, to understand patterns and trends in bird response will also require an understanding of food resource availability (e.g., fisheries), changes in habitat (e.g., loss of emergent marsh), and/or changes in climate-related events (e.g., sea-level rise). Hence, it is imperative that monitoring efforts operate in a holistic and integrated fashion. The information presented herein provides a clear vision of the data needs related to bird monitoring. It is our hope that these Strategic Bird Monitoring Guidelines serve as a useful tool to guide decision-making and future bird monitoring efforts, and places those activities in the larger context of holistic restoration across the northern Gulf of Mexico.

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Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

WHY STRATEGIC BIRD MONITORING GUIDELINES FOR THE GULF OF MEXICO?

AUTHORS:

R. Randy Wilson (1*)
Mark S. Woodrey (2,3)
Auriel M. V. Fournier (3,4)
Jeffrey S. Gleason (5)
James E. Lyons (6)

1. U.S. Fish and Wildlife Service, Migratory Bird Program, Southeast Region, Jackson, MS
2. Grand Bay National Estuarine Research Reserve, Moss Point, MS
3. Mississippi State University, Coastal Research and Extension Center, Biloxi, MS
4. Forbes Biological Station–Bellrose Waterfowl Research Center, Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Havana, IL
5. U.S. Fish and Wildlife Service, Migratory Bird Program, Southeast Region, Chiefland, FL
6. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD

(*) Corresponding author: randy_wilson@fws.gov

Bird survey. Photo credit: U.S. Fish and Wildlife Service

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WHY STRATEGIC BIRD MONITORING GUIDELINES FOR THE GULF OF MEXICO?

DECISION CONTEXT

THE LARGE-SCALE RESTORATION WORK UNDERWAY in the northern Gulf of Mexico as a result of the 2010 Deepwater Horizon (DWH) oil spill settlement—work that is conducted under the auspices of the RESTORE Act of 2012, Natural Resource Damage Assessment Trustee Council, and National Fish and Wildlife Foundation (NFWF)—presents opportunities to further avian conservation and recovery in the region and improve monitoring of bird populations and their habitats. Collectively, state and federal agencies in partnership with numerous conservation organizations and citizen groups are making tremendous conservation investments to implement restoration projects to benefit birds and their habitats along the coast of Florida, Alabama, Mississippi, Louisiana, and Texas (Baldera et al. 2018). To maximize benefits of these restoration projects, decision makers need access to information related to avian ecology and strategies for evaluating restoration effectiveness (Burger 2018, Baldera et al. 2018).

Currently there are no legal, regulatory or political underpinnings per se to the implementation of a comprehensive bird monitoring strategy for the Gulf of Mexico. However, the Oil Pollution Act of 1990 (Publ. L. 101-380) requires restoration project monitoring and the Deepwater Horizon Programmatic Damage Assessment and Restoration Plan (DHNRDAT 2016) commits the Trustees to a robust monitoring and adaptive management framework. Additionally, several federal and state wildlife agencies have legal mandates to protect and conserve wildlife resources and their habitats for the continuing benefit of the American people. Hence, the success of designing and implementing a collaborative and integrated monitoring strategy for the Gulf of Mexico requires the commitment and dedication of a wide array of conservation partners (e.g., federal agencies, state wildlife agencies, non-governmental organizations, and joint venture partnerships), all operating under different mandates, missions, and budget constraints.

To that end, these Strategic Bird Monitoring Guidelines serve as a tool to identify needs and provide monitoring recommendations to advance collaborative and integrated bird monitoring efforts along the northern Gulf of Mexico.

Recognizing the need to: (1) increase coordination and collaboration across a multitude of stakeholders and partners; and (2) embrace a more formalized means of coordinating and integrating avian monitoring activities, the Gulf of Mexico Avian Monitoring Network (GoMAMN) was established. Representing a variety of agencies and organizations with interest in the Gulf of Mexico, this self-directed, non-regulatory network of conservation partners used the principles of decision theory (Keeney 1982, 1992) and facilitated structured decision making workshops (Lyons et al. 2008, Conroy and Peterson 2013) to identify a suite of monitoring objectives and evaluation criteria to inform prioritization of future monitoring activities. Collectively, these objectives and associated evaluation criteria define "what matters" about monitoring decisions, drive the search for creative alternatives, and become the framework for comparing alternatives (Gregory et al. 2012). An initial product of these workshops was a consensus fundamental problem statement from GoMAMN partners:

"How does the conservation community develop a cost-effective monitoring strategy for the Gulf Coast avian community and ecosystem that evaluates ongoing conservation activities and chronic and acute threats; maximizes learning; and is flexible and holistic enough to detect novel ecological threats with respect to management triggers and to evaluate new and emerging conservation activities?"

To address this question, GoMAMN partners decided that the purpose of GoMAMN is to develop collaborative, integrated avian monitoring across the northern Gulf of Mexico.

Specifically, GoMAMN strives to:

1. Create and maintain a forum by which stakeholders can coordinate and integrate monitoring efforts for birds and their habitats;
2. Establish clearly articulated core-values, data needs, and fundamental objectives underpinning monitoring efforts;

3. Facilitate the implementation of cost-effective yet scientifically robust regional monitoring plans;
4. Standardize data collection and data management efforts that support adaptive management.

Resulting from a successful forum for coordination and communication (i.e., GoMAMN), these Strategic Bird Monitoring Guidelines outline the contemporary thinking related to the identification of fundamental objectives, core-values, and data needs that serve as foundational pieces of avian monitoring in the northern Gulf of Mexico. GoMAMN partners envision a Community of Practice working collaboratively across partners and programs (Figure 1.1) to leverage existing resources, capacities, and expertise to develop and implement a collaborative Gulf-wide avian monitoring program to address these objectives and data needs as a means to inform and advance bird-habitat conservation as part of the broader Gulf restoration efforts. Additionally, GoMAMN partners foresee a higher-level of coordination across the various monitoring committees supporting Gulf Restoration (Figure 1.1), such that bird monitoring objectives, values, and data needs are communicated across initiatives, stakeholders, and decision makers. Coordination and integration of monitoring efforts could maximize the usefulness of bird monitoring data to inform Gulf restoration activities and evaluate restoration success. Here, we provide additional information that serves as both functional sideboards and foundational aspects of the Strategic Bird Monitoring Guidelines for the northern Gulf of Mexico.

Spatial Scope

The geography covered by these Strategic Bird Monitoring Guidelines is the northern half of the Gulf of Mexico including an inland buffer across the five Gulf States (Figure 1.2). The geographic extent is bounded on the Gulf side by the southern edge of the Marine Bird Conservation Region (#20) that equates to the United States Environmental Economic Zone (EEZ) with the inland extent defined by the RESTORE Act (i.e., individual state boundary from the Coastal Zone Management Act of 1972 [Publ. L. 109-58]), plus a 25 mile inland buffer, except in Florida, where the east-southeastern extent is defined by the Florida Water Management District boundaries (Florida Department of Environmental Protection 2018) excluding the Northeast Florida Water Management District.

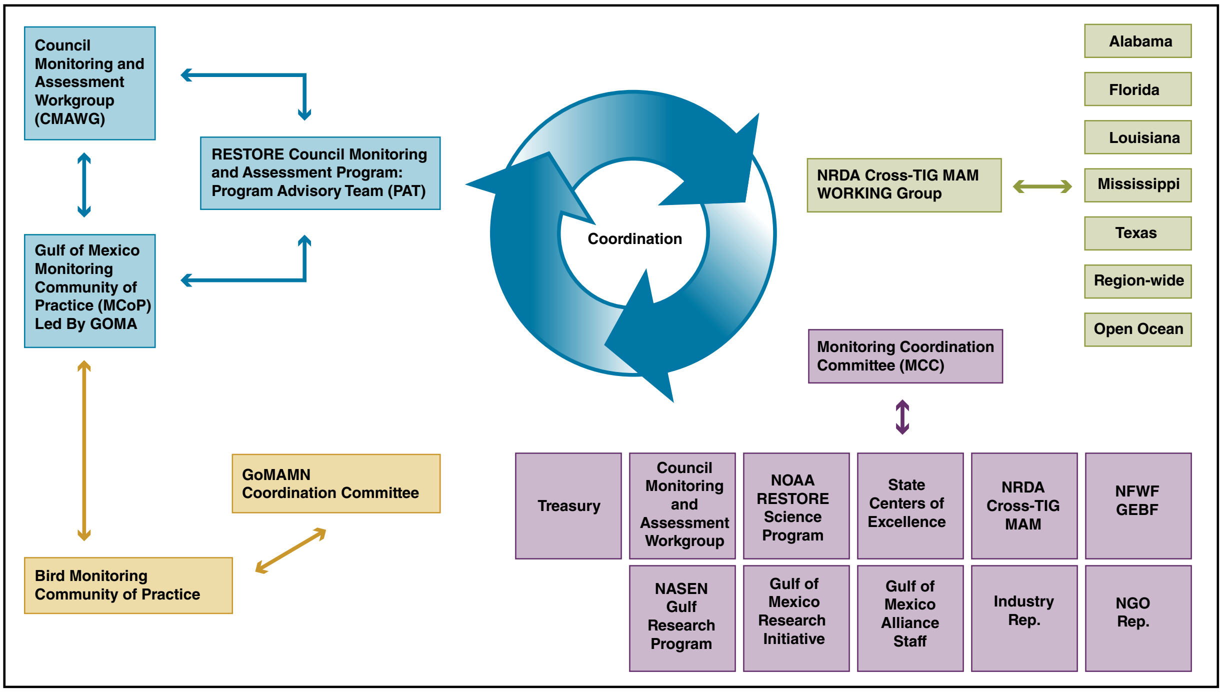

Figure 1.1. *Schematic depicting position of Gulf of Mexico Bird Monitoring Network within the contemporary infrastructure to facilitate cross-program coordination and implementation of monitoring activities across the northern Gulf of Mexico (cross-program infrastructure model adapted from RESTORE Council internal work product, February 2018).*

Figure 1.2. *Geographical boundary used to define bird monitoring objectives and priorities in the Northern Gulf of Mexico.*

Temporal Scope

The information presented within the Strategic Bird Monitoring Guidelines reflects our current knowledge and experiences related to avian populations and information needs. Given the dynamic nature of natural and human systems, and therefore conservation needs, it is imperative that the conservation community refines and modifies these monitoring recommendations as additional knowledge becomes available. To that end, we envision these guidelines as a living-document, that will be updated every five years to reflect our increased knowledge and understanding of how bird populations respond to restoration activities and underlying ecological processes. Moreover, many of the monitoring recommendations and core values put forth herein, are rooted in the application of an adaptive management framework. While it is possible to reduce uncertainty via an adaptive management framework in a relatively short-time period (circa 5 years or less), it is also important to recognize the long-term commitment (>20 years) required to understand and reduce uncertainty associated with underlying ecological processes impacting bird populations. This long-term planning horizon (>20 years) coupled with intervening, short-term updates and revisions (e.g., every 5 years) facilitates an adaptive planning framework to guide future restoration and monitoring activities across the northern Gulf of Mexico.

Birds of Conservation Concern

To facilitate communication among stakeholders, partners, decision makers, and land managers, GoMAMN partners developed a list of avian species in need of conservation across the northern Gulf of Mexico ecosystem (see Appendix 1). To compile the list, we used the following rules: (1a) a species must be identified on ≥50% of the five Gulf-facing State Wildlife Action Plans (SWAPs): Florida, Alabama, Mississippi, Louisiana, and Texas; (1b) species that met criteria for rule 1a, were further reviewed and vetted to remove any non-coastal species (e.g., bird species not occurring in coastal habitats); and (2) due to the fact many States did not consider seabirds in their SWAPs, a sub-set of pelagic seabirds were identified, vetted through the GoMAMN Seabird Working Group, and added to the list. Additional information can be found within the respective State SWAPs or by contacting the authors of chapters 3–9.

The final list includes 68 bird species that warrant special attention due to their population status (i.e., Threatened or Endangered, declining population trends, range restrictions, or % of population using the Gulf of Mexico). Hence, this list differs fundamentally from the list of birds published within the DHNRDAT 2016; Table 4.7-3 and subsequent Bird Strategic Framework (DHNRDAT 2017) due to method of derivation and intended uses. The list generated by GoMAMN is intended to take a more holistic approach and identify avian species of greatest conservation concern in the Gulf region, whereas the DWH-PDARP and Bird Strategic Framework only identifies those species injured during the DWH oil spill. Nevertheless, there is considerable overlap (28 species occur on both lists) between the two lists. As such, decision makers and land managers now have two complementary lists to guide their decision making: one that provides a holistic overview of avian species in need of conservation and one that speaks directly to the recovery of injured resources.

Land Cover Classification

Due to the complexity and variety of ecological systems within the northern Gulf of Mexico, a common nomenclature is warranted to facilitate and standardize communication among stakeholders, partners, and decision makers. To this extent, GoMAMN has adopted the ecological systems nomenclature used by NOAA's Coastal Change Analysis Program (C-CAP) with modifications to better define marine systems and upland open pine systems for GoMAMN purposes (see Appendix 2). Modifications are based upon marine classifications identified within the Coastal and Marine Ecological Classification Standard (Federal Geographic Data Committee, Marine and Coastal Spatial Data Subcommittee 2012) and open pine classifications identified by Nordman et al. (2016). Due to these modifications, some land cover classes (e.g., pine flatwoods, oyster reefs, etc.) are currently not mappable using remote sensing techniques. Nevertheless, we include them within these Strategic Bird Monitoring Guidelines as important land cover classes that support a number of bird species. It is our hope that technological advances will soon permit the remote sensing-based mapping of these important land cover classes. In the interim, users are encouraged to use finer-scale data sets where applicable, e.g., Coastwide Reference Monitoring System (Steyer et al. 2003) and System-wide Assessment and Monitoring Program (Hijuelos et al. 2013).

Using These Strategic Guidelines

Using GoMAMN as a forum to coordinate and collaborate, partners in the Gulf region identified a suite of objectives and associated evaluation criteria through a series of stakeholder workshops. Collectively, these objectives and evaluation criteria have been used to develop Strategic Bird Monitoring Guidelines to facilitate monitoring efforts as the collective Gulf of Mexico restoration enterprise undertakes holistic ecosystem restoration. Specifically, these Strategic Bird Monitoring Guidelines provides greater insight into the fundamental objectives and core values required to advance bird monitoring activities (see Chapter 2), and identifies key data gaps and uncertainties about avian populations across the northern Gulf of Mexico (see Chapters 3–9). The authors of chapters 3–9, in consultation with other subject matter experts, used the fundamental objectives and core values identified by GoMAMN partners as the guiding principles to articulate the most urgent information needs (i.e., our highest priority bird monitoring activities). As such, each chapter was written in a manner to facilitate decision making at multiple levels—from the program manager trying to figure out what information is needed to the field biologist designing and implementing surveys. Furthermore, with the emphasis on integrated and coordinated monitoring, information from this document could also inform decision making not only within but also across organizational boundaries.

Reducing uncertainty and filling the identified data gaps requires field biologists and program managers to reassess traditional monitoring activities by placing greater emphasis on the core values and priorities identified within this report (e.g., working collaboratively to design and implement monitoring efforts across state boundary lines to address a mutual objective). Noteworthy here, these Strategic Bird Monitoring Guidelines do not provide specific survey design and sampling protocols. Given the vast number of data needs across a variety of avian species and habitats, the development and presentation of species-specific survey designs and sampling protocols is beyond the scope of this report; when appropriate, we direct the reader to existing, nationally recognized sampling protocols. It is our hope that program managers and field biologists will embrace GoMAMN as a forum to collaborate and integrate expertise in the design and implementation of future monitoring activities.

The monitoring recommendations outlined within these Strategic Bird Monitoring Guidelines are not regulatory or administratively prescriptive. Instead, they are advisory in nature, with the expectation that they will be incorporated to improve avian conservation through coordinated and collaborative monitoring efforts being implemented by partners, stakeholders, and administrative programs across the northern Gulf of Mexico region. The information presented within these Strategic Bird Monitoring Guidelines reflects over four years of structured and facilitated discussions based on decades of practical, hands-on experience from greater than 100 biologists, land managers, and program administrators. It is our hope that the compilation and synthesis of literature and knowledge presented within these Strategic Bird Monitoring Guidelines will serve as core components to maximize the usefulness of bird data to inform conservation decisions as well as to promote collaborative and integrated monitoring efforts across the northern Gulf of Mexico.

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APPENDIX 1

Gulf of Mexico Avian Monitoring Network Birds of Conservation Concern. Table includes residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).

Common Name	Monitoring Group	PIF Trend[a]	PIF Continental Concern[a]	PIF-Status[a]	Breeding	Wintering	Migratory	Landcover Association(s)[b]
Mottled Duck	Waterfowl	5	17	Watchlist - Red	X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes)
Northern Pintail	Waterfowl	4	12			X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal
Lesser Scaup	Waterfowl	4	11			X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine-Open Water, Marine-Nearshore
Northern Bobwhite	Landbird	5	12	Steep Decline	X	X		Upland Scrub/Shrub, Grassland, Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Mesic Longleaf Pine Flatwoods, Xeric Longleaf Pine Barrens; fire-maintained)
Common Ground-Dove	Landbird	3	9		X	X		Upland Scrub/Shrub, Estuarine Scrub/Shrub, Beach/Dune
Chuck-will's-Widow	Landbird	5	12	Steep Decline	X	X		Upland Mixed Forest, Upland Evergreen Forest
Yellow Rail	Marsh Bird	3	15	Watchlist - Yellow [R]		X		Palustine Emergent Wetland, Estuarine Emergent Wetland, Upland Evergreen Forest (Wet Longleaf & Slash Pine Flatwoods & Savannas)
Black Rail	Marsh Bird	5	17	Watchlist - Red	X	X		Palustine Emergent Wetland, Estuarine Emergent Wetland
King Rail	Marsh Bird	5	15	Watchlist - Yellow [D]	X	X		Palustrine Emergent Wetland
FL Sandhill Crane[UR, FL] (state listed)	Wading Bird	3*	17*	Watchlist - Yellow [R]	X	X		Palustrine Emergent Wetland, Lacustrine/Riverine, Grassland, Upland Evergreen Forest (Wet Longleaf & Slash Pine Flatwoods & Savannas)
MS Sandhill Crane[T&E]	Wading Bird	1*	15*	Watchlist - Yellow [R]	X	X		Palustrine Emergent Wetland, Lacustrine/Riverine, Grassland, Upland Evergreen Forest (Wet Longleaf & Slash Pine Flatwoods & Savannas)
Whooping Crane[T&E]	Wading Bird	1	16	Watchlist - Yellow [R]	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal (saltmarshes, shallow bays, & exposed tidal flats; also harvested cropfields & pasturelands)
American Oyster-catcher	Shorebird	3	14	Watchlist - Yellow [R]	X	X		Estuarine-Coastal
Piping Plover[T&E]	Shorebird	5	18	Watchlist - Red		X	X	Estuarine-Coastal, Beach/Dune
Wilson's Plover	Shorebird	4	16	Watchlist - Yellow [R]	X		X	Estuarine-Coastal, Beach/Dune
Snowy Plover	Shorebird	4	15	Watchlist - Yellow [D]	X	X		Estuarine-Coastal, Beach/Dune

Appendix 1 (continued).

Common Name	Monitoring Group	PIF Trend[a]	PIF Continental Concern[a]	PIF-Status[a]	Breeding	Wintering	Migratory	Landcover Association(s)[b]
Long-billed Curlew	Shorebird	2	12			X	X	Estuarine-Tidal Riverine Coastal, Estuarine-Coastal (during migration habitat may include: dry short-grass prairie, wetlands associated with alkali lakes, playa lakes, wet coastal pasture, tidal mudflats, saltmarsh, alfalfa fields, barley fields, fallow agriculture fields, & harvested rice fields)
Marbled Godwit	Shorebird	3	14	Watchlist - Yellow [R]		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Beach/Dune, Grassland (heavily to over-grazed pastures, sod farms, fallow dry fields w/ limited stem height & little inundation): coastal mudflats adjoining savannas or meadows, estuaries, alkali ponds, sandy beaches, & sandflats
Red Knot[T&E]	Shorebird	5	13	Watchlist - Yellow [D]		X	X	Estuarine-Coastal, Beach/Dune
Dunlin	Shorebird	4	11			X	X	Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Beach/Dune
Buff-breasted Sandpiper	Shorebird	4	14	Watchlist - Yellow [D]			X	Grassland (heavily to over-grazed pastures, sod farms, fallow dry fields w/ limited stem height & little inundation)
Western Sandpiper	Shorebird	3	12			X	X	Palustrine Emergent Wetland (exposed margins), Estuarine Emergent Wetland (exposed margins), Estuarine-Coastal (intertidal mud & sandflats, roosting during high tide on exposed tussocks in the saltmarsh)
Sooty Tern	Seabird	3	9		X		X	Beach/Dune, Estuarine-Open Water, Marine-Nearshore, Marine-Offshore, Marine-Oceanic
Least Tern[1]	Seabird	4	14	Watchlist - Yellow [D]	X		X	Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Coastal, Beach/Dune
Gull-billed Tern	Seabird	4	13		X		X	Estuarine-Coastal, Estuarine-Coastal Riverine Coastal, Beach/Dune
Royal Tern	Seabird	2	11		X	X		Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine Open Water, Marine-Nearshore, Beach/Dune
Sandwich Tern	Seabird	2	11		X	X		Estuarine-Tidal Riverine Coastal, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine Open Water, Beach/Dune
Black Skimmer	Seabird	5	14	Watchlist - Yellow [D]	X	X		Estuarine-Coastal
Common Loon	Seabird	1	9			X	X	Lacustrine/Riverine, Estuarine-Open Water, Marine-Nearshore
Audubon's Shearwater	Seabird	4	14	Watchlist - Yellow [D]			X	Marine-Offshore, Marine-Oceanic
Band-rumped Storm-Petrel	Seabird	4	17	Watchlist - Red			X	Marine-Offshore, Marine-Oceanic
Black-capped Petrel[T&E, IUCN]	Seabird	5	20	Watchlist - Red			X	Marine-Offshore, Marine-Oceanic

Appendix 1 (continued).

Common Name	Monitoring Group	PIF Trend[a]	PIF Continental Concern[a]	PIF-Status[a]	Breeding	Wintering	Migratory	Landcover Association(s)[b]
Wood Stork[T&E]	Wading Bird	3	12				X	Palustrine Forested Wetland (bottomland hardwoods), Palustrine Emergent Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland; utilizes freshwater aquaculture ponds (catfish, crawfish)
Magnificent Frigatebird	Seabird	4	16	Watchlist - Yellow [R]	X		X	Marine-Nearshore, Marine-Offshore
Masked Booby	Seabird	3	12		X		X	Marine-Nearshore, Marine-Offshore, Marine-Oceanic
Northern Gannet	Seabird	1	10			X		Estuarine-Open Water, Marine-Nearshore, Marine-Offshore
Brown Pelican	Seabird	1	10		X	X		Estuarine-Coastal, Estuarine-Open Water, Estuarine-Tidal Riverine Open Water, Marine-Nearshore, Marine-Offshore
American Bittern	Marsh Bird	4	12		X	X	X	Palustrine Emergent Wetland
Least Bittern	Marsh Bird	3	10		X		X	Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes)
Snowy Egret	Wading Bird	1	7		X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland, Palustrine Forested Wetland, Palustrine Scrub/Shrub Wetland, Estuarine Forested Wetland, Estuarine Scrub/Shrub Wetland, Estuarine-Tidal Riverine Coastal
Little Blue Heron	Wading Bird	4	11		X		X	Palustrine Forested Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland
Tricolored Heron	Wading Bird	2	11		X	X		Estuarine Emergent Wetland, Estuarine Forested Wetland, Estuarine Scrub/ Shrub Wetland, Estuarine-Tidal Riverine Coastal
Reddish Egret	Wading Bird	3	15	Watchlist - Yellow [R]	X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Estuarine Scrub/ Shrub, Estuarine-Coastal
Osprey	Raptor	1	7		X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Estuarine Forested Wetland, Estuarine-Tidal Riverine Open Water
Swallow-tailed Kite	Raptor	3	12		X		X	Palustrine Forested Wetland (bottomland hardwoods), Lacustrine/ Riverine, Estuarine Forested Wetland, Upland Evergreen Forest (Wet Longleaf and Slash Pine Flatwoods & Savannas); in se. U.S., nesting & foraging habitat includes various combinations of managed pine forest, hydric pinelands with understory of wetland plants, pine fringe of floodplain & hardwood swamp forests, cypress swamp, wet prairies, freshwater & brackish marshes, hardwood hammocks, tall trees edging sloughs & bayous, mixed cypress-hardwood swamp forest, & mangrove forest
Bald Eagle	Raptor	1	9		X	X		Palustrine Forested Wetland, Estuarine Forested Wetland

Appendix 1 (continued).

Common Name	Monitoring Group	PIF Trend[a]	PIF Continental Concern[a]	PIF-Status[a]	Breeding	Wintering	Migratory	Landcover Association(s)[b]
Short-eared Owl	Raptor	5	12	Steep Decline		X		Grassland, Upland Scrub/Shrub, Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Xeric Longleaf Pine Barrens), Beach/Dune
Red-headed Woodpecker	Landbird	5	13	Watchlist - Yellow [D]	X	X		Upland Deciduous Forest, Upland Mixed Forest
Red-cockaded Wood-pecker[T&E]	Landbird	5	18	Watchlist - Red	X	X		Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Mesic Longleaf Pine Flatwoods, Wet Longleaf & Slash Pine Flatwoods & Savannas; fire-maintained)
SE American Kestrel[2, FL] (state listed)	Raptor	4*	17*	Watchlist - Yellow [R]	X	X		Upland Deciduous Forest, Upland Mixed Forest, Upland Scrub/Shrub
Peregrine Falcon	Raptor	2	10			X	X	Lacustrine/Riverine, Estuarine Forested Wetland, Estuarine Shrub/Scrub Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Beach/Dune
Loggerhead Shrike	Landbird	5	12	Steep Decline	X	X		Upland Scrub/Shrub, Upland Evergreen Forest (Xeric Longleaf Pine Barrens), Beach/Dune
Brown-headed Nuthatch	Landbird	4	13		X	X		Upland Evergreen Forest
Sedge Wren	Marsh Bird	1	7			X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Upland Evergreen Forest (Wet Longleaf & Slash Pine Flatwoods & Savannas)
Marsh Wren	Marsh Bird	1	7		X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes)
Wood Thrush	Landbird	5	14	Watchlist - Yellow [D]	X		X	Upland Deciduous Forest, Upland Mixed Forest
Louisiana Waterthrush	Landbird	2	12		X		X	Upland Deciduous Forests (with med-high gradient 1st to 3rd order flowing streams/rivers), Palustrine Forested Wetland (bottomland hardwoods)
Prothonotary Warbler	Landbird	4	14	Watchlist - Yellow [D]	X		X	Palustrine Forested Wetland (bottomland hardwoods)
Swainson's Warbler	Landbird	1	13		X		X	Upland Deciduous Forest, Upland Mixed Forest, Upland Evergreen Forest, Palustrine Forested Wetland (bottomland hardwoods)
Yellow-throated Warbler	Landbird	2	10		X	X	X	Upland Deciduous Forest, Upland Mixed Forest, Upland Evergreen Forest
Bachman's Sparrow	Landbird	5	16	Watchlist - Red	X	X		Upland Evergreen Forest
Grasshopper Sparrow[3]	Landbird	5	12	Steep Decline	X	X		Grassland
Henslow's Sparrow	Landbird	3	14	Watchlist - Yellow [R]		X		Upland Evergreen Forest (Wet Longleaf & Slash Pine Flatwoods & Savannas; fire-maintained)
Le Conte's Sparrow	Landbird	5	13	Watchlist - Yellow [D]		X		Grassland
Nelson's Sparrow	Marsh Bird	1	12			X	X	Estuarine Emergent Wetland
Seaside Sparrow[4]	Marsh Bird	2	14	Watchlist - Yellow [R]	X	X		Estuarine Emergent Wetland

Appendix 1 (continued).

Common Name	Monitoring Group	PIF Trend[a]	PIF Continental Concern[a]	PIF-Status[a]	Breeding	Wintering	Migratory	Landcover Association(s)[b]
Painted Bunting	Landbird	3	11		X		X	Upland Deciduous Forest, Upland Mixed Forest, Upland Scrub/Shrub, Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Mesic Longleaf Pine Flatwoods, Dry & Mesic Hilly Pine Woodlands)
Rusty Blackbird	Landbird	5	12	Steep Decline		X		Upland Evergreen Forest, Grassland, Upland Scrub/Shrub, Palustrine Forested Wetland (bottomland hardwoods); forages in stubble fields, pasture lands, plowed & idle fallow fields, and swamp borders, wet woodlands and pond edges

[a]Derived from Partners in Flight Species Assessment Database (PIF 2019)- http://pif.birdconservancy.org/ACAD/Database.aspx

[b]Used C-CAP or CMEC Classifications- attempted to associate species to discrete habitat type(s) using landcover classes and information from species accounts in the Birds of North America Online- https://birdsna.org/Species-Account/bna/home. Refer to Chapter 1 and Appendix 2 for more information.

[1]This refers to the non-listed coastal breeding population of Least Tern and not the federally-listed Interior Propulation of Least Tern- https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B07N

[2]The SE American Kestrel is not a federally listed species under ESA and the last candidate review was in 1994. However, it is a state-listed (FL) species- https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B072 and http://myfwc.com/media/1515251/threatened-endangered-species.pdf

[3]This refers to the non-listed wintering population of Grasshopper Sparrow and not the breeding population of FL Grasshopper Sparrow that is federally listed- https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B07G

[4]This refers to and includes all of the subspecies/races of breeding Seaside Sparrows in the GoM and not the breeding population of Cape Sable Seaside Sparrow that is federally listed- https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B00Q

[UR]The FL Sandhill Crane is Under Review as per 2011 Petition and is a state-listed (FL) species- https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=B0NM and http://myfwc.com/media/1515251/threatened-endangered-species.pdf

[T&E]Federally listed species, candidate species, or species Under Review- https://www.fws.gov/endangered/

[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

*Derived via expert opinion using rules and criteria setforth in Partners in Flight Species Assessment Technical Handbook (Panjabi et al. 2017)- http://rmbo.org/pubs/downloads/PIF%20Handbook%20Version%202017.pdf

APPENDIX 2

Gulf of Mexico Avian Monitoring Network: Ecological Systems and Landcover Classes.

BROADLY DEFINED ECOLOGICAL SYSTEMS	LANDCOVER CLASSES	DEFINITION
Agricultural Land	Cultivated Crops	Contains areas intensely managed for production of annual crops. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
	Pasture/Hay	Contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Grassland	Grassland/Herbaceous (and wet prairie)	Contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling vegetation, but can be utilized for grazing.
	Pine Savanna	Contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. Pine basal area typically less than 20sq ft/acre.
Forest Land (upland)	Deciduous Forest	Contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of the total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
	Evergreen Forest	See flatwoods and pine barren landcover classes.
	Dry & Mesic Longleaf Flatwoods	Contains open canopies with irregularly scattered longleaf pine, clumps of midstory scrub oaks and a grassy understory.
	Mesic Longleaf Pine Flatwoods	Contains irregularly scattered longleaf pine, slash pine, or south Florida slash pine on sites where soils show a spodic horizon (wet during the winter and dry in the summer) with a herbaceous ground layer.
	Xeric Longleaf Pine Barrens	Contains open woodlands dominated by longleaf pine and a turkey oak or blackjack oak midstory with herbaceous ground layer on consistently dry sites.
Forest Land (Upland)	Mixed Forest	Contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of the total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.
Scrub Land	Scrub/Shrub	Contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
Palustrine Wetlands	Palustrine Forested Wetland	Includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
	Palustrine Shrub/Scrub Wetland	Includes tidal and non tidal wetlands dominated by wood vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.
	Palustrine Emergent Wetland	Includes tidal and non tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. Plants generally remain standing until the next growing season.

Appendix 2 (continued).

BROADLY DEFINED ECOLOGICAL SYSTEMS	LANDCOVER CLASSES	DEFINITION
Estuarine Wetlands	Estuarine Forested Wetland	Includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
Estuarine Wetlands	Estuarine Scrub/Shrub Wetland	Includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
	Estuarine Emergent Wetland	Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 per-cent. Perennial plants usually dominate these wetlands.
Beach / Dune	Beach/Dune	Includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
Water and Submerged Lands	Open Water	Includes areas of open water, generally with less than 25% cover of vegetation or soil. Does not include marine waters; does not include oyster reefs.
	Marine - Nearshore	Includes marine area from landward side to the 30m contour line.
	Marine - Offshore	Includes marine area from 30m contour line to the continental shelf break.
	Marine - Oceanic	Includes marine area from continental shelf break to open ocean.
	Oyster Reefs	Straight or sinuous, ridge-like reefs formed by oysters and typically found in the intertidal zone.
	Palustrine Aquatic Bed	Includes tidal wetlands and deepwater habitats in which salinity due to ocean derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. Total vegetation cover is greater than 80 percent.
Water and Submerged Lands	Estuarine Aquatic Bed	Includes tidal wetlands and deepwater habitats in which salinity due to ocean derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cov-er principally on or at the surface of the water. Total vegetation cover is greater than 80 percent.

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2

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

CHALLENGES, OPPORTUNITIES, AND STAKEHOLDER VALUES

Authors:

Auriel M. V. Fournier (1,2)
Mark S. Woodrey (1,3)
R. Randy Wilson (4*)
Stephanie M. Sharuga (5,6)
David B. Reeves (5,7)

1. Mississippi State University, Coastal Research and Extension Center, Biloxi, MS
2. Forbes Biological Station–Bellrose Waterfowl Research Center, Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Havana, IL
3. Grand Bay National Estuarine Research Reserve, Moss Point, MS
4. U.S. Fish and Wildlife Service, Migratory Bird Program, Southeast Region, Jackson, MS
5. National Academies of Science, Engineering & Medicine / U.S. Fish and Wildlife Service, Gulf Restoration, Southeast Region, Lafayette, LA
6. Genwest Systems, Inc./National Oceanic and Atmospheric Administration, Santa Rosa, CA
7. Gulf Environmental Benefit Fund, National Fish and Wildlife Foundation, Baton Rouge, LA

(*) Corresponding author: **randy_wilson@fws.gov**

Seeking stakeholder input. Photo credit: U.S. Fish and Wildlife Service

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Chapter 2

CHALLENGES, OPPORTUNITIES, & STAKEHOLDER VALUES

CHALLENGES AND OPPORTUNITIES

Spanning the coast of Florida, Alabama, Mississippi, Louisiana and Texas, the coastal habitats and offshore waters comprising the northern Gulf of Mexico represents one of the most ecologically (Burger 2018) and socio-economically (Sumaila et al. 2012) important ecosystems in the world. Collectively, the natural resources in the northern Gulf of Mexico produce approximately 30% of the United States of America's gross domestic product (GCERTF 2011) through offshore oil and gas production, commercial and recreational fishing, and tourism. At the same time, these same coastal habitats and offshore waters are home to thousands of plant and animal species.

The Deepwater Horizon (DWH) oil spill directly impacted birds and their habitats at an unprecedented scale within the northern Gulf of Mexico (DHNRDAT 2016). Early efforts to determine pre-spill baseline conditions for avian resources highlighted the lack of adequate data to inform decision-makers (Love et al. 2015), including the lack of comprehensive, integrated bird data that could be used in: (1) the injury assessment phase of the Natural Resource Damage Assessment across the northern Gulf of Mexico, and (2) the evaluation of bird response to future on-the-ground restoration efforts. However, this environmental disaster has also resulted in an equally unprecedented focus on the Gulf ecosystem and resources to support its restoration and recovery (Baldera et al. 2018), as well as the ability to reduce uncertainty via large-scale coordinated monitoring efforts.

Historically, the conservation community of dedicated scientists and managers within the northern Gulf of Mexico—from on the ground habitat managers and researchers to those making programmatic, region-wide funding allocations—have done an admirable job of monitoring the "species/topic du jour," usually in the form of a short-term, small-spatial scale research projects. However, the conservation community continues to struggle to design and implement a large-scale, coordinated bird monitoring program (Lindenmayer et al. 2012; Leve et al. 2015). Designing such a coordinated, integrated, and collaborative avian monitoring program for this system has many challenges, including but not limited to: (1) the scope and scale of the Gulf ecosystem; (2) the diversity, abundance, and seasonal dynamics of birds using the Gulf; (3) the number of partners and stakeholders with diverse values and objectives; and (4) the proposed level of funding required to successfully design and implement a Gulf-wide long-term avian monitoring program. Yet meeting these challenges are imperative to understanding cause and effect relationships that underscore demographic processes and population trends, as well as providing a basis for evaluating success of Gulf restoration efforts (NASEM 2017).

Birds that use the Gulf of Mexico each year are remarkable natural resources that occupy a wide variety of habitats and ecological niches. Barrier islands, beaches, marshes, grasslands, forests, and the open ocean support hundreds of species and billions of individual birds (Farnsworth and Russell 2007, Moore et al. 2017, Horton et al. 2019). Colonial-nesting waterbirds (Portnoy 1978, 1981) feed near the top of the food chain in shallow water, while overwintering shorebirds forage on mudflats and beaches (Clapp et al. 1983, Withers 2002, Burger 2017). Marsh birds forage for a variety of prey amongst the marsh vegetation at the land-water interface. Coastal habitats provide essential stopover sites for billions of Nearctic-Neotropical migratory birds twice a year (Cohen et al. 2017, Horton et al. 2019). Whereas the bays and associated marsh serve as one of the most important areas on the continent for wintering waterfowl (De Marco et al. 2016, Ward 2017). Unfortunately, the Gulf Coast is increasingly affected by a variety of anthropogenic activities (e.g., land development, pollution, oil spills, sea-level rise/subsidence) and natural events (e.g., tropical storms, hurricanes, and floods) that often affect birds and their use of these habitats.

The value of coastal habitats for birds is sometimes at odds with human needs, creating challenges when determining the best approaches for managing and conserving important habitats and the birds that use them. Anthropogenic and natural disturbances can result in loss, fragmentation, and/or reduced quality of important habitat. Direct loss of habitat can occur because of wetland drainage, hardening shorelines, dredging, and clearing of forest and scrubland areas. In addition to direct habitat loss, urban development along the coast often yields degraded and fragmented habitat that results in increased bird mortality due to increased predators (e.g., feral cats, raccoons), increased collisions with man-made structures and vehicles, introduction of invasive species, reduced and/or competition for food resources (Loss et al. 2015). Climate change also introduces myriad new threats such as shifting faunal community composition (Walther et al. 2002) and sea-level rise drowning emergent marsh vegetation, converting these areas to open water with resulting impacts on coastal birdlife (Rush et al. 2009).

Quantifying the magnitude of these impacts, as well as evaluating contemporary restoration and management actions, is critical to advance bird-habitat restoration and conservation. Unfortunately, the avian conservation community has long-struggled with designing and implementing a large-scale coordinated avian monitoring program given the scope, scale, and interconnectedness of the Gulf of Mexico ecosystem that includes over 500 bird species that use a variety of habitats throughout their annual life-cycle (e.g., breeding, wintering, and migration)and are impacted by a variety of ecosystem stressors.

Given the diversity of birds found in the Gulf region and the multiple stressors impacting the region, there is a clear need for a more structured and coordinated framework that supports the implementation of a bird monitoring strategy in the Gulf of Mexico. Federal and state wildlife agencies often have legal mandates to manage migratory birds while other groups (e.g., non-governmental organizations, joint venture partnerships) also have a stake in conserving birds and their habitats. However, these stakeholders often have different mandates and missions. Therefore, the successful design and implementation of a coordinated monitoring strategy for the Gulf of Mexico requires consensus among a wide variety of conservation partners regarding their values and common monitoring objectives.

As a means to reach consensus of the fundamental needs and objectives underpinning avian monitoring efforts in the northern Gulf of Mexico, we framed the discussion around the restoration and conservation efforts being deployed in the aftermath of the DWH oil spill. The DWH settlement has created an unprecedented opportunity to restore and enhance both the ecological and the socio-economic values of the northern Gulf of Mexico ecosystem. As such, this model of conservation (Figure 2.1) provides a platform by which the avian conservation community can: (1) identify their role; and (2) rally around a set of common objectives and data needs, thereby aligning monitoring efforts across agencies and organizations to facilitate learning and reducing uncertainty around restoration actions.

More specifically, as the conservation community at large moves towards a holistic vision of integrated restoration and management of the Gulf of Mexico ecosystem, a structured way of doing business is required, one that closely follows the principles of adaptive management (e.g., plan, implement, evaluate, and adjust decision making based on the evaluation)(Williams and Brown 2012). The Adaptive Management Model requires a double feedback loop to facilitate learning in that, information learned must be applied not only against the restoration and management actions being implemented, but also applied against the

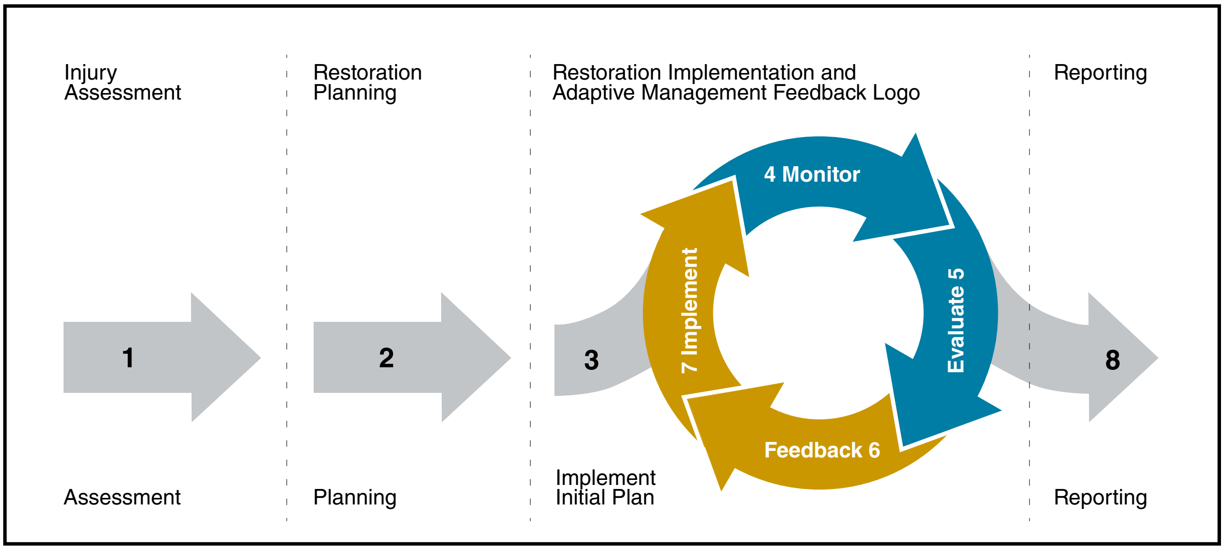

Figure 2.1. *The Monitoring and Adaptive Management Framework presented by the DWH Trustees in the Programmatic Damage Assessment and Restoration Plan and Programmatic Environmental Impact Statement (PDARP/PEIS); adapted from the Monitoring and Adaptive Management Manual (DHNRDAT 2017).*

fundamental objectives and assumptions underpinning the initial planning process (Figure 2.1). For Adaptive Management to be fully successful, monitoring activities must be framed in context with both the original planning objectives and assumptions as well as, with the evaluation of on-the-ground restoration activities. It is within this context, that we frame bird monitoring objectives, values, and priorities.

Identifying Stakeholder Values

Historically, the avian conservation community has struggled to develop and implement a Gulf-wide, coordinated monitoring program due mainly to: (1) lack of a forum by which to coordinate across agencies and organizations; (2) the inability to dissect the many inter-dependent issues and complexities of how birds use the Gulf ecosystem (i.e., agree to common values and needs); and (3) funding limitations. However, in the wake of DWH, an enormous amount of intellectual (planning) and physical (implementation) energy and funding is now being devoted to restoring and enhancing the northern Gulf of Mexico ecosystem. This renewed interest also brings many new mechanisms (e.g., Natural Resource Damage Assessment and Restoration Trustee Council [NRDAR], Gulf Coast Ecosystem Restoration Council, and National Fish Wildlife Foundation [NFWF]) and forums (e.g., Gulf of Mexico Alliance [GoMA], Gulf of Mexico Avian Monitoring Newtork [GoMAMN]) by which to coordinate and implement Gulf-wide monitoring efforts to enhance our collective ability to learn and reduce uncertainty. Hence, the remaining limiting factor is a process by which to deconstruct the complexities surrounding what, when, and where to monitor.

To address this limitation, we have used the principles of decision theory and conceptual models (i.e., influence diagrams) to deconstruct the complexities surrounding avian monitoring in the context of Gulf restoration. In brief, decision theory allows "a formalization of common sense for decision problems which are too complex for informal use of common sense" (Keeney 1982). More specifically, Keeney (2004) describes the elements of decision making as: (1) defining the problem; (2) specifying the objective of your decision; (3) specify alternative means to accomplish the objective; (4) describe the consequences of each alternative in terms of meeting the objective; (5) identify trade-offs relative to how each alternative meets your objective; (6) identify and quantify uncertainty affecting your decision; (7) account for willingness to accept risk; and (8) plan ahead by linking current decisions with future decisions. Whereas influence diagrams are graphical representations of conceptual models that articulate relationships between decisions, external factors, uncertainties, and outcomes. These diagrams facilitate consensus building and encourage structured thinking per cause and effect relationships, as such they clearly link the "things we can affect" with "the things we care about" (Gregory et al. 2012).

Using this formal process of decision making, a series of workshops were hosted to address each of the eight steps identified by Kenney (2004). Because the actual decision and objectives are deeply rooted in stakeholder needs and values, a multitude of stakeholders, representing wide-variety of "decision makers" (e.g., on-the-ground biologists; state, federal and non-governmental wildlife program managers; program managers within NRDAR; Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act [RESTORE]; NFWF; and academic researchers) participated and contributed to the discussions and helped shape the fundamental objectives and the associated core values underpinning each fundamental objective. Here we present information related to Keeney's (2004) elements (1) (identify the decision[s]) and (2) (identify what we value about the decision). We used these two elements as a means to: (1) articulate the roles and components of an avian monitoring program; and (2) serve as a basis for informing programmatic design and implementation of monitoring activities to address key data gaps. Additional information deemed necessary (e.g., cause and effect relationships articulated via influence diagrams) for setting bird monitoring priorities are presented and discussed in Chapters 3–9. Technical information related to other elements of decision theory such as alternatives, consequences, and trade-off analysis are discussed in Fournier et al. (in press).

Based on discussions at the GoMAMN stakeholder workshops, participants agreed that the goal of GoMAMN is to maximize the utility of bird monitoring data to inform restoration and advance bird-habitat conservation across the northern Gulf of Mexico. The GoMAMN conservation community of practice identified a set of fundamental objectives and sub-objectives:

OBJECTIVE 1.0: Maximize the relevancy of monitoring data within the northern Gulf of Mexico.

SUB-OBJECTIVE 1.1: Maximize our collective ability to understand management actions and their respective impacts on avian populations.

SUB-OBJECTIVE 1.2: Maximize our collective ability to conduct population and habitat status assessments.

SUB-OBJECTIVE 1.2.1: Status assessment of birds of conservation concern

SUB-OBJECTIVE 1.2.2: Status assessment of primary (habitats) land cover

SUB-OBJECTIVE 1.3: Maximize our collective ability to understand ecological processes and their respective impacts on avian populations.

OBJECTIVE 2.0: Maximize rigor of monitoring projects.

OBJECTIVE 3.0: Maximize integration of monitoring projects.

At the core of good decision making is a set of well-defined objectives and evaluation criteria. Together they define "what matters" about a decision (Gregory 2012). Using the objectives outlined above, participants at the stakeholder workshops identified and vetted a suite of evaluation criteria as a means of further elucidating what we value about each of the fundamental objectives, as well as providing a transparent means of evaluating success in achieving monitoring objectives. This suite of values serves as the foundational components underpinning the organizational structure, data needs, and priorities presented in chapters 3–9. Additionally, these values can be used to compare alternative monitoring strategies through a series of trade-off analyses. While beyond the scope of presentation within this report, Fournier et al. (in press) provide additional information on trade-off analysis and the construction of monitoring portfolios. Here we provide a general overview of the values underpinning each of the fundamental objectives (i.e., what do we value about each of the fundamental objectives) as a means to frame our philosophical approach to informing and guiding avian monitoring efforts across the northern Gulf of Mexico. To facilitate discussions and presentation of information, we have structured the fundamental objectives and associated evaluation criteria as an objective hierarchy to better communicate the objectives and associated values (Figure 2.2)

In order to maximize the usefulness of bird monitoring data to inform restoration and advance bird-habitat conservation across the northern Gulf of Mexico, the conservation community is challenged to address three fundamental

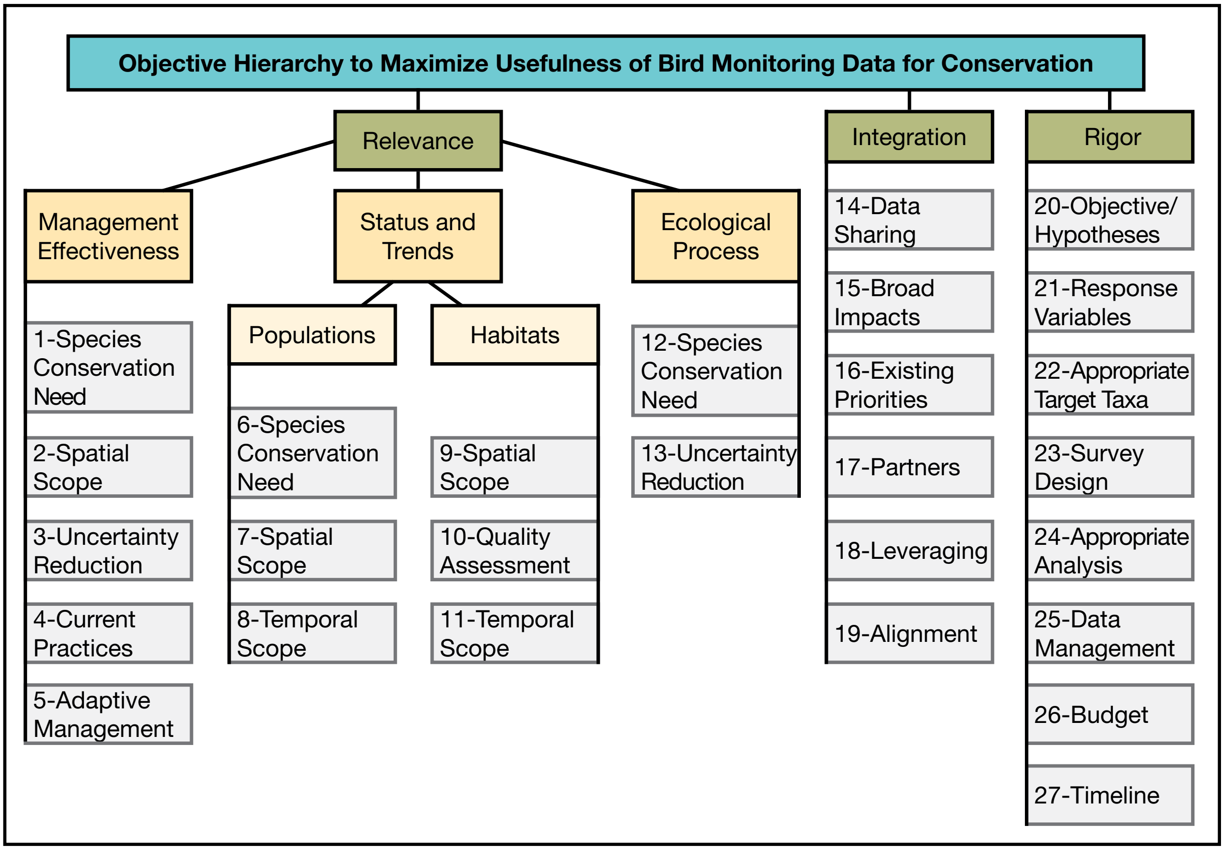

Figure 2.2. *Gulf of Mexico Avian Monitoring Network's objectives hierarchy of fundamental objectives and evaluation criteria underpinning bird monitoring in northern Gulf of Mexico.*

objectives: (1) maximize the relevance of monitoring projects; (2) maximize the integration of monitoring projects; and (3) maximize the scientific rigor of monitoring projects. Collectively, these objectives require monitoring projects to be integrated across partners and taxonomic groups and to address contemporary needs with scientific rigor. To fully understand the implications of this collective statement requires a greater understanding and appreciation for the individual parts.

Relevancy of Monitoring Data

If monitoring data is to truly be useful, it must be relevant; but relevant to what? Through the series of stakeholder workshops, discussions frequently returned to three primary needs underpinning Gulf restoration: (1) evaluation of restoration/management actions; (2) establishment of baselines; and (3) understanding ecological processes. To that end, these needs serve as sub-objectives under the fundamental objective of maximizing relevancy. In other words, if we (collectively) do not evaluate contemporary management actions, establish baselines, and reduce uncertainty around how ecological processes impact avian populations, we will have missed the mark in terms of informing Gulf restoration and bird-habitat conservation. Furthermore, it is important to note that the establishment of baselines more specifically refers to status assessments of both avian populations and habitats. Both pieces of information are required to make informed decisions, hence they are both included as sub-objectives under the establishment of baselines.

As the conservation community moves forward with Gulf restoration, it is imperative that we evaluate on-the-ground restoration and management actions, but which ones? All of them? Given the expense, it's likely not feasible nor practical to evaluate every project that "hits the ground." To answer this question, we can look at the evaluation criteria underlying the "evaluate management effectiveness" monitoring objective to see the stakeholder values: (1) focus on projects that impact Birds of Conservation Concern (see Appendix 1); (2) evaluate management actions that have broad applicability across the Gulf; (3) evaluate management actions with high uncertainty regarding potential impacts on avian populations; (4) focus on management actions that have a high frequency of implementation; and (5) evaluate projects in an adaptive management context. Based on these values, greater value is given to monitoring projects that evaluate frequently occurring management actions with broad applicability and high degree of uncertainty related to the impacts on birds of conservation concern within an adaptive management framework.

Likewise, it is important to conduct status assessments for both avian populations and their habitats (see Appendix 2) if the conservation community is to understand population responses at scales larger than the project-level implementation of a management action (e.g., state-scale, Gulf-wide). Status assessments not only provide information by which population and habitat trends can be assessed, but also provide important baseline datasets by which management effectiveness and future anthropogenic (e.g., oil spills) and natural events (e.g., hurricanes) can be assessed. Specifically, stakeholders value population status assessments that: (1) address birds of conservation concern; (2) cover large percentage of the species' gulf-wide range; and (3) spans long periods of time. Similarly, stakeholders value habitat assessments that: (1) address habitat quantity; (2) habitat quality; and (3) spans long periods of time. Thus, priority should be given to status assessments that span large portions of the Gulf, extend over long periods of time, and address birds of conservation concern and their habitats.

Bird populations are sustained via an intricate interplay of basic ecological processes, such as climate dynamics, patterns in primary and secondary productivity, hydrologic regime, formation and maintenance of habitats, interactions between and among species, movement ecology and natural disturbances (see Newton 1998). Understanding these intricate relationships can only be derived through explicit acknowledgment and understanding of the ecological processes driving avian populations. Such a body of knowledge is both fundamental to long-term conservation of avian populations and necessary to interpret effects of specific management actions on avian populations. Monitoring to understand the ecological drivers of avian populations will generally occur at much larger spatial and time scales (decades, thousands of km^2) than those typical of studies designed to monitor specific management actions (years, tens to hundreds of km^2). The separation of ecological processes and management actions in terms of designing and informing monitoring actions is based on these general differences in scaling (NASEM 2017). With respect to monitoring ecological processes, stakeholders value information that reduces uncertainty of how ecological processes impact birds of conservation concern. To provide further insight of values and priority processes to be evaluated, each of the avian-taxonomic groups has identified a suite of ecological processes that warrant further study (see Chapters 3–9).

Integration and Rigor of Monitoring Data

One major objective of GoMAMN is to provide a forum to facilitate coordination and integration of monitoring efforts across the northern Gulf of Mexico. Hence, it is not surprising that the stakeholders developed a fundamental objective that speaks to maximizing the integration of monitoring data. But what does integration of monitoring data mean? Cambridge dictionary describes integration as "to combine two or more things in order to become more effective". Throughout the series of stakeholder meetings this was also a recurring theme—"how do we leverage resources across partners and existing monitoring efforts in an attempt to become more efficient and effective?" To facilitate the integration process, stakeholders identified seven criteria by which the conservation community could collectively work to better integrate monitoring efforts: (1) sharing of data; (2) broaden applicability of data beyond bird monitoring (e.g., curriculum development, environmental compliance, etc.); (3) address existing priorities within conservation plans (e.g., joint venture implementation plans); (4) increase collaborations /partnerships; (5) increase leveraging of resources (e.g., equipment, funding, etc.); (6) standardization of protocols and procedures; and (7) alignment with existing bird and non-bird monitoring programs. Given the vast number of partners working to restore the Gulf, it is imperative that the conservation community breaks from its respective "silos" to look for ways to become more efficient and effective. It is our expectation that, collectively, the conservation community will look for ways to incorporate the values described above into future monitoring efforts, as a means to increase collaborations and applicability of monitoring data to inform Gulf restoration and bird-habitat conservation.

Any monitoring project is only as good as the quality of its data. Which is in turn determined by the rigor with which (1) the project is conceived, designed, and implemented, and (2) the manner in which those data are managed, analyzed, and made available to others (see Chapter 11). The importance of having scientifically robust data was not lost during discussions with the various stakeholders, evident by the fact that rigor is a fundamental objective on the same level within the objective hierarchy as relevance and integration. Evaluation criteria for rigor reflect the principles of the scientific method of discovery and include: (1) clearly stated objectives/hypotheses; (2) clearly stated response variable(s); (3) identification of the appropriate target species/taxa; (4) clearly articulated survey design; (5) use of appropriate statistics; (6) clearly articulated data management plan; (7) articulation of appropriate and efficient budget; and (8) articulation of appropriate and reasonable timeline to address objectives/hypotheses. Unfortunately, many monitoring efforts continue to be implemented with little consideration of these criteria. Without explicit recognition and incorporation of these criteria, it is questionable how useful data will be to produce actionable results that inform Gulf restoration and bird-habitat conservation across the northern Gulf of Mexico. Thus, it is our hope that future monitoring efforts will incorporate these criteria a priori to implementing any avian monitoring efforts.

Defining Success

As the Gulf Restoration Enterprise of federal, state, non-governmental agencies and organizations work to implement holistic restoration of the northern Gulf of Mexico ecosystem, monitoring and adaptive management are foundational aspects (DHNRDAT 2017). As such, GoMAMN provides a mechanism to facilitate coordination, collaboration and integration of avian monitoring across a broad range of partners, stakeholders and decision makers. In summary, the goal of GoMAMN is to maximize the usefulness of bird monitoring data to inform gulf restoration and bird-habitat conservation across the northern Gulf of Mexico. To that end, GoMAMN will be successful if we can: (1) create and maintain a forum by which stakeholders can coordinate and integrate monitoring efforts for birds of conservation concern and their habitats; (2) establish clearly articulated core-values, data needs, and fundamental objectives underpinning monitoring efforts; (3) facilitate the implementation of cost-effective yet scientifically robust regional monitoring plans; and (4) standardize data collection and data management efforts that support adaptive management.

To address these challenges will require the monitoring community of practice to embrace and incorporate the stakeholder values (e.g., fundamental objectives and evaluation criteria; Figure 2.2) into their respective monitoring activities and programs. Hence success hinges upon our collective ability to collaborate and integrate on the design and implementation of region-wide monitoring activities that address stakeholder values. Furthermore, due to the nature and legal mandates of how funding is allocated (within states vs. Gulf-wide) among the various sources (e.g., NRDAR, NFWF, RESTORE Act, state wildlife grants, etc.), success will also be determined by how well we (collectively) leverage funding resources to implement region-wide monitoring to address multiple objectives (e.g., project-level and programmatic-level) in an efficient manner.

Using the GoMAMN forum, a suite of objectives and associated evaluation criteria (values) have been identified through a series of stakeholder workshops. In chapters 3–9 we used these objectives and values to identify bird monitoring priorities and provide a transparent strategic framework to guide the design and implementation of a coordinated and integrated avian monitoring program, one that will allow us to evaluate future restoration activities and conduct ecosystem assessments across the Gulf-region (Figure 2.3). Furthermore, we expect such a collaborative and integrated program will lead to cost-effective yet scientifically robust regional monitoring effort, with standardized data collection and data management procedures that support adaptive management. Finally, due to the broad spectrum of partners within GoMAMN, this network provides a forum by which conservation planners and land managers can continue to coordinate, collaborate, and seek additional information related to bird populations and habitats, as well as to identify best management practices for restoration and management (Figure 2.3). With these objectives, values, and expectations as a foundation, hereafter, we synthesize data needs relative to birds of conservation concern (see Chapters 3–9) as a means to better articulate key uncertainties and focus monitoring efforts as we collectively work to implement holistic ecosystem restoration and monitoring. ❦

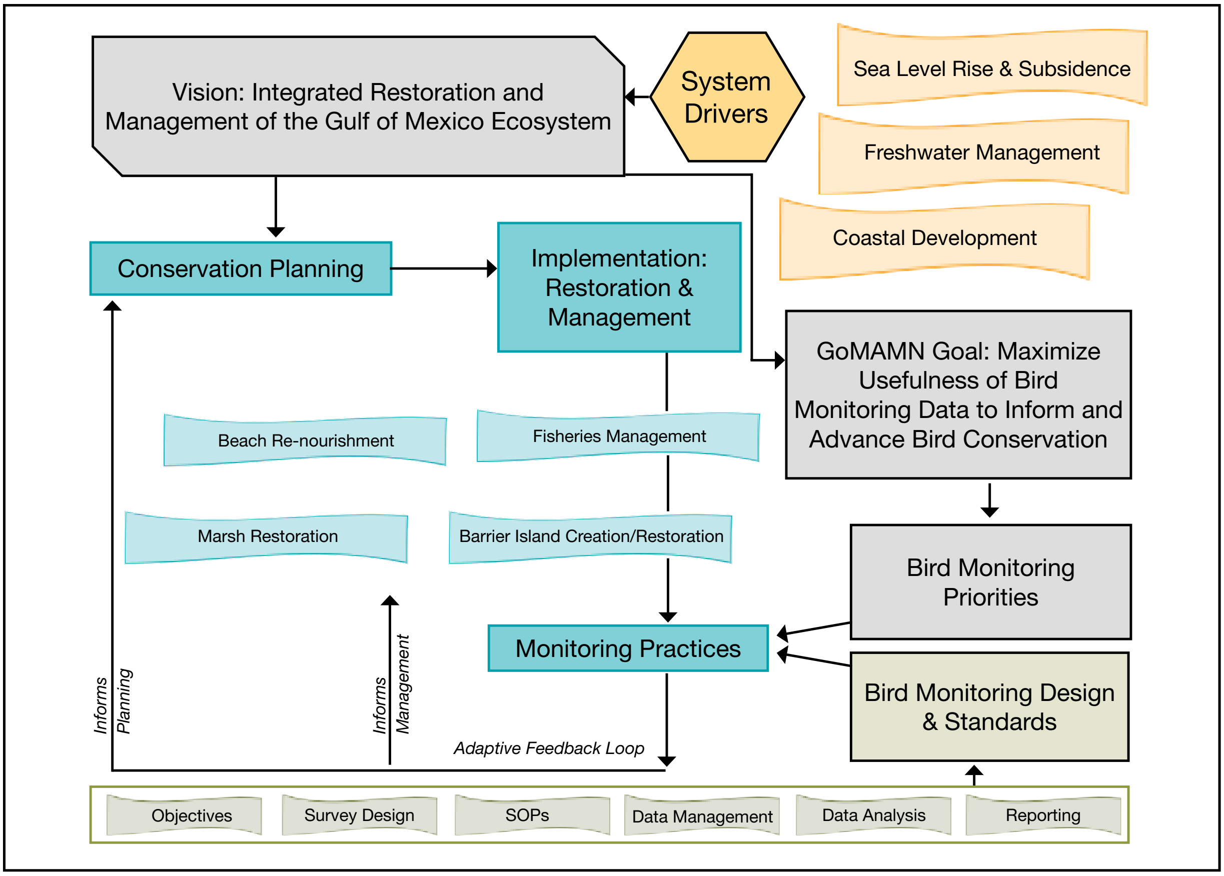

Figure 2.3. *Schematic depicting the role of the Gulf of Mexico Avian Monitoring Network within the larger context of Gulf restoration. Stakeholder values and objectives are shown in gray, the adaptive decision process in blue (with examples in wavy boxes), monitoring components in green, and system drivers (with examples) in orange.*

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3

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: LANDBIRDS

Authors:
Theodore J. Zenzal Jr. (1,2,3*^)
William G. Vermillion (4)
Jacqueline R. Ferrato (5)
Lori A. Randall (3)
Robert C. Dobbs (3,6^)
Heather Q. Baldwin (7)

1. University of Southern Mississippi, School of Biological, Environmental, and Earth Sciences, Hattiesburg, MS
2. University of Illinois, Department of Natural Resources and Environmental Sciences, Urbana, IL
3. U.S. Geological Survey, Wetland and Aquatic Research Center, Lafayette, LA (^current address)
4. U.S. Fish and Wildlife Service, Gulf Coast Joint Venture, Lafayette, LA
5. The Nature Conservancy, San Antonio, TX
6. Louisiana Department of Wildlife and Fisheries, Coastal and Nongame Resources Division, Lafayette, LA (^current address)
7. U. S. Geological Survey, Northern Prairie Wildlife Research Center, Rapid City, SD

(*) Corresponding Author: **tzenzal@usgs.gov**

Wood Thrush (*Hylocichla mustelina*). Photo credit: Steve Maslowski

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GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: LANDBIRDS

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

LANDBIRDS IN THE GULF OF MEXICO REGION include an ecologically diverse group of taxa that depend on a wide range of terrestrial habitats and the airspace above them. For the GoMAMN region of the Gulf of Mexico, the Landbird Working Group identified 19 species from 12 families as priorities for monitoring (Table 3.1). In addition, all species that stopover within the GoMAMN region during migration (i.e., passage migrants) are of concern, as are the habitats they use. The 19 priority species use a wide range of habitat types and include species that spend some (e.g., breeding, wintering, migration seasons) or all (e.g., residents) of their annual cycle in the GoMAMN region. The GoMAMN Landbird Working Group organized the priority landbirds into five groups based on a combination of habitat and season—forest breeding, forest wintering, grassland breeding, grassland wintering, and passage migrants—realizing that there would be overlap of habitats and seasons for some species. For example, Swainson's Warbler (*Limnothlypis swainsonii*) breeds in and migrates through forested habitat in the Gulf of Mexico region and Northern Bobwhite (*Colinus virginianus*) uses both prairie grasslands and evergreen forest (i.e., open pine savannas) (Table 3.1). For some species, such as Painted Bunting (*Passerina ciris*) and Common Ground-Dove (*Columbina passerina*), which often use scrub/shrub vegetation, the habitat-based designations above may be overly simplistic. Although it occurs along higher, drier fringes of palustrine and estuarine emergent marsh habitat, Sedge Wren (*Cistothorus platensis*) is included here as a landbird (rather than a marsh bird) because it is most commonly found during the winter along the Gulf coast in upland evergreen forest (i.e., wet pine savanna) habitat and grassland habitats. Selection of the five groups was predicated on the assumption that management efforts would be similar for species using these habitats in a given season, and that monitoring methods would be habitat and season specific.

For some of the 19 priority landbird species, such as Northern Bobwhite and Red-cockaded Woodpecker (*Dryobates borealis*), there is extensive literature examining life history, ecology, and population status and trends, while others have been studied little. Twelve of the 19 species are currently of moderate to high conservation concern at the continental scale (Rosenberg et al. 2016, U.S. Fish and Wildlife Service 2017). These rankings are from the Avian Conservation Assessment Database, which scores North American landbirds on six criteria with a maximum possible score of 20 (Partners in Flight 2017). The continental concern scores for the 19 species identified by GoMAMN range from 7 for Sedge Wren to 18 for the federally- endangered Red-cockaded Woodpecker (Table 3.1). The 2016 Partners in Flight (PIF) Landbird Conservation Plan (Rosenberg et al. 2016) lists 86 species of continental concern (the PIF Watch List), grouped into three categories:

1. **RECOVER:** Red Watch List – Species with extremely high vulnerability due to small population and range, high threats, and range wide declines. Two of GoMAMN's priority landbird species are in this category: Red-cockaded Woodpecker and Bachman's Sparrow (*Peucaea aestivalis*).

2. **PREVENT DECLINE:** "R" Yellow Watch List – Species not declining but vulnerable due to small range or population and moderate threats. Henslow's Sparrow (*Centronyx henslowii*) falls in this category.

3. **REVERSE DECLINE:** "D" Yellow Watch List – Species with population declines and moderate to high threats. Four of GoMAMN's priority landbird species are in this category: Red-headed Woodpecker (*Melanerpes erythrocephalus*), Wood Thrush (*Hylocichla mustelina*), Prothonotary Warbler (*Protonotaria citrea*), and LeConte's Sparrow (*Ammospiza leconteii*).

Additionally, PIF has identified 24 species as common birds in steep decline. These species are still fairly common and widespread, but have lost from 50–90% of their populations since 1970, and are projected to lose another 50% within the next 20–25 years. GoMAMN landbird species with this designation are Northern Bobwhite, Chuck-will's-widow (*Antrostomus carolinensis*), Loggerhead Shrike (*Lanius

TABLE 3.1 - *Landbird 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[a]	Latin Name	Breeding	Wintering	Migration	Landcover Association(s)[a]	Continental Trend Score	Continental Concern Score
Northern Bobwhite	*Colinus virginianus*	X	X		Grassland, Evergreen Forest, Mixed Forest, Scrub/Shrub	5	12
Common Ground-Dove	*Columbina passerina*	X	X		Evergreen Forest, Scrub/Shrub	3	9
Chuck-will's-widow	*Antrostomus carolinensis*	X		X	Evergreen Forest, Mixed Forest	5	12
Red-headed Woodpecker	*Melanerpes erythrocephalus*	X	X		Deciduous Forest, Evergreen Forest, Mixed Forest, Palustrine Forested Wetland	5	13
Red-cockaded Woodpecker	*Dryobates borealis*	X	X		Evergreen Forest	5	18
Loggerhead Shrike	*Lanius ludovicianus*	X	X	X	Grassland, Scrub/Shrub	5	12
Brown-headed Nuthatch	*Sitta pusilla*	X	X		Evergreen Forest, Mixed Forest	4	13
Sedge Wren	*Cistothorus platensis*		X		Grassland, Evergreen Forest	1	7
Wood Thrush	*Hylocichla mustelina*	X		X	Deciduous Forest, Mixed Forest	5	14
Louisiana Waterthrush	*Parkesia motacilla*	X		X	Deciduous Forest, Mixed Forest, Palustrine Forested Wetland	2	12
Prothonotary Warbler	*Protonotaria citrea*	X		X	Palustrine Forested Wetland	4	14
Swainson's Warbler	*Limnothlypis swainsonii*	X		X	Deciduous Forest, Evergreen Forest, Mixed Forest, Palustrine Forested Wetland	1	13
Yellow-throated Warbler	*Setophaga dominica*	X	X	X	Deciduous Forest, Evergreen Forest, Mixed Forest, Palustrine Forested Wetland	2	10
Bachman's Sparrow	*Peucaea aestivalis*	X	X		Evergreen Forest	5	16
Grasshopper Sparrow	*Ammodramus savannarum*	X	X	X	Grassland	5	12
Henslow's Sparrow	*Centronyx henslowii*		X		Grassland, Evergreen Forest	3	14
LeConte's Sparrow	*Ammospiza leconteii*		X		Grassland	5	13
Painted Bunting	*Passerina ciris*	X	X	X	Deciduous Forest, Evergreen Forest, Mixed Forest, Scrub/Shrub, Palustrine Forested Wetland	3	11
Rusty Blackbird	*Euphagus carolinus*		X		Palustrine Forested Wetland, Cultivated Crops, Pasture/Hay	5	12

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

ludovicianus), Grasshopper Sparrow (*Ammodramus savannarum*), and Rusty Blackbird (*Euphagus carolinus*). The remaining six landbird species identified by GoMAMN are birds of regional concern.

Finally, all passage migrants are a GoMAMN priority because it is thought that these species encounter the greatest mortality risk of their annual cycle during migration (e.g., Sillett and Holmes 2002, Newton 2007, Paxton et al. 2017) and stopover habitat may limit some populations within this group (Sherry and Holmes 1995, Newton 2007, 2008). Identifying migrant-habitat relations, including habitat characteristics and quality, threats to populations, and best conservation practices will benefit passage migrants, as well as breeding and wintering species, by establishing unified conservation partnerships (Cohen et al. 2017).

Breeding Season

Fifteen of the 19 selected priority landbird species breed within the GoMAMN boundaries, though some are more common in migration or winter than in the breeding season. Loggerhead Shrike and Northern Bobwhite occur in grassland, scrub/shrub, and savanna habitats throughout the extent of the GoMAMN region (Yosef 1996, eBird 2018, Brennan et al. 2014). Other species occupy only part of the GoMAMN region, or their abundance varies in predictable ways within the region. Common Ground-Dove, while breeding in scrub/shrub and edge habitats throughout the GoMAMN region, shows marked differences in densities during the breeding season, with higher densities in south Texas and Florida, and lower densities in south Louisiana and Mississippi (Bowman 2002, eBird 2018). The breeding ranges of several species are tied to the extent of evergreen forests (i.e., coastal pine flatwoods) within the GoMAMN region, including Chuck-will's-widow, Red-headed Woodpecker, and Brown-headed Nuthatch (*Sitta pusilla*); the woodpecker also uses savanna-like conditions that occur in areas of human habitation (eBird 2018, Straight and Cooper 2012, Slater et al. 2013, Frei et al. 2017). Red-cockaded Woodpecker and Bachman's Sparrow also occur in evergreen forest (i.e., coastal pine flatwoods) but are restricted to specific seral stages and management regimes, resulting in localized distributions (Jackson 1994, eBird 2018, Dunning et al. 2017). For a description of open pine habitats utilized by Red-cockaded Woodpecker, Bachman's Sparrow, and several other GoMAMN priority landbirds, see Appendix 2, GoMAMN Ecological Systems and Nordman et al. (2016).

Within the GoMAMN region, Painted Bunting regularly breeds in scrub/shrub and forest edge-like habitats from the Texas-Mexico border to western Mississippi and becomes much less common in eastern Mississippi, Alabama, and Florida (eBird 2018, Lowther et al. 2015). Prothonotary Warbler is largely absent as a breeder in southern peninsular Florida as well as south of the Texas mid-coast, and is associated with the presence of palustrine forested wetlands in the region in between (Petit 1999, eBird 2018). Yellow-throated Warbler (*Setophaga dominica*) breeds within approximately the same geography as Prothonotary Warbler, but in a greater variety of habitats (eBird 2018, McKay and Hall 2012) (Table 3.1). Wood Thrush, Louisiana Waterthrush (*Parkesia motacilla*), and Swainson's Warbler also breed in forest habitats from the Florida panhandle into Texas, but their distribution in the GoMAMN region is restricted and they are uncommon breeders, being more prevalent during spring and autumn migration than during the breeding season (Mattson et al. 2009, Anich et al. 2010, Evans et al. 2011, eBird 2018). Similarly, although it does breed in the GoMAMN region, Grasshopper Sparrow is more common as a wintering bird than during the breeding season (eBird 2018). Within the GoMAMN region, the species breeds in grassland habitat in coastal Texas (Vickery 1996, Lockwood and Freeman 2004, eBird 2018). Additionally, there is a resident, federally-listed endangered subspecies (*Ammodramus savannarum floridanus*) in southern peninsular Florida (Vickery 1996, U.S. Fish and Wildlife Service 2017); however, GoMAMN's monitoring focus is on the non-listed subspecies (*A. s. pratensis* and *A. s. perpallidus*) which winter throughout the region.

Spring and Autumn Migration Seasons

Habitat within the GoMAMN region may be more important to transient versus breeding landbirds. The majority of Nearctic-Neotropical landbirds breeding in the eastern United States, as well as many western populations of landbirds, move through the region in spring and fall each year (Barrow et al. 2005, Buler et al. 2007a, Buler and Moore 2011, eBird 2018, Lafleur et al. 2016). Given that the habitats used during stopover are generally similar to those used on the breeding grounds (Moore et al. 1995), the majority of passage migrants within the GoMAMN region use forest habitat types (e.g., deciduous, evergreen, and mixed forest types, palustrine forested wetlands; Table 3.1), with grassland and scrub/shrub habitats used to a lesser degree. Additionally, Moore et al. (1995) concluded that during spring migration, forest-dwelling landbirds on the northern Gulf Coast preferentially select structurally-diverse stopover sites consisting of forested areas with mixed shrub layers. This observation is further supported by research, including analysis of weather surveillance radar data to detect reflectivity caused by departing birds, which indicates the importance of the remaining large blocks of riverine hardwood forests along the Gulf of Mexico rim (Able 1972, Barrow et al. 2005, Buler et al. 2007a, 2007b, Buler and

Moore 2011, Lafleur et al. 2016).

Although individuals might prefer specific site characteristics, they tend to show plasticity during migration and may behave differently between migration seasons (Petit 2000). For example, energetic condition and weather can strongly influence habitat selection by forcing migrants to land in areas they might have otherwise overflown (Able 1972, Moore and Aborn 2000, Petit 2000). Moreover, migrant-habitat relations are often scale dependent and are influenced in part by landscape- and habitat-scale factors (e.g., Moore et al. 1995, Buler et al. 2007b, Zenzal et al. 2018). This means an individual's position in space and time may influence where an individual lands and, in turn, the likelihood of encountering different functional habitat types en route that can vary in their size and quality. Toward this end, Mehlman and colleagues (2005) have prioritized functional stopover habitat types for migratory landbirds according to the definitions described below:

- **"FIRE ESCAPE"**: Like fire escapes in human habitations, these stopover sites are infrequently used, but are utterly vital when needed during inclement weather or energy shortfalls. These habitats tend to be small forested or scrub/shrub habitats, such as chenier or coastal/maritime forest, within a typically inhospitable matrix adjacent to an ecological barrier (e.g., ocean or desert). Habitat quality may be too low to allow birds to gain significant mass especially when migrant densities are high, but provides shelter for rest, refueling possibilities (Moore et al. 2017), and freshwater.

- **"CONVENIENCE STORE":** Forested patches, such as small parks or woodlots, in a non-forested matrix and located along migratory routes. These sites offer a place where birds can briefly rest and gain some mass easily, perhaps between short flights to higher quality sites, or when migrants' fuel stores are moderate. A given convenience store may serve the needs of some species better than others.

- **"FULL-SERVICE HOTEL":** Forested sites in a mostly contiguous forested landscape. Full-service hotels are places where all needed resources (food, water, and shelter) are relatively abundant and available. These places serve many individuals of many species. Palustrine forested wetlands (e.g., bottomland hardwood forests) are a good example.

Red-headed Woodpecker (*Melanerpes erythrocephalus*).
Photo credit: Jessica Bolser

Each functional stopover habitat type plays an important part in the journey of migratory landbirds. For example, although only used sporadically, smaller blocks of forested habitat, especially those adjacent to the Gulf of Mexico shoreline, have been shown to receive heavy use by migrants during inclement weather (Gauthreaux 1971, Barrow et al. 2000, Barrow et al. 2005, Buler et al. 2007b, Buler and Moore 2011, Lafleur et al. 2016). The importance of large blocks of forest (i.e., full-service hotels) is evident based on migrant densities (Barrow et al. 2005, Buler et al. 2007b, Buler and Moore 2011, Lafleur et al. 2016); however, information is lacking on how non-coastal forests (full-service hotels and convenience stores) in the GoMAMN region function for migrants in terms of resource availability and refueling potential. Once we understand how migrants respond to each habitat type as well as the relationships between stopover habitat types across the GoMAMN region (e.g., Cohen et al. 2014), we can begin to estimate the amount of each habitat type needed to sustain or increase migrant populations (reviewed by Cohen et al. 2017).

Winter Season

Although numerous GoMAMN priority landbirds overwinter in the region, the presence of only four species is largely limited to the winter season. Rusty Blackbird typically uses palustrine forested wetlands for foraging and roosting, but also forages in agricultural fields adjacent to forested wetlands and pecan groves (Mettke-Hofmann et al. 2015, Avery 2018). Henslow's and LeConte's Sparrows and Sedge Wren are grassland species overwintering in the GoMAMN region (Vickery 1996, Herkert et al. 2002, Lowther 2005). Henslow's Sparrow and Sedge Wren also utilize the grassland-like conditions that exist in evergreen forest (i.e., open pine savanna habitat) (Herkert et al. 2002). Red-headed Woodpecker breeds and winters in the GoMAMN region, but the area is believed to be most important during winter. Various forest types are used by the woodpecker, with a unifying similarity being an open, savanna-like quality (Frei et al. 2017). Other species (besides year-round residents) have breeding and wintering populations in the GoMAMN region. South Florida is an important wintering area for Painted Bunting and Chuck-will's-widow (Straight and Cooper 2012, Lowther et al. 2015). Yellow-throated Warbler overwinters in south Florida, south Texas, and in smaller numbers throughout the rest of the GoMAMN region (McKay and Hall 2012). The Gulf coast is believed to be an important overwintering area for Loggerhead Shrikes breeding in Canada and the northern U.S. (Miller 1931, Burnside 1987, Yosef 1996). Winter habitat used by Painted Bunting, Yellow-throated Warbler, and Loggerhead Shrike is similar to their breeding habitat. Chuck-will's-widow uses a greater variety of GoMAMN region habitats in winter vs. summer, including scrub/shrub in south Texas (Oberholser 1974) and coastal live oak forests (cheniers) in southwestern Louisiana (Lowery 1974).

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

A myriad of threats exist for breeding, migrating (passage migrant), and wintering landbirds in the GoMAMN region (Figure 3.1; Appendix 3). For the current PIF Landbird Conservation Plan, Rosenberg et al. (2016) identified and analyzed continental-scale threats. Their analysis indicated that habitat loss due to urbanization and habitat degradation due to changing forest conditions represented the most critical threats to landbirds in the U.S. and Canada, affecting nearly half of 98 PIF Watch List species and Common Birds in Steep Decline. Habitat loss due to agricultural conversion and tropical deforestation, along with habitat loss and degradation due to climate change, impacted ~30 of these species, and habitat degradation due to rangeland management impacted 20 species (Rosenberg et al. 2016). Other major threats identified in the plan, in order of species impacted, are energy/resource extraction, contaminants, disease, invasive species, and hunting/trapping. Rosenberg et al. (2016) also highlights the direct mortality of North American landbirds from anthropogenic sources including feral cats, collisions with man-made structures such as buildings and power lines, as well as auto strikes (see also Loss et al. 2013, Loss et al. 2014a, 2014b).

The majority of the causes for habitat loss and alteration, and anthropogenic sources of direct mortality described above, are operating in the GoMAMN region (Cohen et al. 2017). Loss or degradation of forests and grasslands due to urbanization and existing management practices is one of the most significant and pervasive threats to landbirds Gulf-wide (Moore et al. 1995, Barrow et al. 2000, Barrow et al. 2005, Buler and Moore 2011, Barnes et al. 2013). The human population along the Gulf Coast continues to grow (Crossett et al. 2004, Partnership for Gulf Coast Land Conservation 2014), and with that growth comes conversion and fragmentation of forested and grassland habitats (e.g., Abdollahi et al. 2005), as well as increased risk of direct mortality from anthropogenic sources.

Invasive plant and animal species have also impacted GoMAMN priority landbird habitat. Chinese tallow (Triadica sebifera) is a medium-sized tree native to China (USDA, NRCS 2017) and is believed to have been introduced into the United States as early as the 1700's as an ornamental and as a source for oil to manufacture soap and candles. Since its introduction, Chinese tallow has spread throughout the southeastern U.S. as well as California. It has significantly altered the composition of Gulf of Mexico coastal prairies and forests due to its ability to rapidly invade prairie soils or forest gaps and out-compete native plant species (Barrilleaux and Grace 2000, Bruce et al. 1995, 1997). Once established, Chinese tallow trees are difficult to remove and control, typically requiring multiple mechanical treatments and herbicide applications. Fire can be effective in controlling Chinese tallow in coastal prairie habitats before it becomes well-established. Chinese tallow has the ability to replace native tree species with monotypic stands that may be ecological traps for insectivorous birds because the foliage contains compounds that render leaves unpalatable to herbivorous arthropods. For example, Barrow and Renne (2001) found that Chinese tallow hosted fewer insects and spiders than native trees in Gulf coastal habitats, and spring migrant landbirds spent significantly less time feeding in Chinese tallow compared to their availability in coastal forests. Similarly, Barrow et al. (2000) noted that Chinese tallow was avoided by spring migrant birds at Smith Point, Texas, an important stopover site for migrant landbirds. Conversely, during autumn migration Conway et al. (2002) recorded 24 species of birds foraging on Chinese tallow fruits during 1995 and 1996, with Yellow-rumped Warbler (*Setophaga coronata*) and Baltimore Oriole (*Icterus galbula*) accounting for 72% of frugivory incidents. Additionally, a study conducted at sites in South

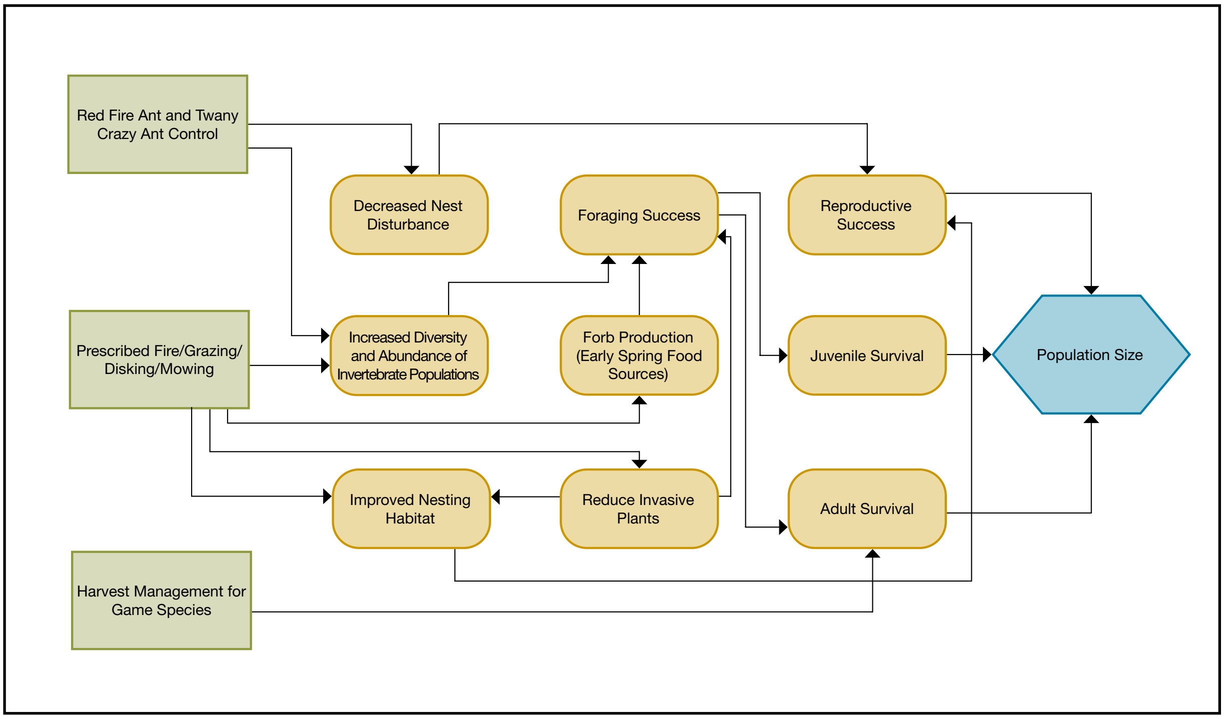

Figure 3.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Northern Bobwhite*** *(Colinus virginianus) in grasslands within the Gulf of Mexico region.*

Carolina and Louisiana identified Red-bellied Woodpecker (*Melanerpes carolinus*), Northern Flicker (*Colaptes auratus*), Eastern Bluebird (*Sialia sialis*), American Robin (*Turdus migratorius*), European Starling (*Sturnus vulgaris*), and Northern Cardinal (*Cardinalis cardinalis*) as the most important species to disperse and drop Chinese tallow seeds (Renne et al. 2002). These results suggest that landbirds rely more heavily on the use of Chinese tallow in autumn compared to spring, likely due to availability of tallow fruit in autumn and overall fewer arthropod resources. However, Baldwin et al. (2008) found that Chinese tallow fruits did not constitute a valuable energy source for Northern Cardinals because of their inability to efficiently metabolize the high-melting point fatty acids comprising the fruits. Yet Yellow-rumped Warblers, postulated to be an important dispersal agent (Conway et al. 2002), have a specialized digestive system allowing assimilation of waxy fruits, such as wax myrtle (*Morella cerifera*), and Chinese tallow trees may provide an important winter food source for this species.

In addition to its unsuitability as foraging habitat for insectivorous birds, Chinese tallow has invaded and altered much of the remaining grassland habitat in southeastern Texas and southwestern Louisiana (Bruce et al. 1995, USFWS/USGS 1999), rendering it largely inhospitable for grassland-dependent bird species such as Henslow's, LeConte's and Grasshopper Sparrows. Similarly, various exotic, sod-forming grasses have been introduced along the Gulf Coast, including bermudagrass (*Cynodon dactylon*), tall fescue (*Schedonorus arundinaceus*), and cogongrass (*Imperata cylindrica*), to the detriment of grassland dependent birds (Barnes et al. 2013). These plant species typically provide poor habitat for grassland birds due to their tendency to form thick mats at ground level, making foot travel difficult or impossible for species such as Northern Bobwhite. These exotic grasses form monotypic stands with relatively low insect diversity compared to native grassland-forb habitats (Barnes et al. 2013). An additional problem with cogongrass, a pyrogenic species, is that it has the capacity to disrupt natural fire regimes. Cogongrass fires burn ~15-20% hotter than typical fires occurring in southern pine ecosystems, which reduces competition and increases areal coverage, limiting natural succession from native plants and facilitating development of monotypic cogongrass stands (McDonald 2007). Without fire management or other intervention methods, native woody species such as eastern baccharis (*Baccharis halimifolia*) can also convert grasslands into scrub/shrub habitat that is unsuitable for some priority grassland bird species (USFWS/USGS 1999, Grace et al. 2005).

Invasive animal species, like feral hogs (*Sus scrofa*), also affect landbird habitats along the Gulf coast. In addition to consuming the eggs of ground-nesting bird species (Timmons et al. 2011), feral hogs can significantly alter the structure and plant diversity of forests (Siemann et al. 2009). In Texas, the saplings of large-seeded tree species, such as oaks and hickories, were twice as numerous in forested plots that were inaccessible to hogs. In unprotected plots, hogs created conditions conducive to invasion by Chinese tallow, which as described above is of less value to birds than many native tree species. While efforts are underway in the GoMAMN region as well as other areas of North America to reduce feral hog populations (e.g., hunting, targeted removal, etc.), complete eradication is unlikely.

Climate change is a potentially important ecological process impacting priority landbirds in the GoMAMN region. One concern is that increased temperatures will cause asynchrony between peak resource abundance and peak migrant landbird arrival in the GoMAMN region and the northern hemisphere in general (Both and Visser 2001, Strode 2003, Marra et al. 2005, Visser and Both 2005). While it seems that some North American migrant bird species have adjusted their arrival dates in spring, research indicates that other species have not adjusted their timing to match phenological changes in spring conditions (Paxton et al. 2014, Cohen et al. 2015, Mayor et al. 2017). In addition, climate change may increase the intensity of hurricanes (Scavia et al. 2002; Knutson et al. 2010; Holland and Bruyère 2014), which can alter forest structure and composition and impact migrant landbirds (Lain et al. 2017, Sugi et al. 2017, Dobbs et al. 2009). Barrow et al. (2007) used weather surveillance radar and remotely-sensed vegetation greenness indices (i.e., the normalized difference vegetation index) to document a shift in stopover habitat use from bottomland forests to adjacent pine forests in the Pearl River Basin of Mississippi and Louisiana after the bottomland forests were severely damaged by Hurricane Katrina. However, migrants tend to be less selective during spring migration as found by a lack of response from the majority of species using a hurricane disturbed chenier in southwest Louisiana during the years following hurricanes Rita and Ike (Lain et al. 2017).

Climate change-related sea-level rise has the potential to alter and likely reduce habitats within the GoMAMN region. Reduction in the areal coverage of coastal forests through increased salinities and prolonged flooding, elevated water tables, or through mechanical action from erosion can occur with sea-level rise (Williams et al. 1999). Tree regeneration can be eliminated by increased salinities and/or flooding duration (Conner and Day 1988), though canopy trees may persist for many years. In some areas of the GoMAMN region that experienced sea-level rise, salt tolerant plant species have replaced salt-intolerant plant species (Saha et al. 2011), while in other areas, forests have transitioned into "ghost" forests of dead tree stems underlain with marsh or open water (Penfound and O'Neill 1934, Williams et al. 1999).

Grasshopper Sparrow (*Ammodramus savannarum*).
Photo credit: Aron Flanders

Climate change impacts to existing grasslands in the GoMAMN region are difficult to predict (Bagne et al. 2012). Some experiments have shown that woody plants, legumes, and forbs would be favored over grasses under elevated carbon dioxide levels, whereas others indicate that some grasses would be favored in arid regions due to resistance to desiccation and tolerance of high temperatures and low soil nitrogen levels (Bagne et al. 2012). However, one of the likely changes summarized by Bagne et al. (2012) was that climate suitable for Gulf Coastal grasslands in Texas was expected to contract towards southeastern Texas and have a high proportion of no-analog climates (e.g., projected climates not matching any contemporary biomes). Whether or not GoMAMN priority grassland birds can adapt to novel climate regimes and habitat contraction is unknown. Species with relatively limited dispersal ability, such as Northern Bobwhite, may experience local extirpation.

Direct mortality from anthropogenic sources, such as collisions with towers and other structures, auto strikes, and predation from free-ranging and feral cats, has been identified as a significant source of mortality for North American birds, with losses estimated in the billions per year (Avery 1979, Erickson et al. 2005, Loss et al. 2013). Additionally, due to increasing human population and resultant habitat loss, alteration, and fragmentation, the GoMAMN Landbird Working Group identified the potential for disease to impact populations of migrant birds, as those individuals are constrained to use increasingly smaller areas of stopover habitat, a factor when combined with the stress of migration and resultant high relative bird densities could facilitate disease transmission.

In addition to stopover habitat, there is a growing appreciation of airspace as habitat for passage migrants (Diehl 2013, Cohen et al. 2017). Many questions remain regarding the temporal and spatial bounds of migrant traffic and effects of 1) meteorological, climatic, and geographic features, 2) migrant density and species composition of airspace habitats, and 3) variation at multiple scales in all these features. Nevertheless, threats to airspace habitat are growing along with threats to stopover habitat, as communication towers, wind turbines, and buildings invade the space above traditional, terrestrial habitats.

As with all the bird groups treated under the GoMAMN aegis (Figure 1.2), the threats discussed above relate to how they affect and interact with three overarching science needs:

1. effects of management actions,
2. population status and trends, and
3. effects of ecological processes.

Though the body of scientific literature and other investigation for some landbirds, such as Northern Bobwhite, is comparatively greater than that accumulated for other groups like secretive marsh birds or seabirds, significant data gaps still exist for all three science needs (e.g., Cohen et al. 2017).

IDENTIFICATION OF PRIORITIES

Priority Management Actions

GoMAMN values insights into both the effectiveness of management targeted towards priority avian species, as well as assessment of the impacts of other commonly occurring management actions in the region where avian benefits are not a high priority or even considered. The most important management actions, in terms of the number of priority species affected, include ecosystem restoration, sustainable agriculture and forestry, invasive species removal, and prescribed fire (see Table 3.2). However, because of the diversity of species selected through the GoMAMN process, these actions pertain to a number of habitats in the region—evergreen, deciduous, and mixed forests, grasslands, palustrine forested wetlands, and scrub/shrub (see Appendix 1). Also applicable to all migrant species and to a lesser extent resident birds is anthropogenic collision management—using siting, lighting modifications, or construction techniques to eliminate or minimize bird collisions with man-made structures.

The majority of priority landbirds identified by GoMAMN either occur exclusively in evergreen-dominated systems or utilize these habitats under appropriate management regimes. This includes some species that are normally thought of as grassland dependent (e.g., Northern Bobwhite and Henslow's Sparrow). Sustainable use, restoration, and management of grasslands are high priorities as well, and because grassland and scrub/shrub birds will utilize appropriately managed agricultural habitat, sustainable agriculture is another important technique. One of the most important and widely used management tools in evergreen, mixed forest, and grassland habitat is prescribed fire, albeit use is increasingly constrained by human encroachment on these fire-dependent ecosystems (Haines et al. 2001, Cohen 2008). Management and restoration of mixed and deciduous forests as well as palustrine forested wetlands impact many priority GoMAMN landbirds. A lesser number of species are affected through scrub/shrub management and restoration actions, and three species respond to establishment of artificial nest boxes—Red-cockaded Woodpecker and Brown-headed Nuthatch, in appropriately managed evergreen forest habitat, and Prothonotary Warbler in palustrine forested wetland habitat. Across all habitats, invasive species management can affect numerous GoMAMN priority landbirds. We assume ecosystem restoration actions would include management of invasive plant and animal species.

Geographic ranges differ across the suite of priority landbird species identified by GoMAMN (see Description of Species Groups and Important Habitats in the Gulf of Mexico Region section above and Table 3.1). A few species are found throughout the region in the appropriate season and habitats (e.g., Northern Bobwhite, Loggerhead Shrike, and Sedge Wren), with passage migrants adding a large number of species utilizing habitats across the region in spring and autumn. The other species are mainly restricted to the evergreen forests (i.e., coastal pine flatwoods) from the Florida panhandle to southeast Texas. South Florida is a wintering area for Chuck-will's-widow, Yellow-throated Warbler, and Painted Bunting (McKay and Hall 2012, Straight and Cooper 2012, Lowther et al. 2015). Management actions which are relevant to a high proportion of the GoMAMN region or habitats are highly valued (see Table 3.2, Figure 3.1, Appendix 3). Due to the variety of species selected by GoMAMN as priority

Table 3.2. *Uncertainties underpinning the relationship between management decisions and populations of landbirds in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Grassland Landbirds Breeding	Site / Area Management (Land Use)	Does unsustainable agriculture lower grassland bird nesting and reproductive success by degrading soil health, increasing erosion, or altering habitat structure?	Nutrient retention, soil stability, water holding capacity, bulk density, particulate organic matter	Grazing strategies can significantly influence soil function, most research shows rotational versus continuous grazing results in higher organic carbon, C/N ration, and reduced soil compaction. Site-specific conditions, however, may play a role in determining sustainable grazing regimes.	Low	High
Grassland Landbirds Breeding/ Wintering	Invasive / Problematic Species Control (Contaminants)	Does the use of pesticide lead to poor body condition and decline in reproductive success of grassland birds due to decreased invertebrate food sources?	Invertebrate species richness and abundance, avian body condition, fledgling success	Previous research shows invertebrate diversity and abundance decrease in areas where pesticide use is high	Low	High
Grassland Landbirds Breeding/ Wintering	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	Does overgrazing lower reproductive success of grassland birds through the removal of cover and nesting substrate as well as decrease seed and invertebrate food sources?	Invertebrate species richness and abundance, avian body condition, fledgling success	Previous research shows that rotational grazing and light stocking rates increase grassland bird diversity across a landscape	Low	High
Grassland Landbirds Breeding/ Wintering	Invasive / Problematic Species Control (Habitat Management - Invasive Plants)	Does habitat for grassland obligate bird species become unsuitable when invasive species, like woody plants or non-native grasses and forbs, alter the vegetation community and structure?	Amount of woody cover, seed source diversity	Uncertainty regarding season, frequency and intensity of applications to benefit grassland bird survival and successful reproduction.	Low	High
Grassland Landbirds Breeding	Site / Area Management (Land Use)	What constitutes a suitable patch size, shape, and location for grassland birds in the GoMAMN region?	Habitat use, population density	Patch size, shape, and juxtaposition limitations for several species is not well defined. The degree to which patch size influences predation risk is also dependent upon surrounding land use practices. Size limitations for several species is not well defined.	High	High
Grassland Landbirds Breeding	Site / Area Management (Energy Development)	What effects do wind turbines and related activities have on deterring or attracting grassland bird species and nest success along the Gulf Coast?	Habitat use, population density	Which species are most affected? What are the long term effects or cumulative impacts on grassland bird communities? Which species would eventually re-establish or be completely driven out?	High	Unknown
Forest Landbirds Breeding	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	How do agricultural practices associated with cultivated crops affect the quality of adjacent habitat for forest breeding landbirds?	Survival, productivity	Relatively little uncertainty that birds breeding in forest blocks fragemented by agriculture experience decreased productivity.	Low	High
Forest Landbirds Wintering	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	How do agricultural practices associated with cultivated crops affect the quality of adjacent habitat for forest wintering landbirds?	Survival, body condition at spring departure (wintering)	Uncertainty about the long-term effects on populations of landbirds that winter in forest remnants adjacent to row crop agriculture.	High	Unknown

Table 3.2 (continued).

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Forest Landbirds Breeding/ Wintering	Habitat and Natural Process Restoration (Habitat Management-Forestry)	How do silvicultural practices affect habitat quality for forest landbirds?	Survival, population size, productivity (breeding), body condition at spring departure (wintering)	Silvicultural practices can have positive and negative effects on habitat quality of adjacent forest.	High	High
Forest Landbirds Breeding/ Wintering	Site / Area Management (Land Use)	What are the important forest stand characteristics (block size/shape, age, species composition, vertical structure, proximity to other forest blocks, etc.) for maintaining and/ or increasing populations of forest landbirds? What are the appropriate silvicultural techniques for attaining those desired forest characteristics?	Survival, population size, productivity (breeding), body condition at spring departure (wintering)	It is currently unclear how interactions among stand- and site-level vegetation characteristics, forest block size, shape and connectivity, fire history, and arthropod and fruit densities affect avian demography. The degree to which silvicultural practices and other management can replicate natural processes in creating habitat for bird species of concern is not clear, or varies by species.	High	High
Forest Landbirds Breeding	Species Recovery (Habitat Management)	Is deployement of artificial nest boxes an effective and efficient management tool to increase local populations of Prothonotary Warblers or Brown-headed Nuthatches?	Population size, productivity	It is unclear whether investment in nest box deployment programs for Prothonotary Warblers and Brown-headed Nuthatches are an effective management option. It is unknown whether these species' populations are most limited by availability of suitable nest cavities.	Low	Unknown
Forest Landbirds Breeding/ Wintering	Site / Area Management (Land Use)	How does human development affect the quality of remaining habitat for forest breeding landbirds?	Survival, population size, productivity (breeding), body condition at spring departure (wintering)	Some generalist forest breeding species can persist in these altered environments depending on structure and composition of post-development vegetation. Significance of impacts to remnant adjacent forest tracts through increased predation (and/or nest parasitism during the breeding season) will vary depending on the size of the converted area and the size of the remaining adjacent forested tracts.	Low	High
Passage migrant landbirds Migration	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	How do agricultural practices influence likelihood of stopover and stopover success (e.g., food availability, mass gain, stopover duration) in cultivated crop habitats?	Migrant density, refueling rates, stopover duration, survival, population size	Passage migrants such as Dickcissel and Bobolink may use cultivated crop fields during migration, yet little is known about how agricultural practices influence habitat quaility and stopover success.	High	Low
Passage migrant landbirds Migration	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	How do agricultural practices influence likelihood of stopover and stopover success (e.g., food availability, mass gain, stopover duration) in pasture and hay field habitats?	Migrant density, refueling rates, stopover duration, survival, population size	Passage migrants such as Dickcissel and Bobolink may use pasture/hay fields during migration, yet little is known about how agricultural practices influence habitat quaility and stopover success.	High	Low

Table 3.2 (continued).

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Passage migrant landbirds Migration	Habitat and Natural Process Restoration (Habitat Management)	How do changes in vegetation composition affect stopover habitat quality, passage migrant habitat usage, condition, and survival?	Migrant density, refueling rates, stopover duration, survival, population size	Studies have shown that migrants exhibit differential selection related to vegetation composition and habitat structure, but more study is needed to determine how habitat use during migration is related to survival or carryover effects.	High	High
Passage migrant landbirds Migration	Site/Area Management (Land Use)	How do land use-related changes in vegetation composition and structure affect the quality of stopover habitat?	Migrant density, refueling rates, stopover duration, survival, population size	There is uncertainty about how land use changes in vegetation composition and structure affect quality and carrying capacity of stopover habitat.	High	High
Passage migrant landbirds Migration	Site/Area Management (Land Use)	How does the number and size of habitat patches in the landscape influence survival of passage migrants?	Migrant density, refueling rates, stopover duration, survival, population size	There is uncertainty about the number and size of habitat patches needed to support passage migrants given that extrinsic factors can influence where migrants stopover.	High	High
Passage migrant landbirds Migration	Site/Area Management (Land Use)	How does anthropogenic development affect stopover habitat selection, stopover success, and survival of passage migrants?	Migrant density, refueling rates, stopover duration, survival, population size	Uncertainty about how the distribution of anthropogenic development and its associated threats affects survival of passage migrants	High	High
Passage migrant landbirds Migration	Site/Area Management (Species Stewardship)	Does artificial lighting affect migrant distribution patterns at stopover?	Migrant density, refueling rates, stopover duration, survival, population size	Artificial lights are known to attract migrants and there is uncertainty about how lights influence stopover habitat selection.	High	High

[a]Categories follow the classification scheme and nomenclature presented by Salafsky et al. (2008) and Conservation Measures Partnership (2016). GoMAMN derived level three actions are noted in parentheses.
[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.

landbirds, the body of management-related research is large for certain species, such as Northern Bobwhite and Red-cockaded Woodpecker, and sparse for others.

In particular, little management-related research has been directed towards effects on wintering or migrant species; most management that does occur is directed at breeding landbirds. And, even where breeding-season focused management is taking place, the long-term effectiveness is not clear. A review of literature including the Birds of North America accounts pertinent to the GoMAMN's priority landbirds identifies some management-related research needs to reduce uncertainty and better manage landbird populations (see literature cited). For example, despite the large volume of management-related research previously directed at Northern Bobwhite, Brennan et al. (2014) note the need for studies relating to seven different factors, including restoration techniques and various habitat management applications. For most other GoMAMN priority landbirds the list of identified management-related research needs is brief or non-existent. For species with identified needs, questions exist regarding prescribed fire intervals and season for Red-headed Woodpecker, Brown-headed Nuthatch, and Grasshopper Sparrow (Vickery 1996, Slater et al. 2013, Frei et al. 2017), the effects of various silvicultural harvest methods, entry interval, and snag creation for Red-headed Woodpecker, Brown-headed Nuthatch, Wood Thrush, and Swainson's Warbler (Anich et al. 2010, Evans et al. 2011, Slater et al. 2013, Frei et al. 2017), and the effects of timing and types of disturbance regimes for grasslands and scrub/shrub habitat for Common Ground-Dove, Grasshopper Sparrow, Henslow's Sparrow, and LeConte's Sparrow (Vickery 1996, Bowman 2002, Lowther 2005, Baldwin et al. 2007, Johnson et al. 2011).

The management practices commonly used as part of restoration activities in the Gulf of Mexico region are 1) prescribed fire, 2) ecosystem restoration, 3) invasive species removal, and 4) establishment of artificial nest boxes. Other common management actions unrelated to restoration can have significant effects on landbirds in the GoMAMN region. These include conversion of forest to agriculture and subsequent agricultural practices, and silvicultural practices to produce forest products (e.g., pulp and lumber). Landbird priorities for management actions, management related questions, and suggested avian response variables and non-avian covariates to monitor can be found in Table 3.2 and in the Influence Diagrams (Figure 3.1 and Appendix 3). Priorities ranked as high, impact a larger number of priority species as well as passage migrants.

For all monitoring projects that address management actions and their impacts on landbirds, the timing of those actions in different seasons and habitats must also be considered. The same management action, for example, may have a different impact on a species or community depending on when and where it is performed (e.g., burning during the breeding vs the winter season; burning grassland vs evergreen habitat). Additionally, it is essential to understand the full annual cycle (Marra et al. 2015, Cohen et al. 2017) as the conditions experienced one season can carry over to influence subsequent seasons (e.g., Smith and Moore 2003, Paxton and Moore 2015, Paxton and Moore 2017).

Priority Status and Trend Assessments

Species status and trend information is a common currency of wildlife management and strongly influences conservation funding as well as research and management priorities. Therefore, this information is valued by the GoMAMN community of practice, at the full range of spatial scales (global to local), as a measure of response to priority management actions and ecological drivers. The continental concern score for each of our priority species is included in Table3.1. For some priority species, population level status and trend assessments are likely accurate and appropriate (e.g., Northern Bobwhite, Red-cockaded Woodpecker), whereas these metrics may not be appropriate for other, less well-studied species. Additionally, given the large suite of species that make up passage migrants, we are unable to provide metrics for each species, but long-term datasets reveal that some passage migrant species have declined over the past quarter century (see Terborgh 1989, Askins et al. 1990, Both et al. 2006, Wilcove and Wikelski 2008).

Priorities follow the metrics found in the status and trends section of the objective hierarchy, in which we value collecting information on species with declining trends and/or great uncertainty about their trend (Figure 2.2). Ideal monitoring and research efforts will collect data over large spatiotemporal scales, which can greatly reduce uncertainty as well as provide meaningful conservation and management implications (e.g., Buler et al. 2007b, Buler and Moore 2011, Cohen et al. 2015, Lain et al. 2017, Moore et al. 2017, Sands et al. 2017). In conjunction with bird monitoring data, we value the committed collection of habitat quantity and quality data over long time scales for species of interest. For the collection of these data over broad geographic scales, we rely on data collected by the Gulf States via the Gulf of Mexico Alliance Master Mapping Program, the Multi-Resolution Land Characteristics Consortium, a Federal agency partnership responsible for production of the National Landcover Database (NLCD), NOAA Coastal Change Analysis Program (C-CAP), and the Council Monitoring and Assessment Program, a RESTORE Council led effort. In addition, we will collaborate with habitat data collection and evaluation with the Migratory Bird Joint Venture programs (Migratory Bird Joint Ventures 2018) in the GoMAMN region: Gulf Coast, Atlantic Coast, East Gulf Coastal Plain, Lower Mississippi Valley, Rio Grande, and Oaks and Prairies.

Given that information on status and trends as well as monitoring programs should be more similar for species that share the same habitat during various seasons, below we provide information specific to: forest breeding, forest wintering, grassland breeding, grassland wintering, and passage migrant landbirds.

FOREST BREEDING. Some status and trend information for GoMAMN forest breeding birds is available through analysis of Breeding Bird Survey (BBS) data, a road-based point count program. For detailed information on the BBS see Sauer et al. (1997). The BBS currently provides trend information from 1966–2015. Trend information is available by state and physiographic region, but unfortunately there is no direct correspondence with the GoMAMN boundary, thus no trend information is available for that specific area. For each region in which a species' trend is reported, the BBS provides a species and region-specific Regional Credibility Measure, indicated by one of three colors: red, yellow, or blue (Sauer et al. 2017). The lowest confidence category (red) includes data with important deficiencies related to very low abundance, small sample size (less than five routes in the region) or imprecision such that a 5% change per year would not be detected over the long term. The second highest level of confidence (yellow) reflects data with deficiencies related to low abundance, small sample size (less than 14 routes in the region), or imprecisions such that a 3% change per year would not be detected over the long term. Estimates with the highest confidence, denoted by blue, include data with moderate abundance, at least 14 samples in the long term, and are of moderate precision. For example, the trend for Northern Bobwhite in Florida is given a blue regional credibility measure, because the species is detected on 90 routes, while the trend for Northern Bobwhite in New Hampshire is given a red credibility measure, due to the species being detected on only four routes and in low numbers. Given sufficient detections, species trends are also available for individual BBS routes in the GoMAMN region. There are ~200 current or historic BBS routes in the GoMAMN region. Sands et al. (2017) used BBS data to analyze trends for 27 bird species in the Gulf Coast Joint Venture (GCJV) geography, and conducted a power analysis to estimate 80% power to detect trends at 3, 5, 10, and 20-year intervals based on ±1%, ±3%, ±5%, and ±10% rates of annual population changes. Several of the 27 species treated in Sands et al. (2017) are also GoMAMN priority landbirds: Bachman's Sparrow, Brown-headed Nuthatch, Loggerhead Shrike, Northern Bobwhite, Painted Bunting, Prothonotary Warbler, Red-cockaded and Red-headed Woodpeckers, Swainson's Warbler, and Wood Thrush. Of these, Red-cockaded Woodpecker had insufficient detections prohibiting reliable trend estimates for the GCJV region. The power analysis indicated that BBS data could reliably estimate trends for 4 of the 27 species: Brown-headed Nuthatch [-0.50%, 95% Confidence Interval (CI) (-1.88%, 1.01%)], Northern Bobwhite [-4.50%, 95% CI (-5.16%, -3.92%)], Swainson's Warbler [-3.44%, 95% CI (-5.73%, -1.09%)], and Wood Thrush [-1.78%, 95% CI (-3.05%, -0.58%)].

Hamel et al. (1996) recommended the use of 5–10 minute point counts as a means for land managers in the southeast U.S. to obtain information on numbers of birds and population trends on their properties. Hamel et al.'s (1996) methodology entails the use of discrete distance and temporal categories, where the bird's distance from the observer and the interval of detection (first three minutes, the next two minutes, or final five minutes of the count) are recorded. Subsequent to publication of Hamel et al. (1996), other researchers expressed doubt regarding the utility of unadjusted point counts in determining bird species abundance or density because of issues related to incomplete detection. Recommendations to address these detection issues include changes in sampling techniques (Nichols et al. 2000, Bart and Earnst 2002) or estimating detection probabilities through data analysis, provided the data are grouped by distance and time observed (Farnsworth et al. 2002, Rosenstock et al. 2002). Similarly, Somershoe et al. (2006) recommended incorporation of distance sampling and quantitative habitat characterization into BBS monitoring, and Twedt (2015) recommended distance sampling and using three 1-minute time intervals on BBS points to improve detection probabilities. If additional information on vital rates is desired, the approach utilized by Saracco et al. (2008) should be considered.

FOREST WINTERING. The Audubon Christmas Bird Count (CBC) is the only long-term dataset available for the GoMAMN region with potential for tracking wintering forest landbird status and trends. However, the CBC was not designed for population monitoring and has numerous problems restricting its use for that purpose, including variability in count effort within and across individual CBC areas (circles), and nonrandom count circle distribution (Dunn et al. 2005). Notwithstanding its flaws, Dunn et al. (2005) cited the potential application of CBC data to large-scale studies because of its broad temporal and spatial coverage, and offered suggestions for improving the utility of existing data, and for collecting future data. Sauer and Link (2002) and Niven et al. (2004) describe modeling approaches they used to account for CBC data shortcomings to develop population trends for selected bird species in specific regions of North America.

Similar to their analysis of BBS data, Sands et al. (2017) used CBC data to analyze population trends of 37 bird species in the GCJV region. Sands et al. (2017) also conducted a power analysis on the CBC data, using the parameters described above for their BBS analysis. GoMAMN priority landbirds included in the analysis were LeConte's Sparrow, Loggerhead Shrike, and Northern Bobwhite. The authors found that the CBC reliably estimated trends for two of the 37 species in the GCJV region: Ring-necked Duck (*Aythya collaris*) and Loggerhead Shrike.

Point count methodology (Hamel et al. 1996) that has been modified to improve detection probabilities (Nichols et al. 2000, Bart and Earnst 2002, Farnsworth et al. 2002, Rosenstock et al. 2002) may be appropriate to determine the status and trends of priority forest landbirds wintering in the GoMAMN region. If additional information on vital rates is desired, the approach utilized by Saracco et al. (2008) should be considered.

GRASSLAND BREEDING. Status and trend information from 1966–2015 and 2005–2015 are available through the aforementioned BBS analysis (Sauer et al. 1997) for Northern Bobwhite in several survey regions that overlap with the GoMAMN boundary; all indicate an overall decline in bobwhite abundance for these regions. Credibility measurement indicators for all survey regions within the GoMAMN boundary are in the blue category, meaning sample size, precision, and abundances are adequate for reliable trend estimates. Similarly, Loggerhead Shrike shows declines across the GoMAMN region according to the BBS, with reliable trend estimates according to BBS credibility measurement indicators. Grasshopper Sparrow breeding is much more localized in the GoMAMN region vs Northern Bobwhite and Loggerhead Shrike. The BBS indicates a non-significant increasing trend for the Gulf Coastal Prairie and Tamaulipan Brushland physiographic regions, but assigns a red credibility measurement indicator for the data, reflecting some combination of very low abundance, very small sample size, and/or imprecision. Besides BBS trend data, comprehensive population trend data are scarce for grassland species breeding in the U.S. Gulf Coastal Plain.

Buckland (2006) provides information comparing five common methods of estimating bird densities: five-minute point counts where the observer remained stationary and recorded distances to birds detected, three-minute snapshot surveys where the observer was allowed to move around after the snapshot period, five-minute cue-count surveys where the observer recorded songbursts only, line transects where the observer traveled along a line and recorded distances to all bird detections, and territory mapping where an observer recorded locations of birds detected during nine visits. Of these sampling techniques, the line transect method proved to be the most efficient sampling method and overall provided the most precise estimates when comparing reported coefficient of variations (CV). Because grasslands have less visual obstruction from an observer point of view and maneuverability tends to be more flexible than in forested habitat, walking line transects may be best suited for monitoring breeding grassland bird densities and abundances. Ideal number of detections for reliable estimates is >60 (Buckland et al. 2001). To maximize number of detections, number and length of transects on the landscape will vary depending on habitat availability and size. The use of multiple covariates may also increase the precision of density estimates (Marques et al. 2007); common covariates used in analyses include observer, julian date, and time of day or hours after sunrise.

GRASSLAND WINTERING. Very limited information is available on population trends of wintering grassland birds in the GoMAMN region. General trends for wintering priority species primarily rely on the Audubon CBC. Number of count circles recording Henslow's Sparrow from 1970–2005 has generally increased, with the lowest number of recordings in 1985 and peak number of recordings in 2001 (Cooper 2012). An analysis of CBC data for the Le Conte's Sparrow from 1965–2002 showed a slight negative population trend; however, populations have generally remained stable (Niven et al. 2004).

Loggerhead Shrike (*Lanius ludovicianus*).
Photo credit: Tom Koerner

Because of the non-parameterized nature of the CBCs, populations trends may be unreliable. Twedt et al. (2008) compared two methods of winter grassland bird surveys: Winter Bird Population Studies, an area-search method by a single observer over multiple visits, and Project Prairie Birds survey where an observer walks a line transect recording birds that are flushed by two "non-observing flushers." The authors found that while the Winter Bird Population Studies method produced higher estimates of species richness, Project Prairie Bird survey methods tended to provide higher abundances, especially of secretive species, and recommended the use of the latter method for species specific surveys. Further, by incorporating distance sampling to the Project Prairie Bird method, researchers can obtain detection probabilities, yielding more precise and comparable estimates of densities and abundances across grassland types throughout the region.

PASSAGE MIGRANTS. There is limited information on the status and trends of the specific populations using stopover habitat within the GoMAMN region, although many migrant populations are in decline (reviewed by Cohen et al. 2017; see also Sauer et al. 2013, Rosenberg et al. 2016). Thus, we would be most interested in broad-scale, population-level trends over time that inform migrant-habitat relations within the Gulf of Mexico region as well as between different functional

Table 3.3. *Uncertainties related to how ecological processes impact populations of landbirds in the northern Gulf of Mexico*

Species Seasons	Ecological Process Category[a]	Question	Endpoint to Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Grassland Landbirds Breeding/ Wintering	Climatic Processes	How are grassland obligate bird populations, nesting productivity, and food sources affected by variation in annual precipitation?	Population size, productivity, invertebrate and seed species richness and abundance	Difficult to predict impacts. Some insect population are cyclic in nature and independent of weather condtions.	High	Unknown
Grassland Landbirds Breeding/ Wintering	Natural Disturbance Regime	How do periods of extreme drought affect population dynamics of grassland obligate birds?	Population size, survival	How long does it take for populations significantly affected by drought to recover? What is the definition of recovery (what is the timeline when determining stable or recovered population: 1, 5, 10 years)?	High	Unknown
Grassland Landbirds Breeding	Interactions Between Organisms	How is nestling success of grassland birds impacted by fire ant predation?	Productivity, nestling and fledgling success, fire ant abundance, habitat use	How are populations of different species affected? Does nesting ecology of species significantly influence vulnerability to predation (i.e. ground nesting birds versus slightly elevated nests)?	Low	High
Grassland Landbirds Breeding/ Wintering	Interactions Between Organisms	How are invertebrate food sources for grassland birds affected by the establishment of red imported fire ant colonies?	Invertebrate species richness and abundance, fire ant abundance, habitat use	What is the overlap between grassland bird and fire ant food sources? Many studies are related to economic rather than ecological impact.	High	Unknown
Forest Landbirds Breeding/ Wintering	Climatic Processes	How do changes in annual precipitation and temperature affect food availability for forest landbirds during breeding and wintering seasons?	Invertebrate species richness and abundance, fruiting plant species richness and abundance, habitat use	Difficult to predict impacts. Some insect population are cyclic in nature and independent of weather condtions.	High	Unknown
Forest Landbirds Breeding	Natural Disturbance Regimes	How do extreme weather events affect the nest success and survival of forest landbirds?	Productivity, fledgling success, survival	Difficult to predict the impacts of extreme weather events and likely impossible to influence.	High	Unknown
Forest Landbirds Wintering	Climatic Processes	How do extreme cold events affect the overwinter survival of forest landbirds?	Invertebrate species richness and abundance, fruiting plant species richness and abundance, survival, body condition	Difficult to predict the impacts of extreme cold events and likely impossible to influence.	High	Unknown
Forest Landbirds Breeding/ Wintering	Natural Disturbance Regimes	How do storm-induced changes in vegetation structure and composition affect habitat quality for forest lanbirds during breeding and wintering seasons?	Invertebrate species richness and abundance, fruiting plant species richness and abundance, survival, body condition at spring/autumn departure, productivity (breeding), habitat use	Depending on the bird species, storm-created forest gaps may have positive or negative effects on forest breeding landbirds.	High	Unknown

Table 3.3 (continued).

Species Seasons	Ecological Process Category[a]	Question	Endpoint to Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Forest Landbirds Breeding	Climatic Processes	Will climate induced changes in vegetation structure and composition affect resources available to forest breeding landbirds?	Invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at autumn departure, productivity, habitat use	There is uncertainty about how climate induced changes in the vegetation composition and structure of habitats influence food availability and nesting substrates for forest breeding landbirds.	High	High
Forest Landbirds Wintering	Climatic Processes	Will climate induced changes in vegetation structure and composition affect resources available to forest wintering landbirds?	Invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at spring departure, survival, habitat use	There is uncertainty about how climate induced changes in the vegetation composition and structure of habitats influence food availability for forest wintering landbirds.	High	High
Forest Landbirds Breeding	Interactions Between Organisms	How does forest patch size and landscape context influence predation on forest breeding landbirds?	Habitat use, population density, survival, productivity	There is uncertainty about the minimum forest patch size needed to reduce predation of forest breeding landbirds and about how this relationship is influenced by landscape context.	High	Unknown
Forest Landbirds Wintering	Interactions Between Organisms	How does forest patch size and landscape context influence predation on forest wintering landbirds?	Habitat use, population density, survival	There is uncertainty about the minimum forest patch size needed to reduce predation of forest wintering landbirds and about how this relationship is influenced by landscape context.	High	Unknown
Forest Landbirds Breeding	Interactions Between Organisms	How does deer browsing affect the nesting and foraging habitat of forest breeding landbirds?	Habitat use, population density, productivity, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at autumn departure	There is uncertainty regarding what level of deer herbivory results in forest block-level changes in survival and productivity of priority forest breeding landbirds, and which GoMAMN priority breeding landbirds are impacted.	High	Unknown
Forest Landbirds Wintering	Interactions Between Organisms	How does deer browsing affect the foraging habitat of forest wintering landbirds?	Habitat use, population density, survival, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at spring departure	There is uncertainty regarding what level of deer herbivory results in forest block-level changes in survival of priority forest wintering landbirds, and which GoMAMN priority wintering landbirds are impacted.	High	Unknown
Forest Landbirds Breeding	Hydrological Processes	How does a change in hydrology affect nest sites and food availability for forest breeding landbirds?	Habitat use, population density, productivity, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at autumn departure	Hydrologic changes that alter plant species composition may have positive and negative affects on nesting substrates and food availability for forest breeding landbirds.	High	Unknown

Table 3.3 (continued).

Species Seasons	Ecological Process Category[a]	Question	Endpoint to Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Forest Landbirds Wintering	Hydrological Processes	How does a change in hydrology affect roost sites and food availability for forest wintering landbirds?	Habitat use, population density, survival, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at spring departure	Hydrologic changes that alter plant species composition may have positive and negative affects on roosting substrates and food availability for forest wintering landbirds.	High	Unknown
Forest Landbirds Breeding	Interactions Between Organisms	How do invasive plant species affect food availability for forest breeding landbirds?	Habitat use, population density, productivity, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at autumn departure	Some invasive plant species produce fruits that can be used by forest breeding landbirds while other plant species decrease food availability by hosting fewer insects than native plants.	High	Unknown
Forest Landbirds Wintering	Interactions Between Organisms	How do invasive plant species affect food availability for forest wintering landbirds?	Habitat use, population density, survival, invertebrate species richness and abundance, fruiting plant species richness and abundance, body condition at spring departure	Some invasive plant species produce fruits that can be used by forest wintering landbirds while other plant species decrease food availability by hosting fewer insects than native plants.	High	Unknown
Passage migrant landbirds Migration	Climatic Processes	Will climate induced changes in precipitation and temperature patterns reduce food availability for passage migrants?	Migrant density, refueling rates, stopover duration, survival, population size, invertebrate species richness and abundance, fruiting plant species richness and abundance	Climate change may result in asynchrony between peak food availability and peak migration traffic. Uncertainty remains about how climate change will affect the food resources migrants currently depend on.	High	High
Passage migrant landbirds Migration	Natural Disturbance Regime	Will increases in severe storm frequency significantly alter the vegetation structure and composition of stopover habitat and affect resources available to migrants?	Migrant density, refueling rates, stopover duration, survival, population size, invertebrate species richness and abundance, fruiting plant species richness and abundance, habitat use	There is uncertainty about how an increase in severe storm frequency will influence the availability of food and shelter for passage migrants.	High	High
Passage migrant landbirds Migration	Natural Disturbance Regime	Do hurricane induced changes in vegetative composition and structure have a negative effect on landbird use of stopover sites?	Migrant density, refueling rates, stopover duration, survival, population size, invertebrate species richness and abundance, fruiting plant species richness and abundance, habitat use	There is uncertainty about how hurricane-induced changes in the vegetation composition and structure of habitats influences stopover success of passage migrants.	High	High

Table 3.3 (continued).

Species Seasons	Ecological Process Category[a]	Question	Endpoint to Measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Passage migrant landbirds Migration	Interactions Between Organisms	Do invasive species negatively affect passage migrants by altering the quality of stopover habitat?	Migrant density, refueling rates, stopover duration, survival, population size, invertebrate species richness and abundance, fruiting plant species richness and abundance, habitat use	Although many passage migrants exhibit dietary plasticity, there is uncertainty that invasive species provide quality food resources for passage migrants.	High	High

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

types of stopover habitats. There are essentially no long-term monitoring programs, and no projects which collect data across multiple states, which limits our ability to understand how en route events in the GoMAMN region impact passage migrant populations. Such monitoring programs are needed to address key research needs, including distribution, timing and habitat associations, habitat characteristics and quality, migratory connectivity, as well as threats to and current conservation status of airspace and stopover habitat (Cohen et al. 2017). However, there have been a few long-term (20+ years) migration banding stations that may provide a starting point for population metrics. Current landbird projects are collecting important data in key stopover areas and we hope many of these projects will continue long term, but data collected at larger continuous spatial scales are needed to truly understand the status and trend of passage migrants (see Cohen et al. 2017 for additional needs). The integration of weather surveillance radar and banding data, along with new technologies, provide powerful tools to better monitor and understand migrants across the region.

Priority Ecological Processes

Identifying important ecological processes and reducing uncertainty associated with their effects on populations of GoMAMN priority landbirds is highly valued by the GoMAMN community of practice. We ranked questions about how ecological processes impact landbirds with a combination of our estimated effect size (Unknown > High > Low) and uncertainty (High > Low). Questions with the same combination of effect size and uncertainty have the same rank and were not placed in a particular order within their group (Table 3.3). The landbird working group developed the elements found in the ecological processes table through several conference calls drawing on expert knowledge from scientists, researchers, and managers across the Gulf of Mexico who study landbirds and/or manage their appropriate habitats. To prioritize these processes, we used the ecological process objective hierarchy values, which emphasize our collective interest in questions relevant to our priority species and reduce uncertainty in how ecological processes influence population dynamics and improve our ability to predict those dynamics (Figure 2.2). We used the landbird influence diagrams (Figure 3.1 and Appendix 3) to connect our ecological processes with population dynamics. The Influence Diagrams and Table 3.3 identify questions associated with priority ecological processes and suggest avian response variables and non-avian covariates that should be considered in developing monitoring programs. Ecological processes for each habitat/season group are described below:

FOREST BREEDING. The GoMAMN Landbird Working Group identified a number of ecological processes influencing populations of forest breeding landbirds. Anthropogenic habitat changes have resulted in conversion of forested habitat to agriculture and residential or commercial development. Loss and fragmentation of forested habitat have negatively impacted many species of North American birds through reduction in available nesting and foraging habitat and increased predation and nest parasitism rates (Freemark and Collins 1989, Robinson 1989, Harris and Gosselink 1990, Smith et al. 1993). Depending on the practices and

Painted bunting (*Passerina ciris*). Photo credit: Robert Pos

bird species of interest, alteration of forest structure and plant species composition through silvicultural practices can have positive or negative impacts (Harris and Gosselink 1990, Drapeau et al. 2000, Bassett-Touchell and Stouffer 2006, Heltzel and Leberg 2006, Brockerhoff et al. 2008, Twedt and Somershoe 2009). Techniques and scale of timber harvest, or conversion of natural forests to monotypic forest product plantations can have significant impacts to forest breeding birds by altering forest structure and plant species composition (Harris and Gosselink 1990, Drapeau et al. 2000, Bassett-Touchell and Stouffer 2006, Heltzel and Leberg 2006, Brockerhoff et al. 2008, Twedt and Somershoe 2009, Yahner et al. 2012). Even-aged timber harvest (e.g. clear-cutting) typically produces habitat dominated by shrubs and saplings and is used by bird species dependent on that vegetative structure, such as Yellow-breasted Chat (*Icteria virens*) and Common Yellowthroat (*Geothlypis trichas*), while bird species which utilize mature forests, such as woodpeckers, are typically absent (Yahner et al. 2012). Even-aged timber harvest may subject nesting birds in adjacent mature forest blocks to increased predation and nest parasitism (Yahner et al. 2012). Conversely, habitat for early successional habitat birds may be lacking in mature forest stands, and managers may utilize selective timber harvest to mimic natural disturbance and create small inclusions of early successional habitat (Twedt and Someshoe 2009). The impacts of weather on food supplies, survival, and forest structure to forest breeding landbirds is believed to be significant (Blake et al. 1989, Sherry and Holmes 1989, Wiley and Wunderle 1993, Torres and Leberg 1996); with the added impacts of altered weather patterns due to changing climatic conditions (Butler 2003, Crick 2004, Hitch and Leberg 2007). Other ecological processes identified by the GoMAMN Landbird Working Group include predation (possibly influenced by anthropogenic habitat changes described above), altered hydrology due to water withdrawals or flood control measures, and invasive plant and animal species.

FOREST WINTERING. The same ecological processes identified for forest breeding landbirds are expected to be important for forest wintering landbirds in the GoMAMN region. Overwinter survival and body condition may be impacted by conversion of forests to other habitat types (Greenberg and Droege 1999, Greenberg and Matsuoka 2010), forest fragmentation (Doherty and Grubb 2000, Doherty and Grubb 2002), alterations to forest structure and species composition through timber management (White et al. 1996), changes in hydrology, weather extremes (Rice 1924, Petit 1989, Avery 2018) and shifts from normal patterns due to climate change, predation, and invasive species. Greenberg and Droege (1999) and Greenberg and Matsuoka (2010) postulated that loss and degradation of woody wetlands on the winter range of Rusty Blackbird was a major factor in that species' population decline. Dougherty and Grubb (2000) studied winter bird distribution in small (0.54–6.01 hectares) forest fragments in Ohio and found strong positive relationships between species presence, density and diversity and forest fragment size. Dougherty and Grubb (2000) also found that isolation, as measured by distance to adjacent forest fragments and patch connection through fencerows, negatively influenced the presence of many bird species. However, Hamel et al. (1993) did not detect any effects of forest fragmentation (smallest patch = 17 hectares) on wintering avian species richness and evenness in Tennessee. White et al. (1996) examined distribution and abundance of wintering birds in Georgia in fragmented mature pine, fragmented mature upland hardwood, and pine plantation habitats. Overall, they found that only about 25% of bird species detected showed significant habitat preferences, but species richness, diversity, and evenness was higher in the mature forest types versus pine plantations.

GRASSLAND BREEDING. Like forest breeding birds, many of the ecological processes affecting grassland breeding birds derive from anthropogenic changes on the landscape. These include invasion of woody species as a result of fire suppression, habitat loss or fragmentation from agriculture, and incompatible land management practices (i.e., inappropriately timed mowing/haying, overstocked livestock) (Potter et al. 2007, Jaster et al. 2012, Kreitinger et al. 2013). The introduction of non-native grasses for livestock forage is a major threat to many grassland birds. Establishment of exotic grasses leads to decreased diversity in plant and invertebrate communities and structural changes to potential nesting habitat (Fleischner 1994, Flanders et al. 2009, Flory and Clay 2010). Many commonly introduced species include cool-season grasses, or grasses that grow during spring or fall when temperatures are cooler (i.e. Tall Fescue [*Schedonorus arundinaceus*], Bromegrasses [*Bromus* spp.], Ryegrasses [*Lolium* spp.]). Native prairies within the GoMAMN region, however, are historically dominated by warm-season grasses that provide appropriate nesting and foraging habitat for grassland birds. Additionally, increased levels of atmospheric CO_2 combined with predictions of hotter, dryer summers are projected to create conditions that favor non-native cool-season grasses (Collatz et al. 1998, Wand et al. 1999).

The use of pesticides in agricultural areas may also pose a significant threat to grassland birds; reduced insect availability to insectivores can affect all life stages of birds and may have an even greater impact on populations than agriculture (Mineau and Whiteside 2013). The introduction of non-native red imported fire ants (*Solenopsis invicta*) and tawny crazy ants (*Nylanderia fulva*) can decrease insect food sources and prey upon ground nesting birds as well (Allen et al. 2004, LeBrun et al. 2013). Little research, however, has been focused on tawny crazy ant effects on wildlife. Other non-anthropogenic related threats include nest predation by Brown-headed Cowbirds (*Molothrus ater*). Songbird reproductive success rates have been shown to be negatively affected by cowbird nest predation, and effects may be further exacerbated with the encroachment of woody vegetation (Shaffer et al. 2003, Patten et al. 2006).

GRASSLAND WINTERING. Most ecological processes that affect wintering grassland birds are the same as those listed under the breeding grassland birds section above. These include invasion of woody species as a result of fire suppression, habitat loss or fragmentation from agriculture, and incompatible land management practices (i.e., inappropriately timed mowing/haying, overstocked livestock) (Potter et al. 2007, Jaster et al. 2012, Kreitinger et al. 2013). Wintering populations may also be affected by climate change. As atmospheric CO_2 increases and climatic conditions begin to favor cool-season non-native grasses, prairies may no longer be able to support populations of wintering grassland birds. Seeds make up the majority diet of overwintering birds. However, as non-native grasses become established and prairie species richness declines, food availability for wintering birds may be significantly limited. Additionally, frequent extreme weather events, such as freezes and floods, can impact foraging success by lowering the abundance of insect food sources (Serie and Jones 1976, Graber and Graber 1979). There is high uncertainty, however, as climate models are variable.

PASSAGE MIGRANTS. Interactions among ecological processes influencing passage migrants are complex and operate at multiple scales, both temporally and spatially, with effects experienced at one place in time (e.g., stopover) carrying over to influence an individual's success in the subsequent stage of the annual cycle (e.g., breeding) (Cohen et al. 2017). During migration, individuals must stop in order to rest and refuel and decisions about when and where to stop typically occur with incomplete information, in unfamiliar places, and within landscapes that have heterogeneous configurations of habitat quality and quantity (reviewed by Moore 2018). At stopover sites, migrants then must attain a positive energy balance in the face of variable food availability, competition with other migrants as well as resident birds, and predation, all the while needing to resume migration in a timely fashion (Moore 2018). The four major categories of ecological processes identified to influence passage migrants include climate change, vegetative composition of stopover sites, anthropogenic development, and habitat availability. Increasing our understanding of these underlying processes will increase understanding of population changes, including the effects of direct management actions versus ecological processes that affect the populations of migratory species.

The effects of climate change on migrant populations is uncertain and has the potential to impact a significant proportion of the population. Climate change can affect passage migrants through a mismatch in peak migration traffic and peak food availability—arguably the most important factor influencing migrant distributions (e.g., Buler et al. 2007b, Zenzal et al. 2018). Additionally, climate change can influence the composition and structure of vegetation, through changes in temperature and precipitation as well as increased frequency of severe storms like hurricanes (Scavia et al. 2002; Knutson et al. 2010; Holland and Bruyère 2014), which may influence the availability and quality of food resources (Dobbs et al. 2009, Lain et al. 2017). In addition to hurricanes, vegetative composition at a stopover site can also be influenced by the invasion of exotic species (e.g., Chinese tallow), which can occur in conjunction with hurricanes. As discussed in the Primary Threats and Conservation Challenges section above, invasive species such as Chinese tallow may provide fewer resources, both direct (fruit) and indirect (arthropods), for migrants (Barrow et al. 2000, Barrow and Renne 2001; but see Conway et al. 2002). Land use changes also influence vegetative composition; for example, the conversion of forested habitat to cattle grazing or agricultural lands may still provide habitat but likely at a lower quality to the detriment of migrants (Barrow et al. 2000, Barrow et al. 2005). Urbanization also decreases available habitat and can introduce factors, such as invasive species, tall structures, pollution, pesticides, and free ranging/feral cats that may degrade existing habitats (Barrow et al. 2005). Additionally, urban areas create artificial light pollution that has been shown to attract migrants, possibly increasing the risk of collision or influencing migrants to select lower quality habitats (Gauthreaux and Belser 2006 and references therein; Van Doren et al. 2017, McLaren et al. 2018). None of these factors act alone, rather they interact in complex ways to influence migrant decisions.

SUMMARY AND MONITORING RECOMMENDATIONS

Forest breeding and wintering birds

★ Forest management practices have profound positive and negative, species-dependent impacts on GoMAMN priority forest breeding and wintering landbirds. Some forestry practices occurring in the region are targeted at production of fiber, with wildlife benefits typically less of a priority. In other instances, forestry practices are intended to produce habitat for game species, and in others, management is executed with the intent of improving habitat for one or more GoMAMN priority bird species. Thus, a range of management-related monitoring is required. In the case of commercial timber and pulp production, monitoring the response of priority birds to normal and experimental forestry practices is needed. In the case of wildlife and bird-specific forestry practices, monitoring the species' response to various treatments to improve future management methodology is critical. For many GoMAMN forest breeding and wintering birds, optimal forest stand conditions are poorly understood, and research needs have not been identified. For species with identified needs, questions exist regarding prescribed fire intervals and season for Red-headed Woodpecker, Brown-headed Nuthatch, and Grasshopper Sparrow (Vickery 1996, Slater et al. 2013, Frei et al. 2017), and the effects of various silvicultural harvest methods, entry interval, and snag creation for Red-headed Woodpecker, Brown-headed Nuthatch, Wood Thrush, and Swainson's Warbler (Anich et al. 2010, Evans et al. 2011, Slater et al. 2013, Frei et al. 2017). These needs can serve as initial foci for experimental forest treatments and monitoring species response.

★ The effects of climate change on forest structure and species composition may have significant effects on priority forest bird species distribution and population trajectory. Monitoring the changes in forest composition and structure and avian species response is a high priority.

★ While existing status and trend monitoring and information is likely better for landbirds than some of the other GoMAMN avian guilds, it is important to maintain (and fully implement) existing protocols, such as the BBS. However, it may be necessary to develop specific status and trend monitoring protocols that are better suited to detect population changes in priority forest bird species.

Grassland breeding and wintering birds

★ Grasslands are one of the most threatened and under-protected habitat types of North America. Conversion of native prairie for livestock and crop production has led to the decline of many bird species populations, including GoMAMN priority grassland breeding and wintering landbirds. However, several conservation programs are available to landowners that aid in protecting land productivity and improvement of habitat for wildlife (e.g., Conservation Reserve Program, Environmental Quality Incentives Program, Conservation Stewardship Program). Although these programs provide assistance to land managers, benefits to wildlife, particularly GoMAMN priority bird species, are not consistently measured or monitored. Additionally, species may respond differently to various management tools and application regimes. For example, Henslow's Sparrow populations have benefited since the establishment of the Natural Resources Conservation Service Conservation Reserve Program while Grasshopper Sparrow population trends continue to decline (Herkert 1997, Sauer et. al. 1999). Because most research on declining species tend to be focused on their breeding range, little is known about response to habitat management within their wintering range. As a result, conservation of wintering habitat may be limited by this lack of information. All GoMAMN priority grassland birds depend on the GoMAMN region during wintering months with two species (Grasshopper Sparrow and Northern Bobwhite) breeding in this region. Research should include influence of management and connectivity of grasslands on species during both wintering and breeding seasons.

★ Climate change may impact prairie quality. Predictions of increased temperatures and reduced rainfall may encourage the spread of non-native grasses and decrease insect availability as well as diversity (Peterson 2003, Thuiller et al. 2007). These changes may also cause phenological shifts that impact grassland bird reproduction, however there is little information or long-term datasets documenting changes in synchrony of food sources or predator/prey interactions (Parmesan 2006, Visser and Both 2005). Encouraging research projects to include collecting data on grassland invertebrate communities may provide better insight to population dynamics of grassland birds..

★ Existing status and trend monitoring protocols, such as the BBS and CBC, provide valuable information about species on a large scale. However, these types of surveys do not lend themselves to understanding how specific habitat management or other changes on the landscape can impact populations of grassland birds. It may be necessary to develop specific status and trend monitoring protocols that are better suited to detect population changes in priority grassland bird species.

Passage migrants

★ Arguably, stopover habitat for migratory landbirds is the most important habitat found within the GoMAMN region. These stopover habitats constitute various forested, grassland, and scrub/shrub habitats, function in different ways (see Mehlman et al. 2005), and are used by a wide variety of species as areas to rest and refuel during both spring and autumn (Barrow et al. 2005, Buler et al. 2007a, Buler and Moore 2011, eBird 2018, Lafleur et al. 2016). The conservation and preservation of these stopover habitats is especially critical given that the migratory period is thought to account for the greatest risk of mortality during the annual cycle (e.g., Sillett and Holmes 2002, Newton 2007, Paxton et al. 2017). Moreover, stopover habitat is thought to limit the population size of some migratory species (see Sherry and Holmes 1995, Newton 2007, 2008).

★ Climate change and anthropogenic activities (e.g., land use change, urbanization) are the two major factors that can impact passage migrants as they can decrease available stopover habitat, alter the vegetative composition and structure of habitats, as well as influence food resources. Climate change, for example, can instigate a mismatch between the arrival of migrants and food availability as well as alter the structure and composition of habitats due to changes in temperature and precipitation. Urbanization can have similar negative impacts, the most obvious decreasing available stopover habitat but also include the introduction of invasive species, tall structures, pollution (e.g., chemicals, light, etc), pesticides, and free ranging/feral cats. While there is some information on how passage migrants cope with these challenges, the impacts of climate change, anthropogenic development, habitat availability, and vegetative composition on population size and other metrics (e.g., refueling rates, stopover duration) are still highly uncertain for the GoMAMN region and should be the focus of monitoring efforts in the near future (Cohen et al. 2017).

★ Due to their ephemeral nature, passage migrants are likely the hardest group for which to monitor status and trends. Unlike breeding and wintering species, which use BBS and CBC protocols, no such widespread monitoring protocol exists for en route migrants. In the absence of well-established protocols, passage migrant populations should be monitored using a multi-scale approach, which can focus on fine scale habitat factors through regional patterns found across the GoMAMN region. At the largest scale, weather surveillance radar can address uncertainties associated with status and trends as well as ecological processes, such as atmospheric conditions across the entire Gulf of Mexico region. Banding stations and surveys can address local and, potentially, landscape scale management actions and ecological processes for the migrant community depending on the sampling design. Finally, automated telemetry can provide information on how individuals respond to management actions and ecological processes locally as well as at larger scales if an appropriate network of automated receiving units exist (e.g., MOTUS). Additionally, integrating these monitoring tools can provide resource managers and conservation planners a holistic framework for which to establish appropriate and meaningful conservation practices for passage migrants as well as reduce uncertainty at multiple scales.

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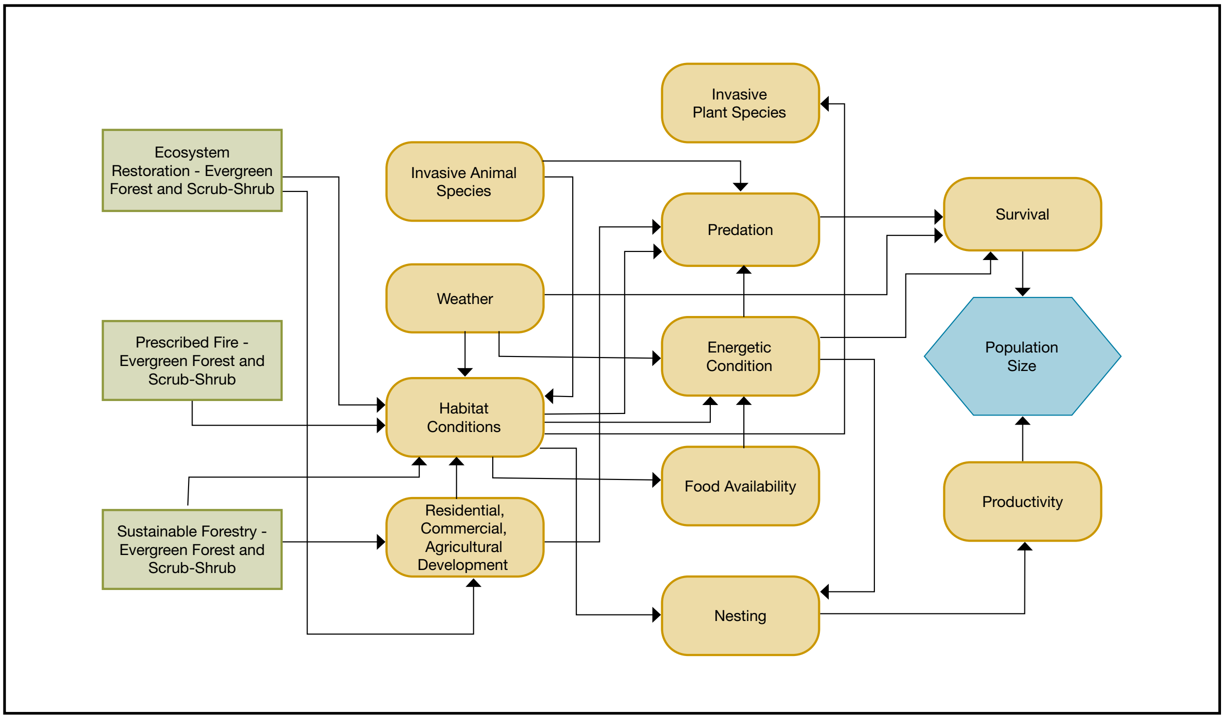
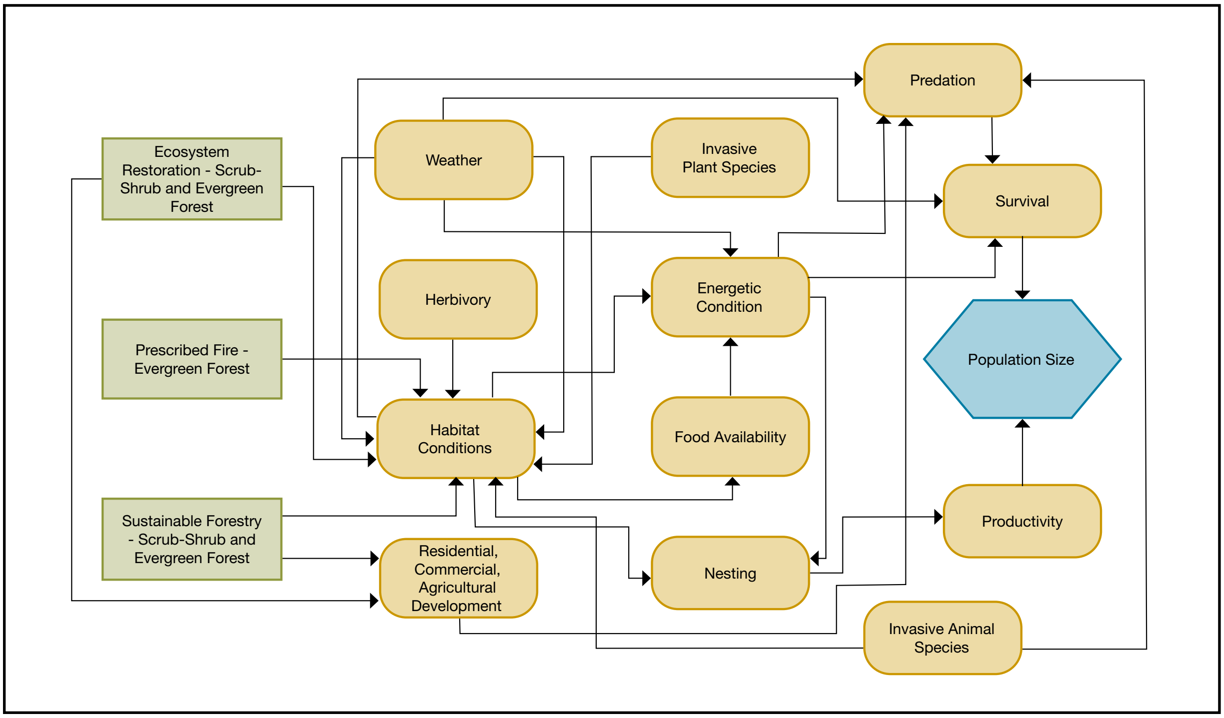
APPENDIX 3

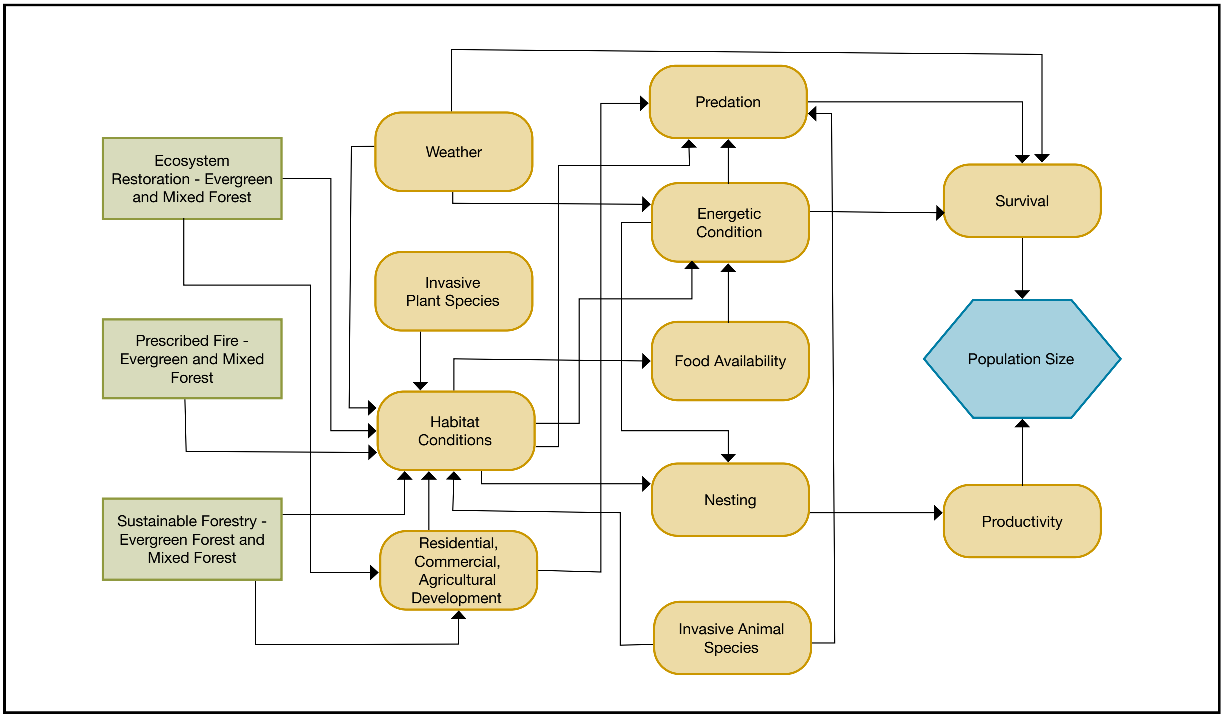
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of landbirds.



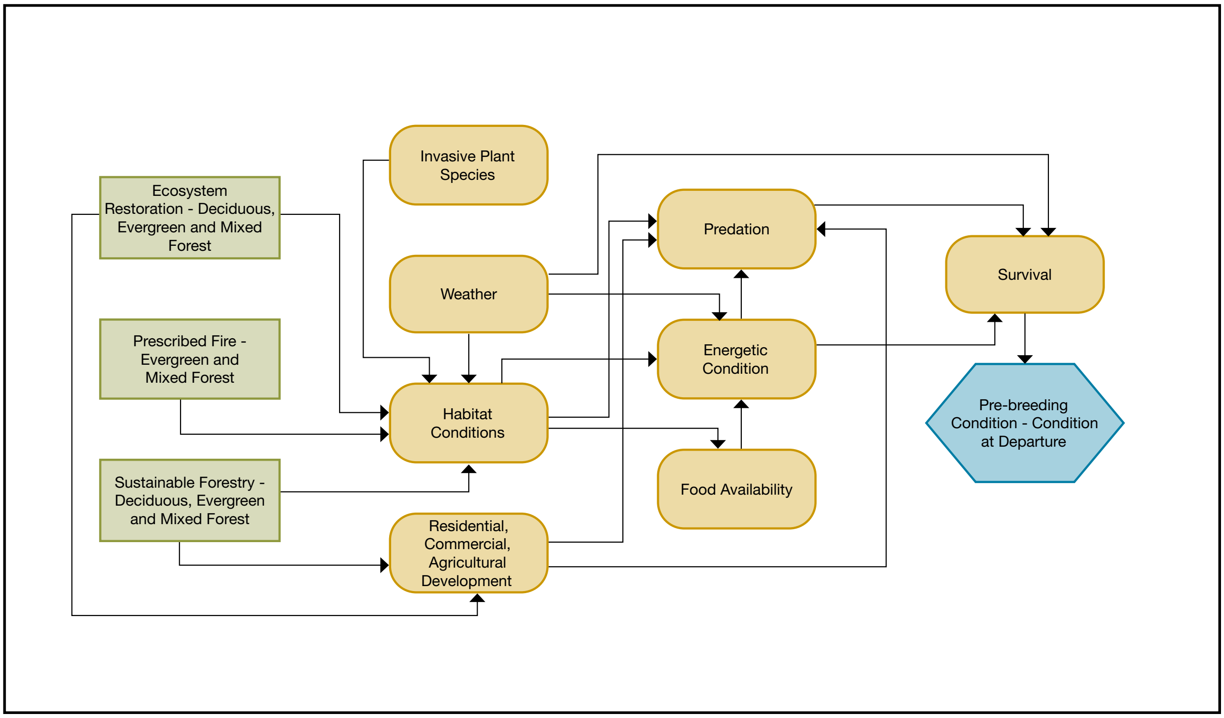
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Northern Bobwhite*** *(Colinus virginianus) forest breeding within the Gulf of Mexico region.*



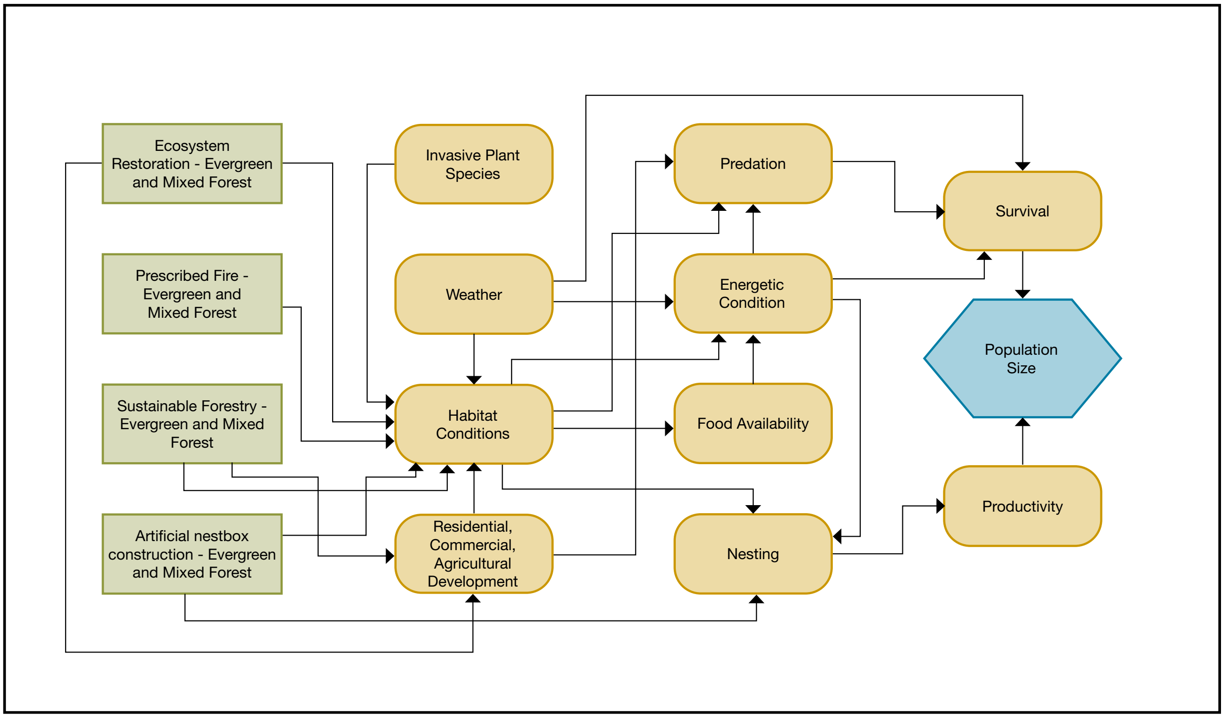
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Common Ground Dove*** *(Columbina passerina) breeding within the Gulf of Mexico region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Chuck-will's-widow*** *(Antrostomus carolinensis) breeding within the Gulf of Mexico region.*

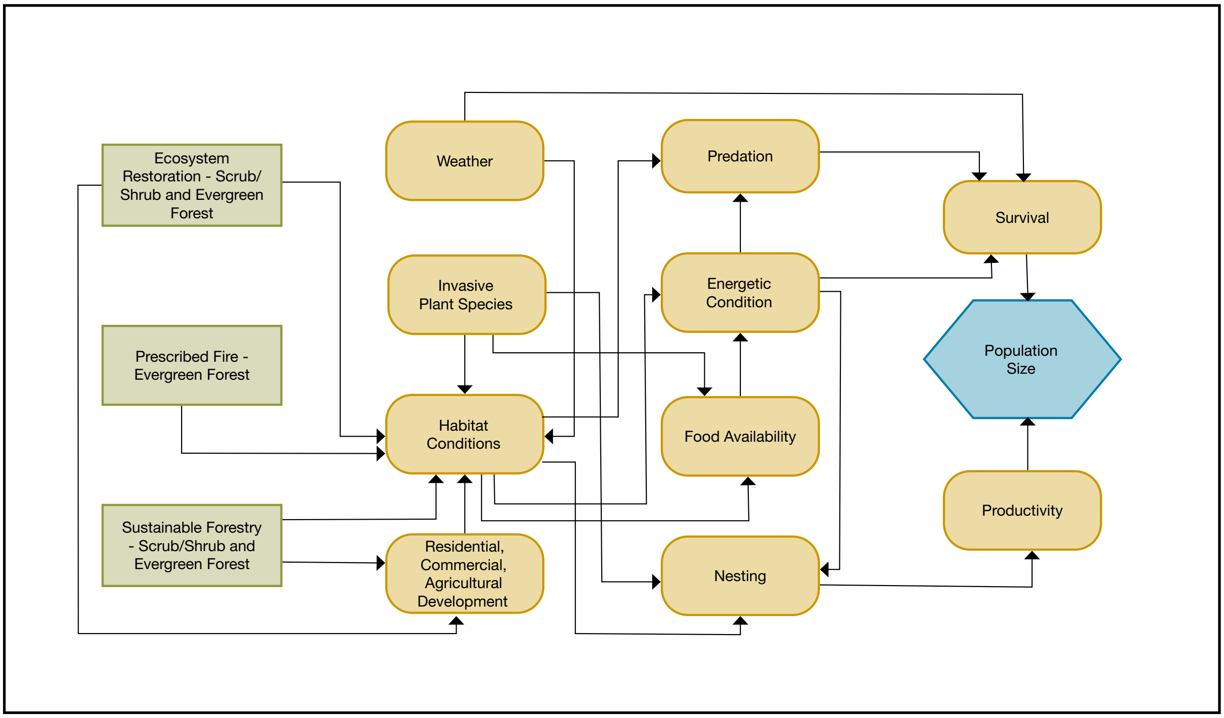


Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and pre-breeding condition-condition at departure (blue hexagon) for the ***Red-headed Woodpecker*** *(Melanerpes erythrocephalus) wintering within the Gulf of Mexico region.*

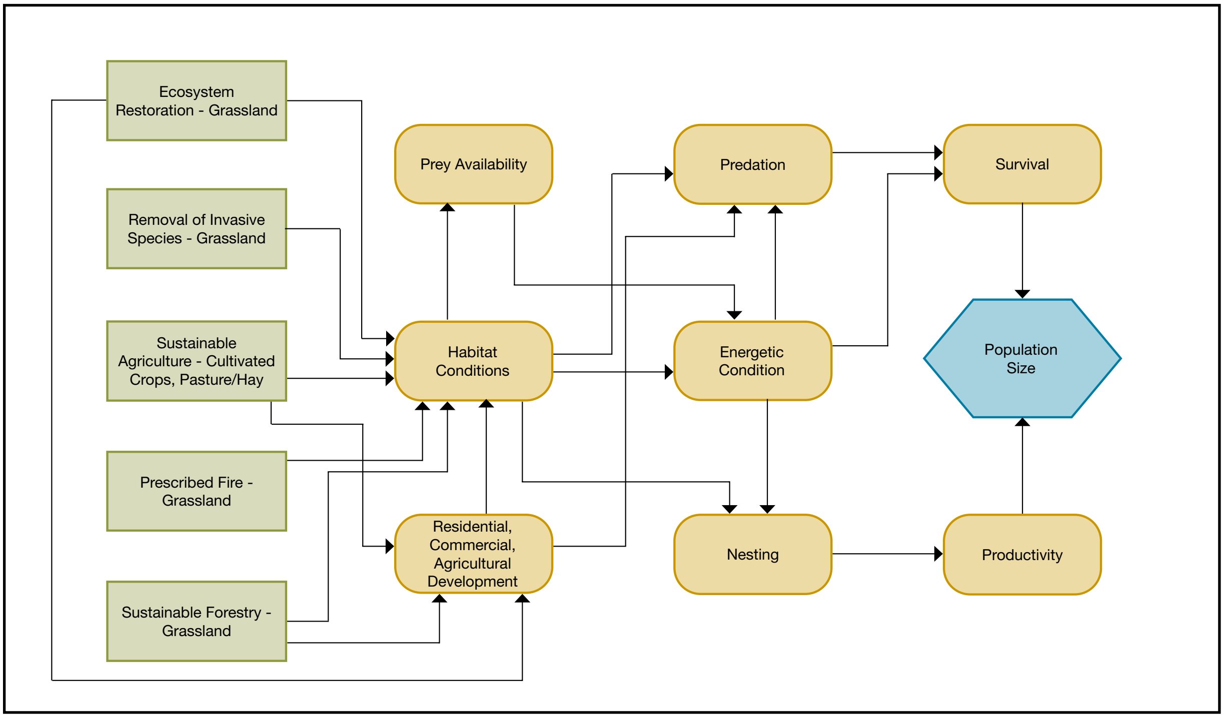


Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Red-cockaded Woodpecker*** *(Dryobates borealis) breeding within the Gulf of Mexico region.*

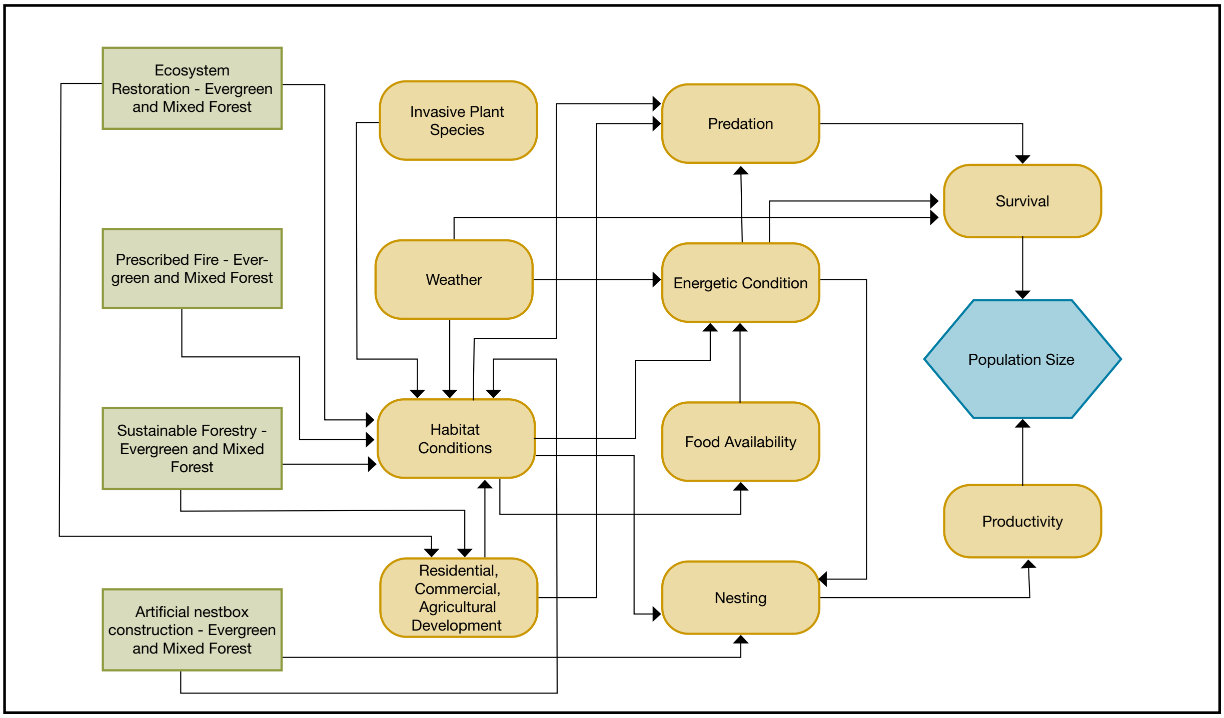
Landbirds



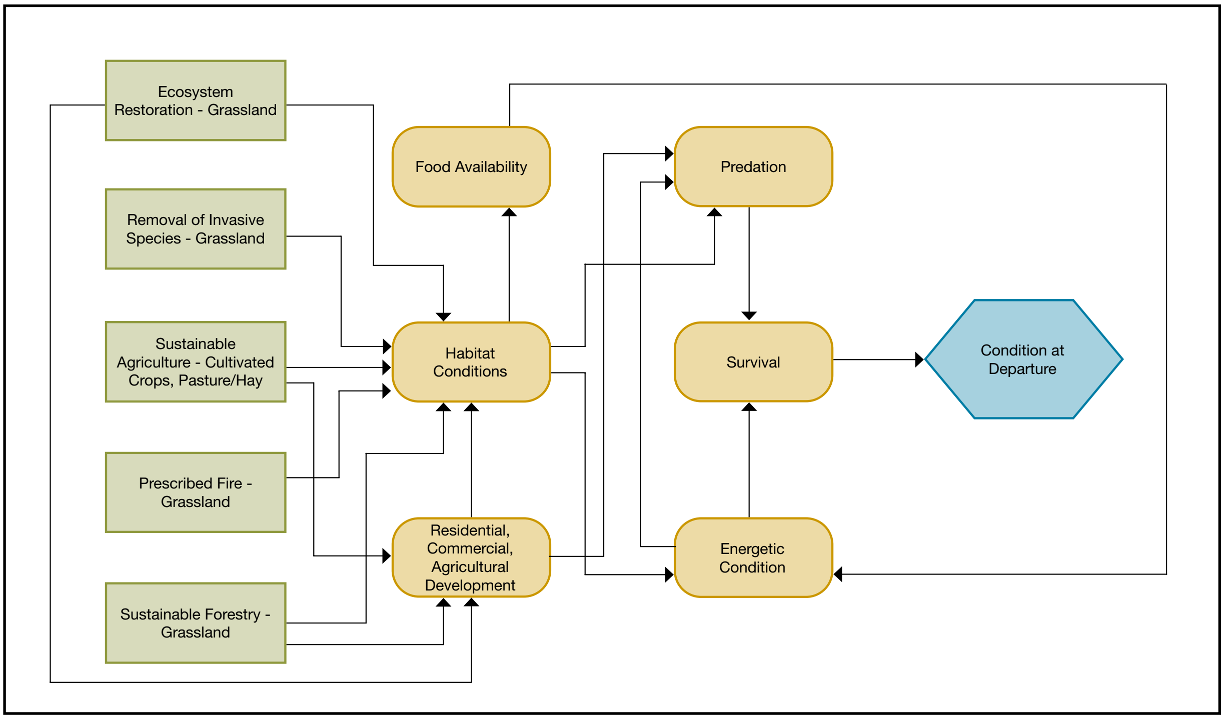
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the forest breeding **Loggerhead Shrike** (Lanius ludovicianus) within the Gulf of Mexico region.*



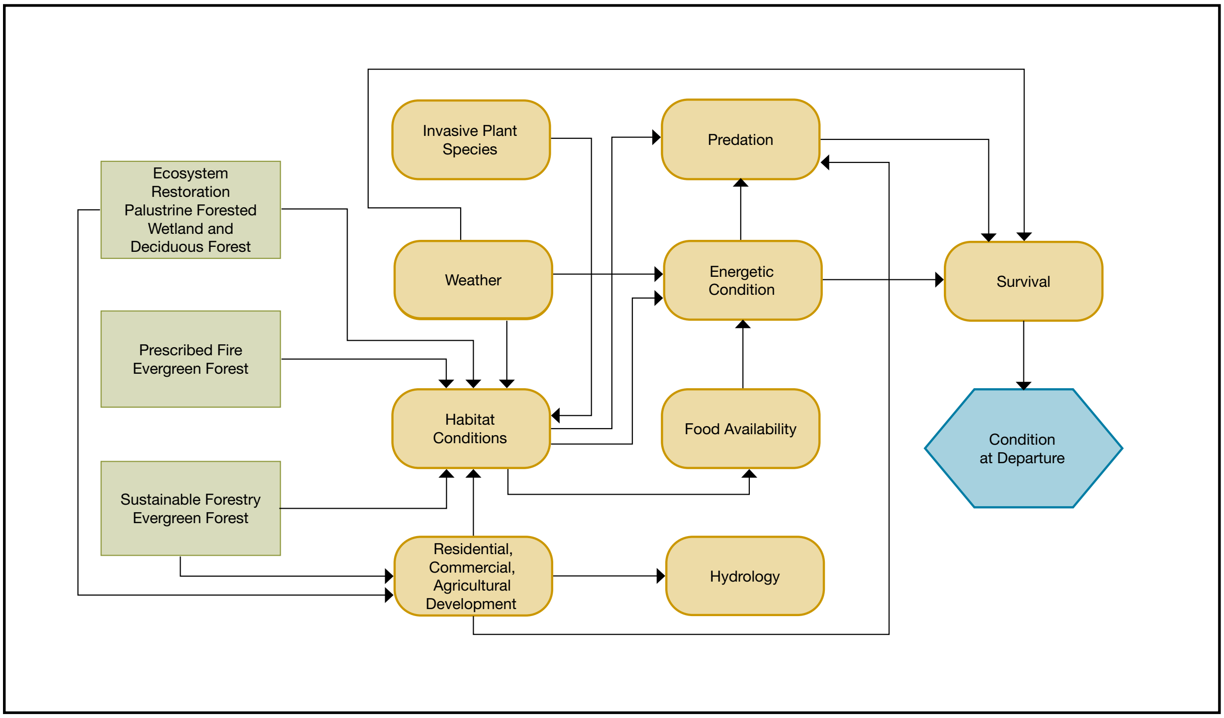
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the grassland breeding **Loggerhead Shrike** (Lanius ludovicianus) within the Gulf of Mexico region.*



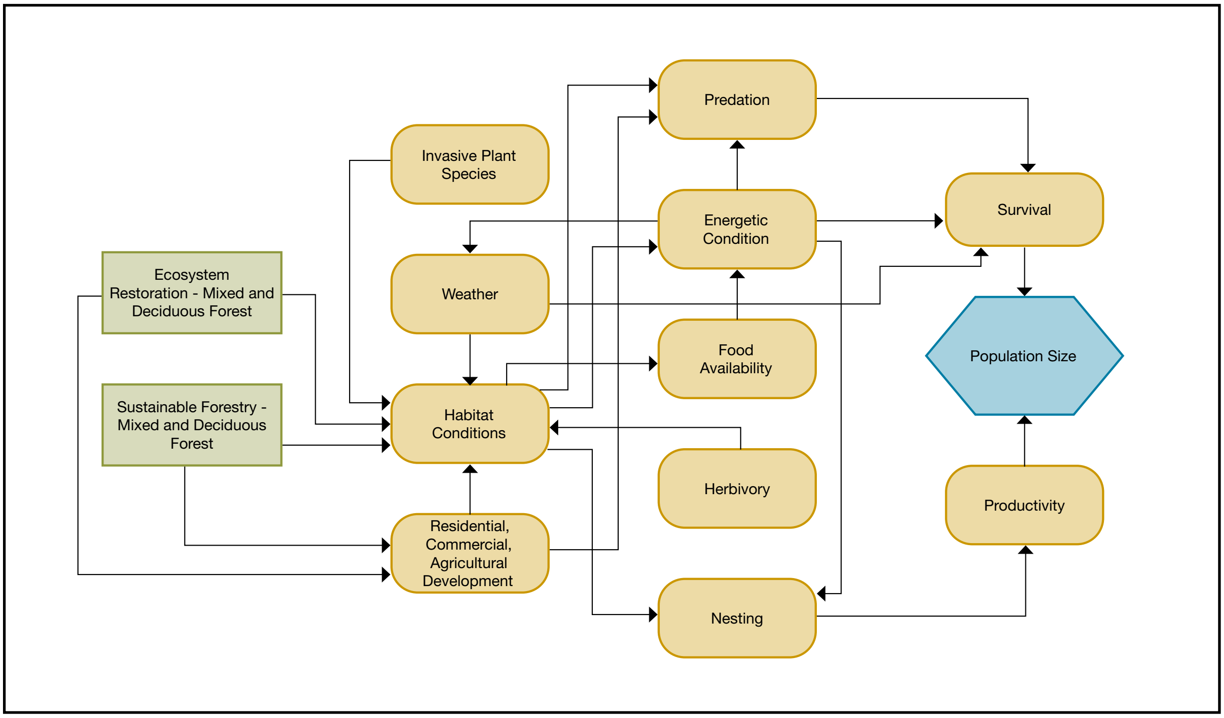
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Brown-headed Nuthatch*** *(Sitta pusilla) breeding within the Gulf of Mexico region.*



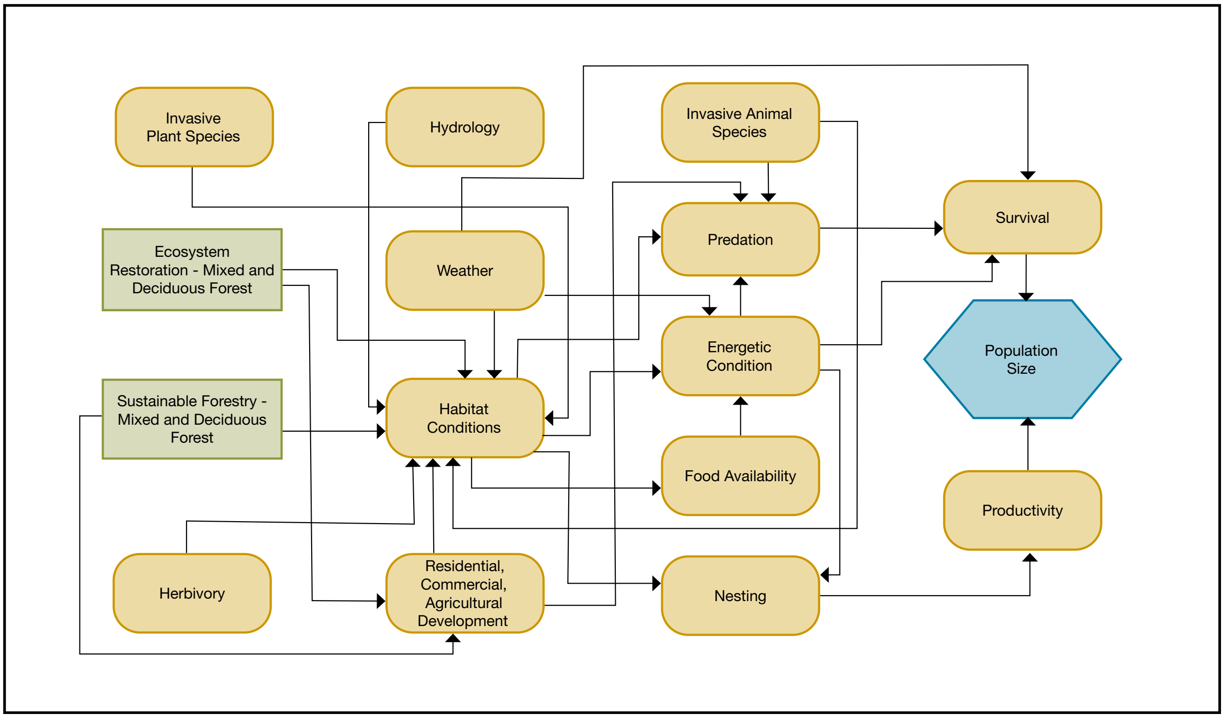
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Sedge Wren*** *(Cistothorus platensis) grassland wintering within the Gulf of Mexico region.*



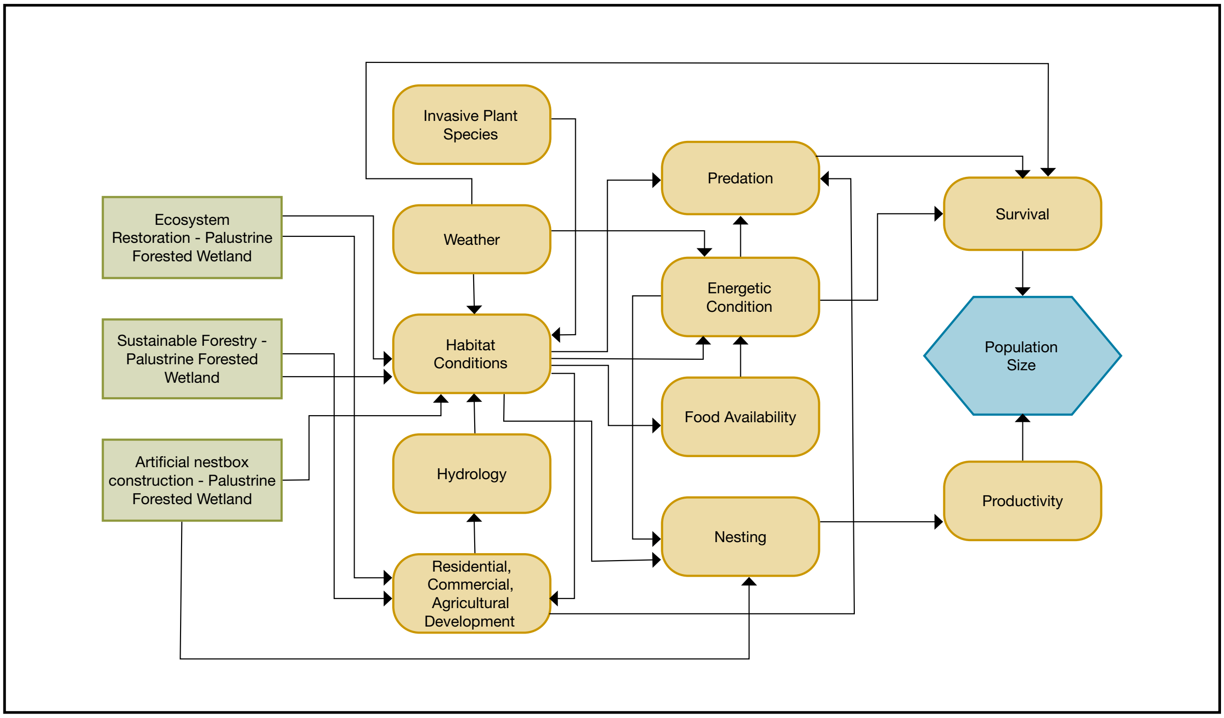
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and condition at departure (blue hexagon) for the ***Sedge Wren*** *(Cistothorus platensis) forest wintering within the Gulf of Mexico region.*



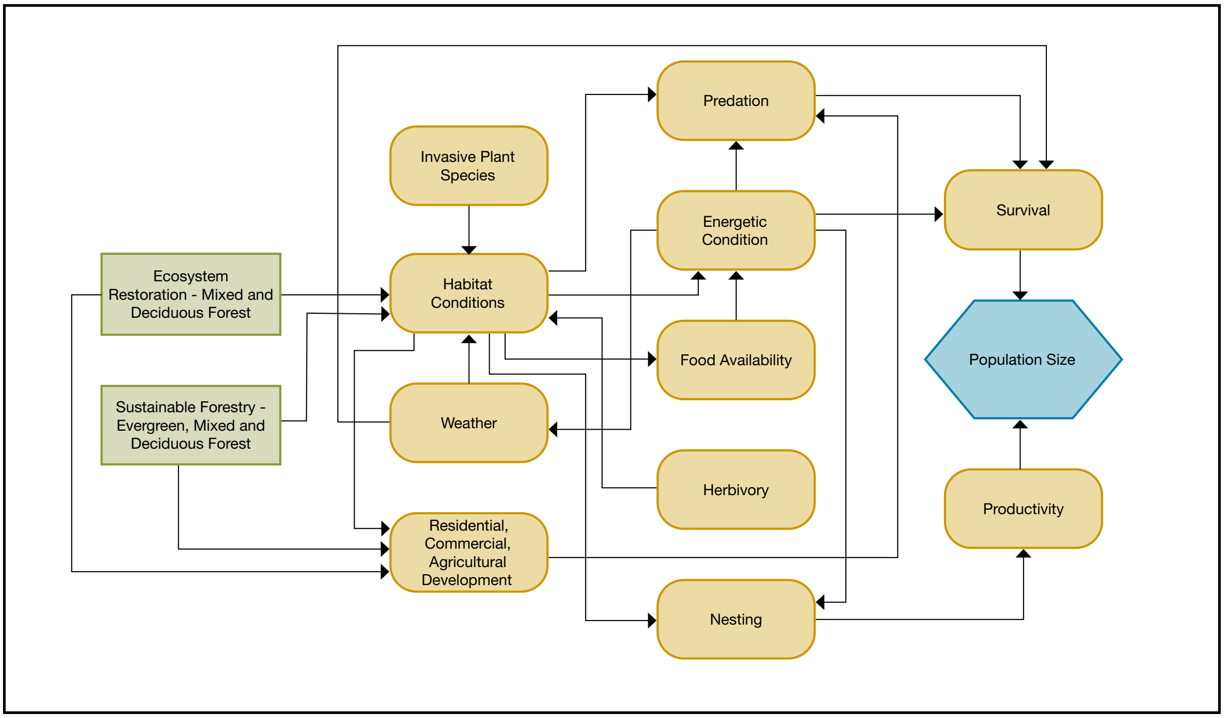
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Wood Thrush*** *(Hylocichla mustelina) breeding within the Gulf of Mexico region.*



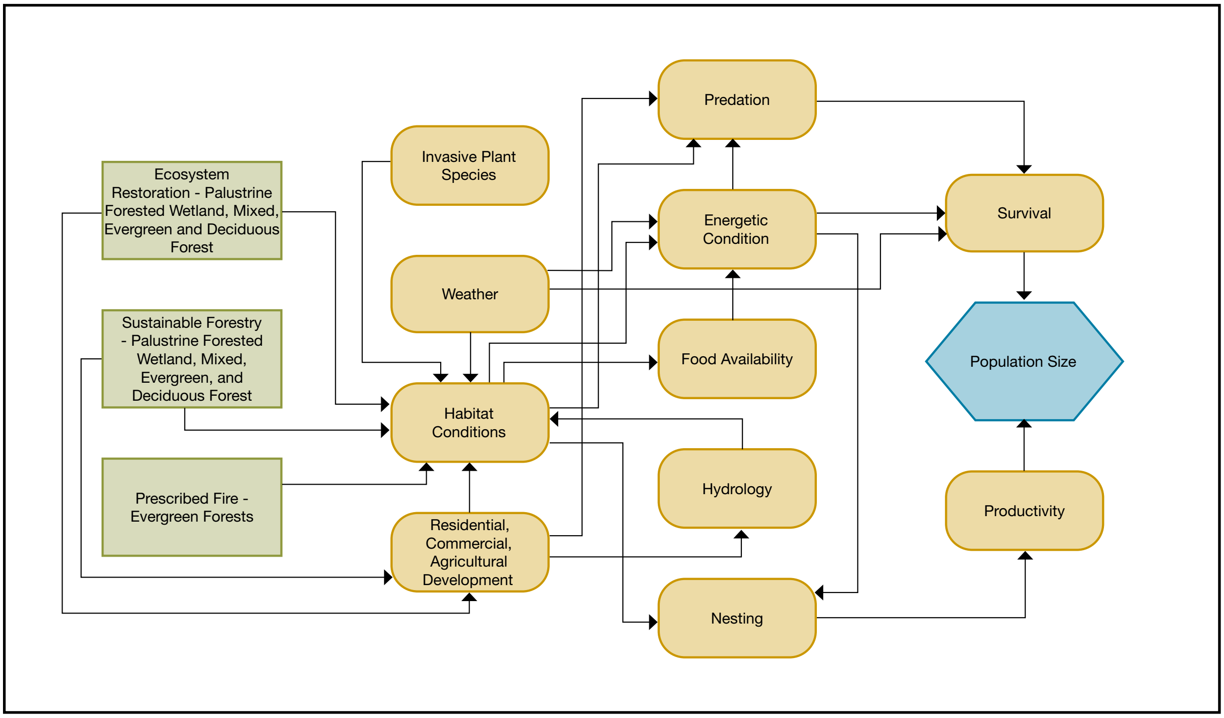
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Louisiana Waterthrush*** *(Parkesia motacilla) breeding within the Gulf of Mexico region.*



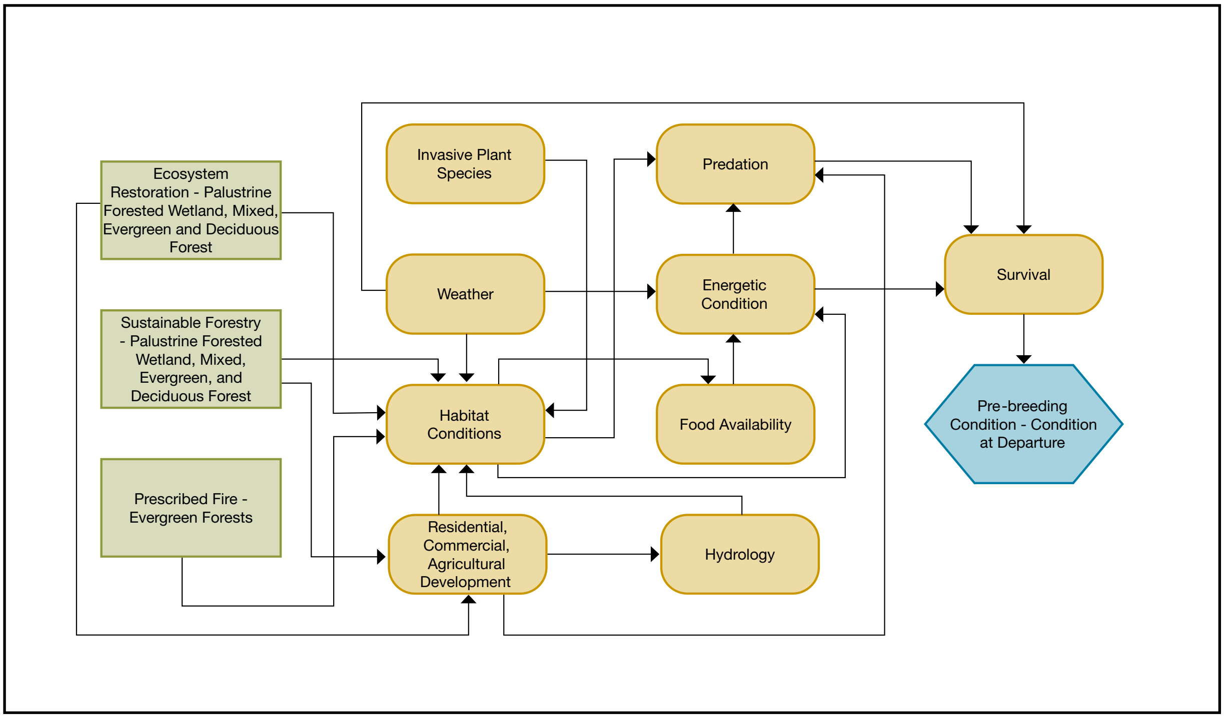
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Prothonotary Warbler*** *(Protonotaria citrea) breeding within the Gulf of Mexico region.*



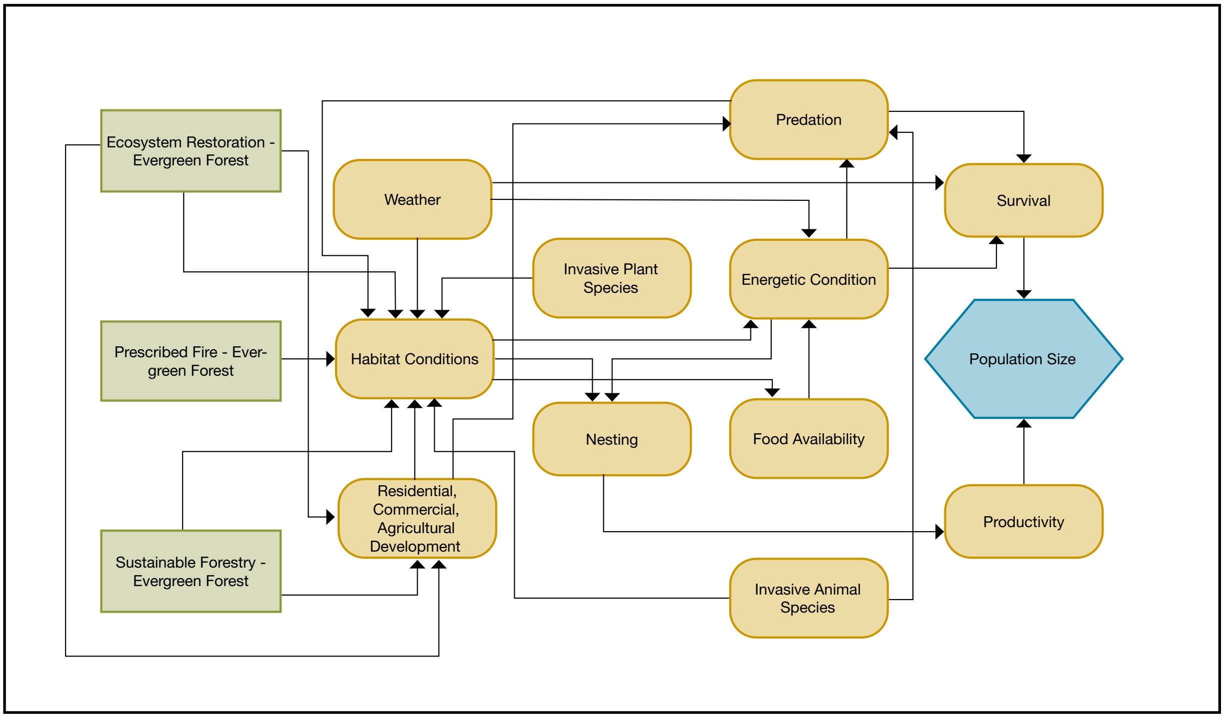
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Swainson's Warbler*** *(Limnothlypis swainsonii) breeding within the Gulf of Mexico region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Yellow-throated Warbler*** *(Setophaga dominica) breeding within the Gulf of Mexico region.*

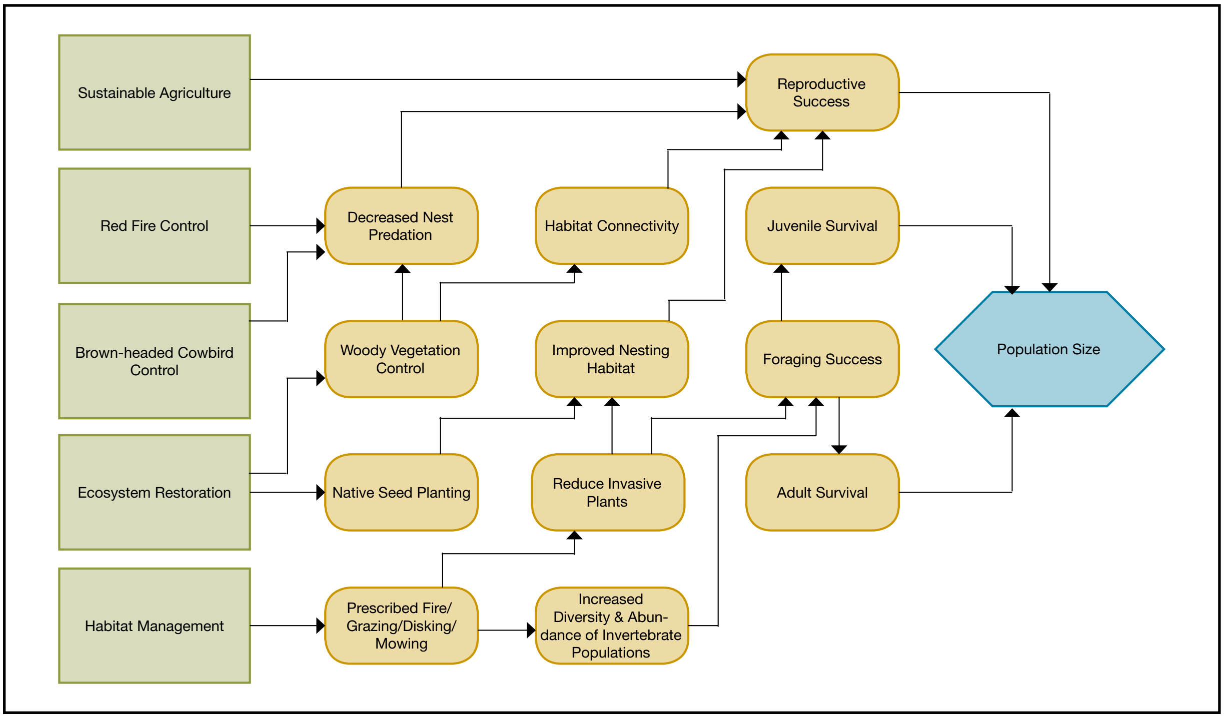


*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and pre-breeding condition - condition at departure (blue hexagon) for the **Yellow-throated Warbler** (Setophaga dominica) wintering within the Gulf of Mexico region.*

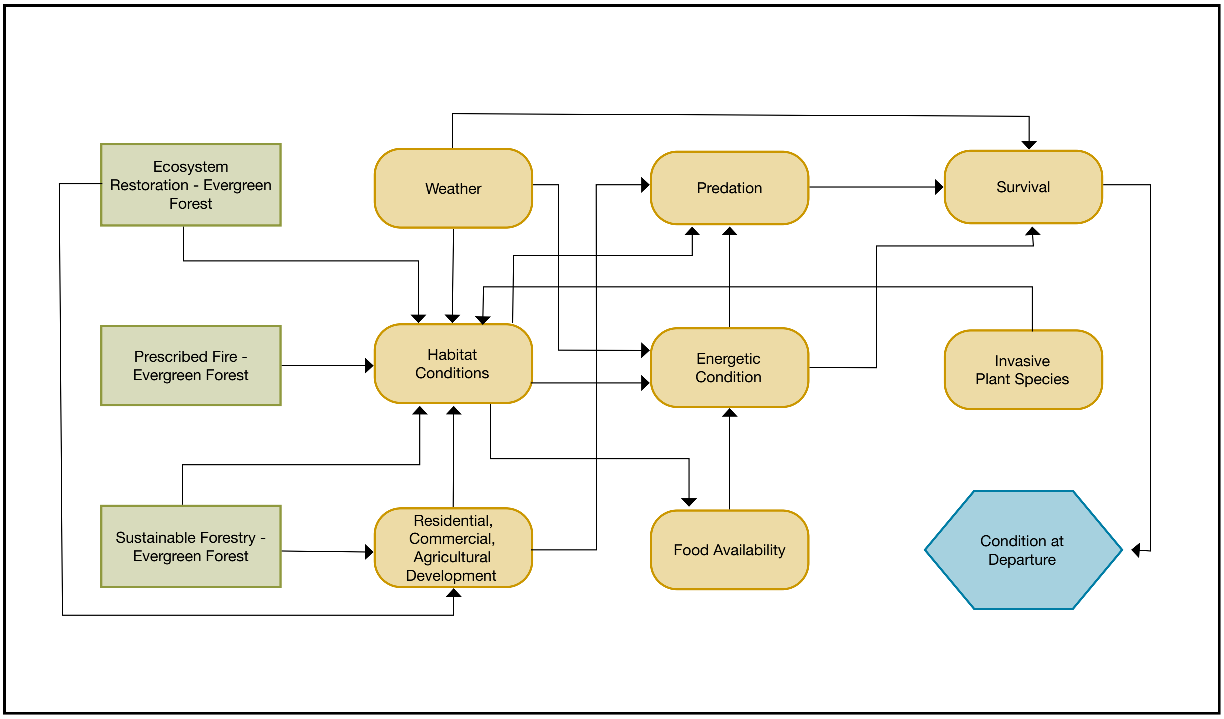


*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and pre-breeding condition - condition at departure (blue hexagon) for the **Bachman's Sparrow** (Peucaea aestivalis) breeding within the Gulf of Mexico region.*

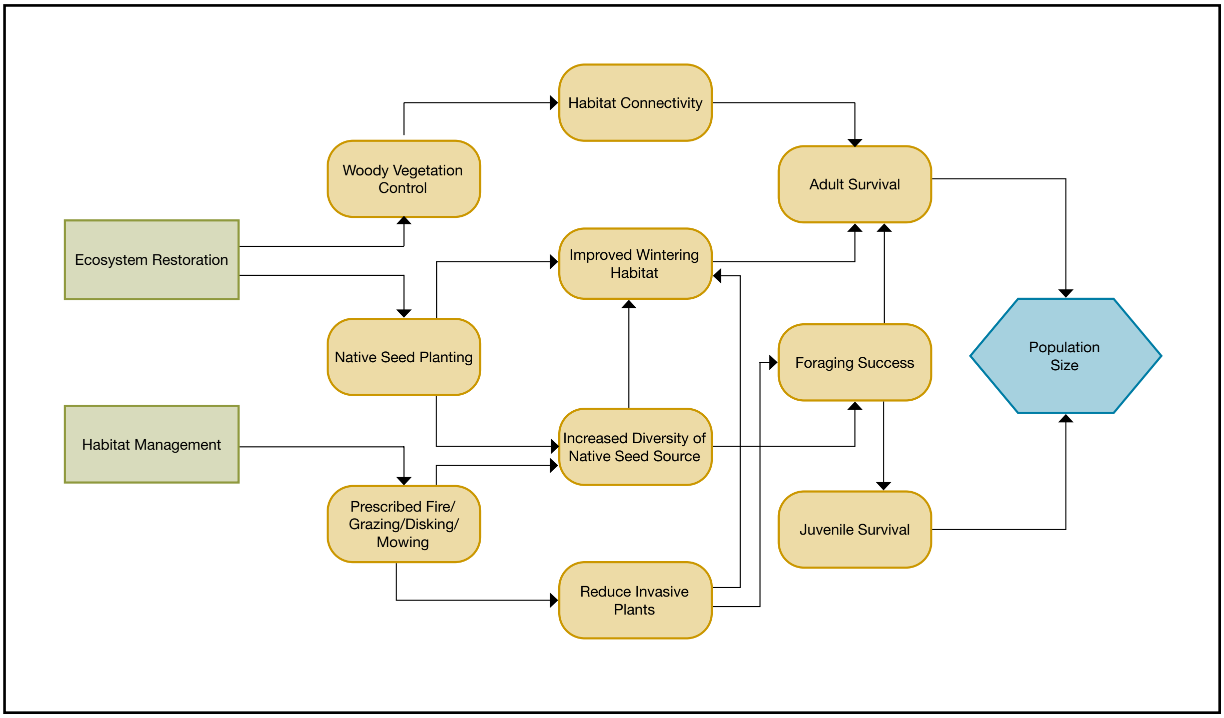
Landbirds



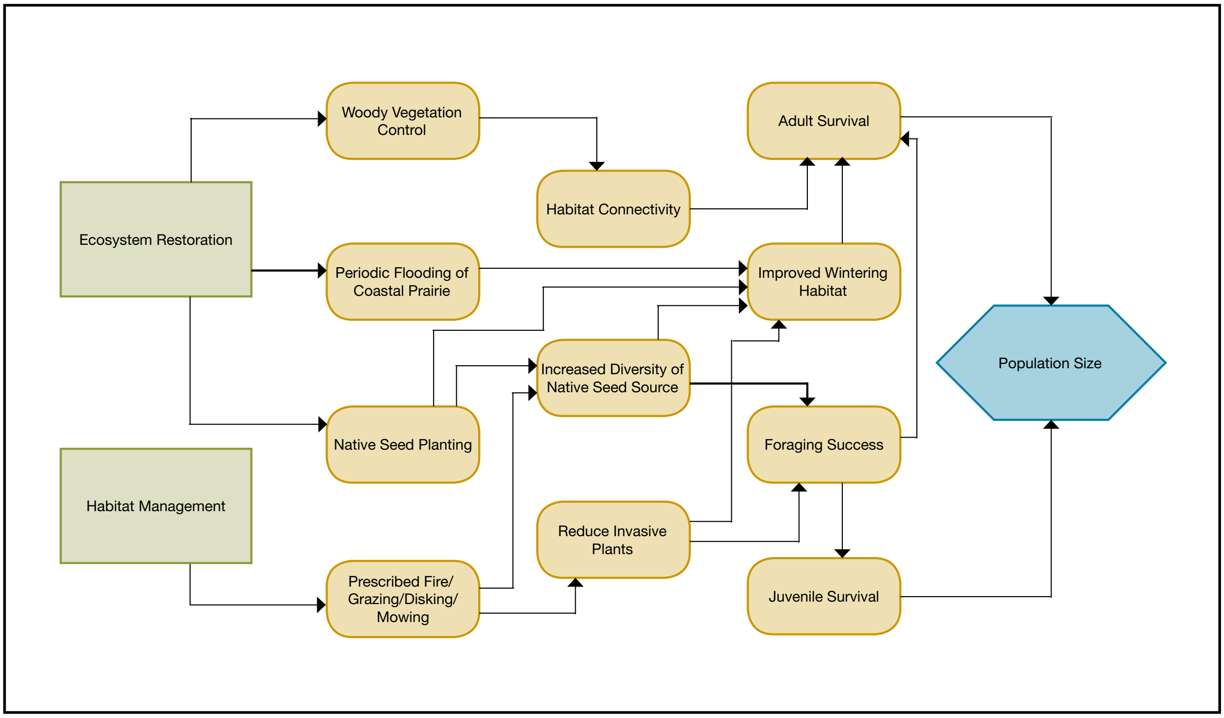
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Grasshopper Sparrow*** *(Ammodramus savannarum) in wintering grasslands within the Gulf of Mexico region.*



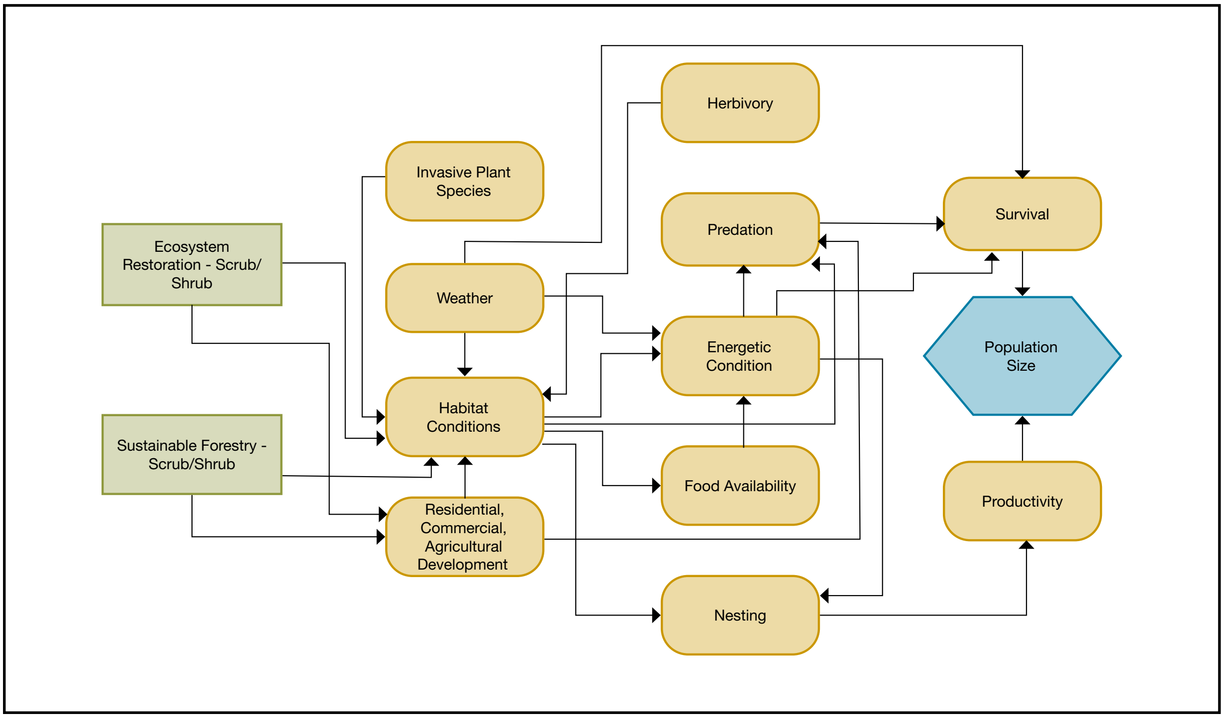
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and condition at departure (blue hexagon) for the ***Henslow's Sparrow*** *(Centronyz henslowii) forest wintering within the Gulf of Mexico region.*



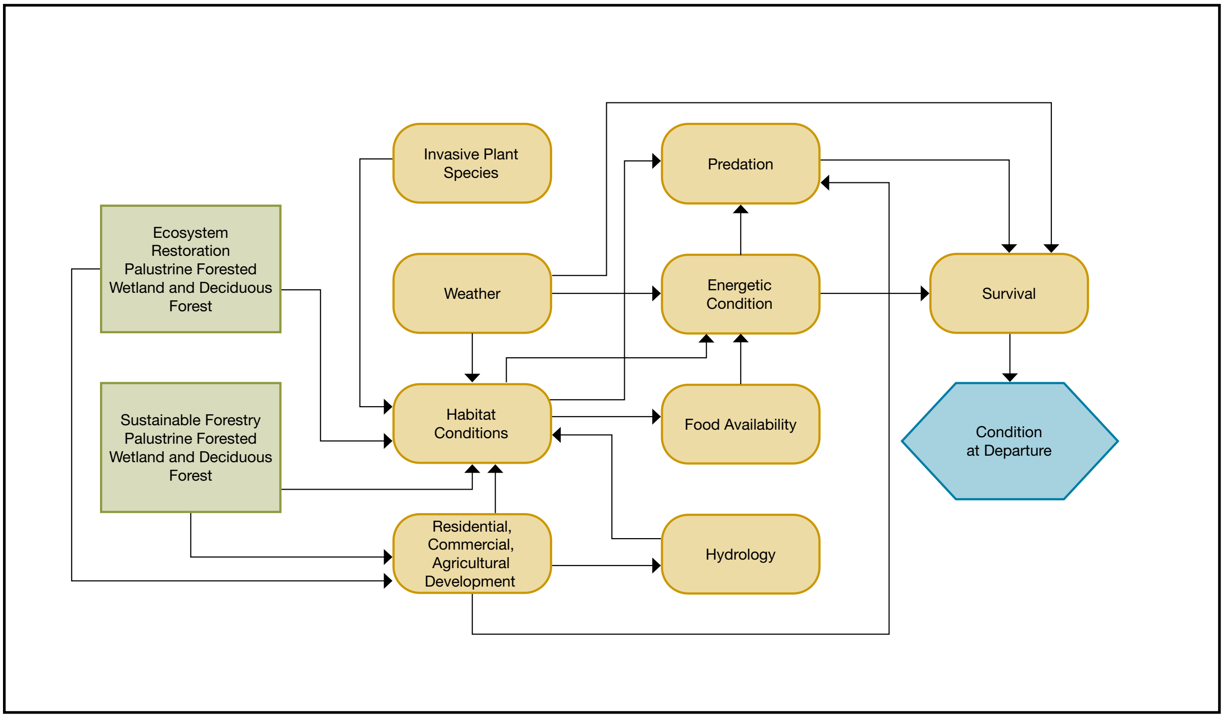
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Henslow's Sparrow*** *(Centronyz henslowii) in wintering grasslands within the Gulf of Mexico region.*



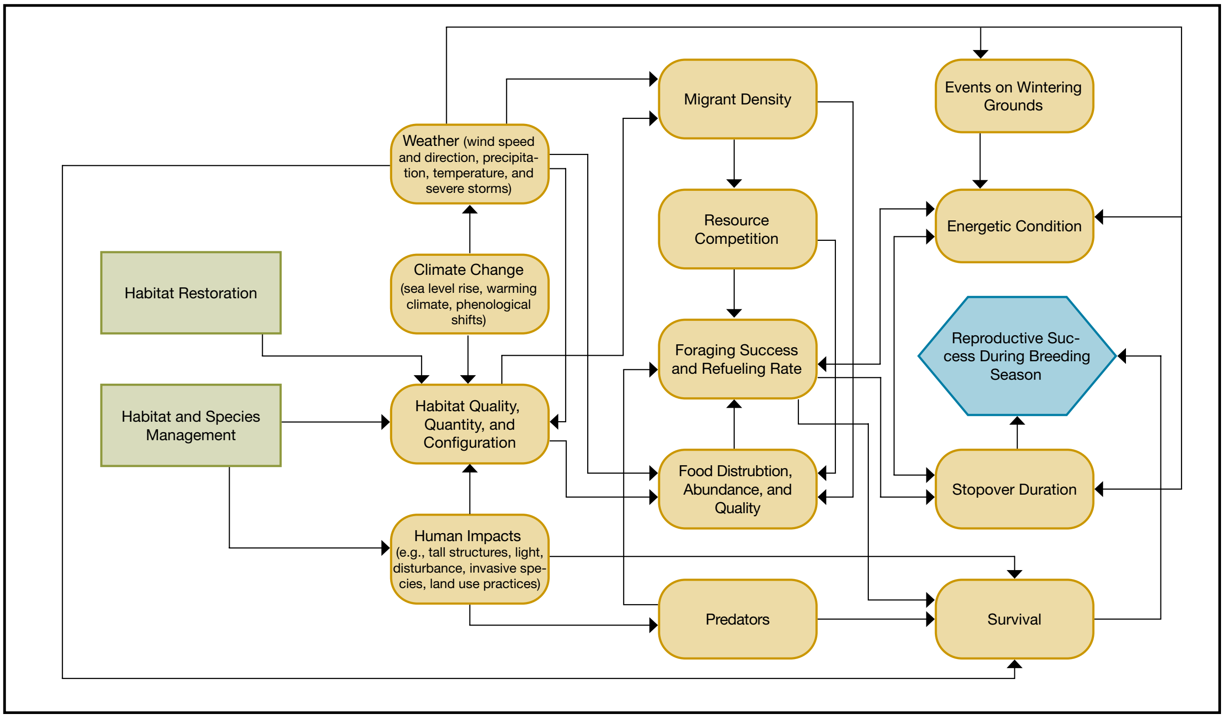
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***LeConte's Sparrow*** *(Ammospiza leconteii) wintering within the Gulf of Mexico region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Painted Bunting*** *(Passerina ciris) breeding within the Gulf of Mexico region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and condition at departure (blue hexagon) for the ***Rusty Blackbird*** *(Euphagus carolinus) wintering within the Gulf of Mexico region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metric) size (blue hexagon) for ***passage migrant landbirds*** *within the Gulf of Mexico region.*

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4

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: MARSH BIRDS

Authors:

Mark S. Woodrey (1,2*)

Auriel M. V. Fournier (1,3)

Robert J. Cooper (4)

1. Coastal Research and Extension Center, Mississippi State University, Biloxi, MS
2. Grand Bay National Estuarine Research Reserve, Moss Point, MS
3. Forbes Biological Station–Bellrose Waterfowl Research Center, Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Havana, IL
4. Daniel B. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA

(*) Corresponding Author: **msw103@msstate.edu**

Clapper Rail (*Rallus crepitans*). Photo credit: Michael Gray.

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GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: MARSH BIRDS

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

Marsh birds are a group of birds living at the interface of aquatic and the terrestrial ecosystems. Living along this edge exposes them to myriad threats and stressors; thus, understanding threats and ecological relationships in both upland and wetland ecosystems is critical to effective conservation of these species. Marsh birds are a poorly understood group, in general, due to their cryptic coloration and generally elusive nature (Ribic et al. 1999, Woodrey et al. 2012). We know relatively little about marsh bird ecology and biology, including their population status and trends (Johnson et al. 2009, Conway 2011). Nearly 50% of marsh bird species in the Gulf region are of conservation concern (Table 4.1), mostly due to the loss of wetland habitats: American (*Botaurus lentiginosus*) and Least Bittern (*Ixobrychus exilis*), Yellow (*Coturnicops noveboracensis*), Black (*Laterallus jamaicensis*), and King Rail (*Rallus elegans*), Marsh (*Cistothorus palustris*) and Sedge Wren (*Cistothorus platensis*), and Nelson's (*Ammospiza nelsoni*) and Seaside Sparrow (*Ammospiza maritimus*) (Table 4.1; Eddleman et al. 1994, Herkert et al. 2001, Post and Greenlaw 2009, Poole et al. 2009, Lowther et al. 2009, Shriver et al. 2011, Kroodsma and Verner 2013, Leston and Bookhout 2015, Pickens and Meanley 2015). Several other marsh bird species are hunted on the Gulf Coast and elsewhere during their annual cycle (Case and McCool 2009). As a group marsh birds display a high degree of endemism—like many other terrestrial vertebrate species found in tidal marshes (Greenberg 2006, Greenberg and Maldonado 2006, Greenberg et al. 2006). In addition, marsh birds have been shown to be bio-indicators of emergent marsh ecosystem health (Novak et al. 2006). Addressing our current uncertainties—a lack of understanding of the status, ecology, and management of this group—is critical to marsh bird conservation.

The Gulf of Mexico (GoM) is home to 20 species of marsh birds, (Woodrey et al. 2012, Table 4.1), from the most common and abundant marsh bird of the Gulf region, the Clapper Rail (*Rallus crepitans*), to the widespread, but locally common Seaside Sparrow, to the Limpkin (*Aramus guarauna*) which is for the most part restricted to freshwater marshes in Florida (Post and Greenlaw 2009, Rush et al. 2012).

Breeding Season

Fourteen marsh bird species breed within the boundaries of the GoM Avian Monitoring Network (GoMAMN) (Figure 1.2, Table 4.1). Clapper Rail is the most abundant species and has a nearly continuous distribution in salt marshes across the region, whereas its congener, the King Rail is less abundant and has a more sporadic distribution concentrated in the coastal marshes of Louisiana and Texas (Rush et al. 2012, Pickens and Meanley 2015). Although a widespread breeder along the Gulf Coast, Common Gallinule (*Gallinula chloropus*) abundance is localized (Bannor and Kiviat 2002). Marsh Wrens are known to breed across much of the GoMAMN region, but in Florida they are not known to breed south of the Big Bend Region (Kroodsma and Verner 2013).

Other breeding marsh bird species have more restricted breeding ranges throughout the Gulf Coast. Black Rails breed from south Florida north through Alabama, with the highest abundance found in south-central Florida and declining towards the northern GoM; coastal Texas appears to be a stronghold for breeding and wintering Black Rails across the eastern United States (Tolliver et al. 2018, Haverland 2019) and they have recently been regularly found in coastal southwest Louisiana throughout the year (Johnson and Lehman 2019). American Coots (*Fulica americana*) breed in peninsular Florida and coastal Texas with isolated populations along the Gulf Coast to west Louisiana (Brisbin and Mowbray 2002). Limpkins are a sporadically distributed, permanent resident of freshwater marshes, found most commonly throughout peninsular Florida (Bryan 2002). Gulf Coast populations of the Seaside Sparrow are irregularly distributed from the Everglades through south Texas (Post and Greenlaw 2009). The Boat-tailed Grackle (*Quiscalus major*) is irregularly distributed along the Gulf Coast from southwest Florida to southeast Texas (Post et al. 2014), breeding throughout most of peninsular Florida, whereas the Great-tailed Grackle (*Quiscalus mexicanus*) has a more western gulf breeding distribution, nesting from southwest Louisiana south through Mexico (Johnson and Peer 2001).

Table 4.1. *Marsh bird species to be considered for monitoring programs at multiple geographic scales across the northern Gulf of Mexico. Table includes species residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).*

Common Name	Latin Name	Breeding	Winter	Migration	Landcover Association(s)[a]	Trend Score	Continental Concern Score
Pied-billed Grebe[b]	*Podilymbus podiceps*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	2	8
Yellow Rail	*Coturnicops noveboracensis*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Evergreen Forest	3	15
Black Rail	*Laterallus jamaicensis*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	5	17
Clapper Rail[b]	*Rallus crepitans*	X	X	X	Estuarine Emergent Wetland	3	13
King Rail	*Rallus elegans*	X	X	X	Palustrine Emergent Wetland	5	15
Virginia Rail[b]	*Rallus limicola*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	1	9
Sora[a]	*Porzana carolina*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	2	9
Purple Gallinule[b]	*Porphyrio martinicus*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	4	11
Common Gallinule[a]	*Gallinula galeata*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	3	10
American Coot[b]	*Fulica americana*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	2	8
Limpkin[b]	*Aramus guarauna*	X	X	X	Palustrine Emergent Wetland	3	10
American Bittern	*Botaurus lentiginosus*		X	X	Palustrine Emergent Wetland	4	12
Least Bittern	*Ixobrychus exilis*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	3	10
Sedge Wren	*Cistothorus platensis*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Evergreen Forest	1	7
Marsh Wren	*Cistothorus palustris*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	1	7
Seaside Sparrow	*Ammospiza maritima*	X	X	X	Estuarine Emergent Wetland	2	14
Nelson's Sparrow	*Ammospiza nelsoni*		X	X	Estuarine Emergent Wetland	1	12
Red-winged Blackbird[b]	*Agelaius phoeniceus*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	4	8
Boat-tailed Grackle[b]	*Quiscalus major*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	4	12
Great-tailed Grackle[b]	*Quiscalus mexicanus*	X	X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	1	4

[a]See Chapter 1 and Appendix 2 for full description of landcover associations.
[b]Species not included on the GoMAMN Birds of Conservation Concern list (see Appendix 1) but included here due to their ecological importance and/or ability to serve as an ecosystem indicator.

Marsh birds use a variety of mostly tidal wetland types across the Gulf Coast, including salt, brackish, intermediate, and fresh marsh (Table 4.1). Salt and brackish marsh (C-CAP Estuarine Emergent Wetland), typically dominated by *Spartina alterniflora* and *Juncus roemerianus* along the Gulf Coast, provide critical habitat for breeding Least Bitterns, Clapper Rails, Marsh Wrens, and Seaside Sparrows (Gabrey and Afton 2004, Rush et al 2009, Stouffer et al. 2013). The importance of salt and brackish marsh (C-CAP Estuarine Emergent Wetland) to Clapper Rails appears to be directly related with the distribution and abundance of fiddler crabs (*Uca* spp.), a critical food resource during the breeding season (Rush et al 2010a, 2010b). Black Rail along the Gulf Coast appear to have very specific habitat preferences; they are typically found along the interface between emergent marsh and upland habitats (C-CAP Estuarine Emergent Wetland and Grassland) in areas that experience infrequent inundation and are dominated by fine-stemmed vegetation such as *Spartina patens* and *S. spartinae* (Haverland 2019).

Some breeding marsh bird species, such as King Rail, Marsh Wren, and Boat-tailed Grackle occur in low numbers in salt marsh habitats (C-CAP Estuarine Emergent Wetlands), but are more common in lower salinity habitats including brackish and intermediate marsh (C-CAP Estuarine Emergent Wetlands and Palustrine Emergent Wetlands). In the case of King Rail, they use cultivated rice fields (C-CAP Cultivated Crops - Rice), with seasonal shifts from more intermediate areas to brackish marsh habitats (C-CAP Palustrine Emergent Wetland and Estuarine Emergent Wetland) during the nonbreeding season (Pickens and Meanley 2015). Other species depend almost exclusively on intermediate and freshwater marsh, including tidal freshwater habitats (C-CAP Palustrine Emergent Wetlands), for nesting (Table 4.1).

Spring and Autumn Migration Seasons

Migratory marsh birds are largely short- to mid-distance migrants that use fresh and salt marshes (C-CAP Palustrine Emergent Wetlands and Estuarine Emergent Wetlands) for stopover habitat during migration (Bent 1926). The GoM provides habitat for migratory marsh birds twice each year (roughly February-May and August-November).

There are seven migratory marsh birds of conservation concern: Least Bittern, American Bittern, King Rail, Yellow Rail, Black Rail, Marsh Wren, and Nelson's Sparrow. For each of these species, part of the population spends the winter along the Gulf Coast and the rest continue migrating and spend the winter farther south. Some Black and King Rails are year-round residents of the Gulf Coast (Butler et al. 2015), while others of both species cover a wide geographic area among their breeding ranges, from the Pacific to Atlantic coasts, and northward to the United States and Canada border (Kroodsma and Verner 2013, Lowther et al. 2009, Pickens and Meanley 2015, Poole et al. 2009, Shriver et al. 2011, Butler et al. 2016, Fournier et al. 2017a,d).

All migratory marsh bird species of conservation concern breed in freshwater or brackish wetlands, and use fresh and saltwater marshes for stopover during migration. Wetlands across the GoM region are diverse and encompass salt marsh to emergent estuarine fresh and brackish systems (C-CAP Estuarine Emergent Wetlands to Palustrine Emergent Wetlands) to heavily forested freshwater swamps (C-CAP Palustrine Forested Wetlands). Each wetland type serves a unique avian community while also serving many other important ecological purposes. These purposes include flood water control, cleaning water, protection from storm surge, as well as supporting the majority of commercially and recreationally important fisheries (Costanza et al. 2008, Engle 2011). For migratory species, the timing of available habitat is crucial, since habitat available at the wrong time of year is of limited benefit to a migratory species (Fournier et al. 2015, 2017b, 2017c, 2018).

How migratory marsh bird species move within and across the GoM is not well understood. Little is known about species-specific timing of their migrations, what populations migrate through the region versus stay along the coast in winter, the spatial extent and seasonality of their movements along the coast, and what proportion cross versus take an overland route around the GoM. Answers to these and other questions relating to marsh bird migration are critical for the development of a strategic comprehensive conservation plan.

Winter Season

In general, little attention has been focused on winter marsh birds in ongoing bird conservation efforts, including in the GoM Region. Yet of the 20 marsh bird species found using Gulf Coast habitats, 18 spend the winter in coastal wetland habitats across the region (Table 4.1). In a recent effort to promote effective monitoring of bird restoration activities, Woodrey (2017) recommended including monitoring focused on non-breeding marsh birds, since non-breeding marsh birds include some species not present in the breeding season and that may have habitat needs that are different from those of breeding birds. Some species, such as Pied-billed Grebe (*Podilymbus podiceps*), Virginia Rail (*Rallus limicola*), Sora (*Porzana carolina*), and American Coot winter across a broad suite of habitat types across a broad geographic area (Muller and Storer 1999, Conway 1995, Melvin and Gibbs 2012, Brisbin and Mowbray 2002). Others, such as Least Bittern, Purple Gallinule (*Porphyrio martinicus*), Limpkin, and Nelson's Sparrow are more restricted in their habitat use and/or their distribution during the winter (Bryan 2002, Poole et al. 2009, West and Hess 2002, Shriver et al. 2011).

Found in the GoM region during winter, American Bitterns are typically associated with freshwater marshes (C-CAP Palustrine Emergent Wetlands) with their highest concentrations in the Everglades and along the Louisiana coast (Lowther et al. 2009). Yellow and Black Rails are also widespread during winter along the Gulf Coast (Eddleman et al. 1994) although Yellow Rails are not found in south Texas (Leston and Bookhout 2015). Recent work on winter Yellow Rails has shown selection for wet pine savanna habitats (C-CAP Evergreen Forest) and high marsh (C-CAP Estuarine Emergent Wetlands; Morris et al. 2017). However, GoM-wide, systematic searches for Yellow Rails are necessary to better understand their regional winter habitat selection. Habitat selection of Black Rails remains unknown although a growing interest in their status and conservation will likely reduce the uncertainty around suitable winter habitat (Watts 2016).

Marsh bird habitat use along the northern Gulf Coast is less varied during the winter season than the breeding season. Nearly all 18 marsh bird species found in the region during the winter can be observed across the salinity gradient of a typical estuary, from high salinity (30–35 ppt) or polyhaline areas to low salinity or oligohaline (0–5 ppt) areas. However, the abundance of a given species varies greatly across these marsh zones in winter. Clapper and King Rail, Marsh Wren, and Nelson's and Seaside Sparrow are most abundant in salt and brackish marsh habitats while many other species, including Pied-billed Grebe, American Bittern, Virginia Rail, Sora, Purple and Common Gallinule, American Coot and Limpkin, are most abundant in freshwater marshes (C-CAP Palustrine Emergent Wetlands, Gabrey et al. 1999, Gabrey and Afton 2000, Greenlaw and Wolfenden 2007). Other species, including Yellow and Black Rail and Sedge Wren, are not typically associated with emergent marsh habitats, instead they are most often observed in adjacent upland habitats (C-CAP Grasslands), including wet pine savanna (C-CAP Evergreen Forest).

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

Threats to coastal marshes and marsh birds are widespread and varied across the northern GoM region. Four of the five Gulf Coast states have experienced significant wetland loss over the last several decades (Table 4.2).

Marsh loss in the GoM Region is due to both anthropogenic and natural threats and stressors. Anthropogenic threats (Eddleman et al. 1988, Greenberg 2006, Greenberg et al 2006, Greenberg et al. 2014) include development, hydrologic modifications, grazing and agriculture, marsh burning, invasive species, contaminants, and sea-level rise.

Of these, coastal development is the primary concern, threatening the integrity of coastal marshes in the GoM and globally (Greenberg 2006, Greenberg et al. 2006, Battaglia et al. 2012, Greenberg et al 2014). Development of coastal areas continues to be driven by the influx of humans to coastal zones; in the GoM region the human population continues to grow at a rate more than double the national average, and wetlands are disappearing faster than anywhere else in the continental United States (Partnership for Gulf Coast Land Conservation 2014).

Hydrologic modifications such as ditching, channel dredging, tidal flow restriction, and water-level manipulations for waterfowl have been and continue to be a major factor influencing marsh systems, resulting in major changes in plant community associations, which in turn affect marsh bird communities (Eddleman et al. 1988, Greenberg 2006, Shriver and Greenberg 2012). Grazing and agriculture alter plant communities in some areas, such as Louisiana and Texas where row crop agriculture, rice, and grazing

Table 4.2. *Percent change of emergent wetland by state for the Gulf of Mexico region.*

State	Percent Change	Years	Citation
Florida	-45[a]	1956-1996	Handley, L., K. A. Spear, C. Thatcher, and S. Wilson. 2015a
Alabama	-54	1955-2002	Handley, L., K. A. Spear, C. Thatcher, and S. Wilson. 2015b
Mississippi	-55	1979-2007	Handley, L., K. A. Spear, C. Thatcher, and S. Wilson. 2015c
Louisiana	-33	1955-2007	Handley, L., K. A. Spear, C. Thatcher, and S. Wilson. 2015d
Texas	+11[b]	1956-2006	Handley, L., K. A. Spear, C. Thatcher, and S. Wilson. 2015e

[a]The percent change for Florida is the mean percent change of two coastal regions of the state.
[b]The percent change for Texas is the mean percent change of two coastal regions of the state.

Seaside Sparrow (*Ammospiza maritima*).
Photo credit: Michael Gray.

are common practices in coastal areas (Stutzenbaker and Weller 1989, Hobaugh et al. 1989). Likewise, marsh burning for waterfowl and furbearers, a relatively frequent practice across portions of the south Atlantic and Gulf Coast Regions and particularly common in coastal Louisiana and Texas, may alter the suitability of these habitats for marsh birds (Stutzenbaker and Weller 1989, Hobaugh et al. 1989, Nyman and Chabreck 1995, Mitchell et al. 2006). However, the broader impacts of more frequent marsh burning than would occur under a natural fire regime are only now being investigated in a rigorous manner (Mitchell et al 2006).

The high frequency of natural disturbance (e.g. tropical storms and hurricanes) make Gulf Coast landscapes highly susceptible to the effects of invasive plant species (Battaglia et al. 2012). Although not specifically evaluated in the GoM Region, negative impacts of invasive plant species on marsh bird communities and other estuarine vertebrates have been demonstrated in other regions of the U.S. (Benoit and Askins 1999, Guntenspergen and Nordby 2006). Direct impacts, including storm-related mortality, are poorly known for marsh birds although short-term population impacts have been documented in a few cases (Holliman 1981, Marsh and Wilkinson 1991). However, broad-scale, process-level studies are lacking but must be implemented to understand the regional variation of impacts to coastal marsh birds.

Sources of contamination in coastal marsh ecosystems include agricultural and urban runoff, application of pesticides, and oil and chemical spills. Polychlorinated biphenyls (PCBs) and metals appear to be most problematic contaminants for marsh birds due to chronic, long-term input, and exposure (Greenberg 2006, Novak et al. 2006). For example, Novak et al (2006) demonstrated that Clapper Rails serve as excellent indicators of PCB contamination in estuarine-marsh ecosystems. In addition to PCBs, mercury contamination may also be a threat in the region. Several areas around the GoM, including the Everglades, Tampa Bay, and Escambia Bay in Florida, Mobile Bay in Alabama, and Vermilion Bay in Louisiana, have been noted as mercury hotspots or suggested as areas to serve as long-term mercury monitoring and research sites (Schmeltz et al. 2011, Commission for Environmental Cooperation 2017). Shriver et al. (2006) and Winder and Emslie (2011) used Sharp-tailed and Nelson's Sparrows, respectively, and Fournier et al. (2016) used Clapper Rails to determine mercury levels in breeding and wintering individual's habitats. Oil spills, while episodic, can have detrimental effects on a variety of coastal wildlife, including marsh birds (Bergeon-Burns et al. 2014). Direct contact with polycyclic aromatic hydrocarbons occur during the initial phase following a spill produces often lethal effects on vertebrate organisms. Nonlethal oil effects typically accumulate over long periods of time given the persistence of many oil-based products. These long-term effects manifest themselves through physiological response and altered coastal food webs, resulting in significant fitness impacts on vertebrate species.

Sea-level rise is expected to have a significant impact on coastal ecosystems and species that occupy coastal emergent wetlands. A recent vulnerability assessment for the GoM region indicated that both natural communities and species are vulnerable to future threats from sea-level rise (Reece et al. 2018). Emergent marsh communities and avian species that depend on these habitats, such as Mottled Duck (*Anas fulvigula*) and Clapper Rail, have a compromised adaptive capacity due to habitat loss and degradation. Modeling studies, focused on marsh bird response to sea-level rise, do provide insight into potential species-level impacts. Rush et al. (2009) predicted species-specific response to sea-level rise: Clapper Rails and Seaside Sparrows, both salt marsh specialists, had a predicted positive response to future increases in sea level while freshwater specialists such as Least Bittern and Marsh Wren showed decreased occupancy rates. In the San Francisco Bay Area, Veloz et al. (2013) also found species-specific variation in response to various sea level rise scenarios. These studies, while informative, are limited in geographic scope but strongly suggest the need for more broad-scale studies to fully understand the implications of future sea-level rise. Conroy et al. (2010) provide an explicit framework for conservation decision-making, using the effects of climate change on coastal marsh birds to illustrate their framework. They provide a series of explicit climate-related hypotheses, predictions, and tests, which can be evaluated using local efforts/studies nested within a regional context to explore population-level impacts on marsh birds.

Outside of the threats noted above, one of the largest conservation issues facing marsh birds is a lack of understanding of their migratory ecology. Understanding migratory connectivity for marsh bird species, like other migratory organisms, is critical because of the consequences to the ecology, evolution, and conservation of their populations (Webster et al. 2002). Given the various migratory life history strategies demonstrated across GoM marsh bird species (Table 4.1), it is imperative that efforts be undertaken to reduce uncertainty around this critical period. We know little about the timing of arrival and departure of different species, the proportion of many of the migratory populations that simply stopover on the Gulf Coast versus those who spend the winter on the coast, and the geographic origins of populations migrating through or to the GoM region. In addition, for most species of marsh birds, migratory routes in the region are unknown, though some have been documented from oil platforms, suggesting at least some individuals cross, rather than circumnavigate, the open waters of the GoM (Russell 2005). Thus, studies that address any of these data gaps should be strongly considered in the near future.

IDENTIFICATION OF PRIORITIES

The conservation community seeks to use the best available information to manage and conserve bird populations and habitats in the face of uncertainty (Mace et al. 2000, Margules and Pressey 2000). To effectively understand the impacts of natural and anthropogenic disasters, such as hurricanes or the Deepwater Horizon Oil Spill, critical data gaps must be addressed (NASEM 2017). Based on experience with the Deepwater Horizon Natural Resources Damage Assessment, long-recognized gaps in avian monitoring data, and evaluation of population and habitat objectives in existing bird conservation plans, GoMAMN identified three broad monitoring priorities across the GoM region (Figure 2.2):

- Evaluating Management Actions (How are things we are doing impacting bird populations?)
- Determining Status and Trends (How are populations and habitats doing?)
- Understanding Ecological Processes (How are the larger ecosystem processes impacting birds?)

Using these priorities, the GoMAMN Marsh Bird Working Group identified specific subsets of priority monitoring activities, discussed below, to be addressed to reduce uncertainty associated with bird populations across the northern GoM region.

Priority Management Actions

Monitoring that answers questions about management and restoration actions is valued by GoMAMN because monitoring these actions will provide improved understanding of marsh bird response to a given management action, evaluate management and restoration success, and better inform future management and restoration decisions relative to marsh bird conservation. We prioritized monitoring management actions that have the highest impact (i.e., reduce uncertainty associated with specific action) on marsh bird populations. For example, we know little about the population level effects of emergent marsh restoration on breeding marsh birds. Specifically, how do marsh bird populations respond to the creation of emergent marsh islands versus marsh restoration adjacent to an existing emergent marsh complex? We are also interested in monitoring management actions which are currently practiced in the Gulf, because monitoring these actions will help inform current management practices.

We developed species-specific influence diagrams, which provide simple graphical representations of the ecological linkages between management actions and our response metric, population size, that potentially impact marsh birds (Conroy and Peterson 2013). There are several management actions including ecosystem restoration, freshwater management, integrated predator control, prescribed fire, stormwater management, sustainable agriculture, and disturbance reduction that are commmon across all species of marsh birds of conservation concern (Figure 4.1 and Appendix 4). We prioritized our management actions based on their uncertainty and effect size because improving our understanding (i.e., reducing uncertainty) is a core value of GoMAMN.

Wetland loss along the northern GoM has been well documented (Handley et al. 2015a, b, c, d, e). In addition, the restoration of emergent marsh habitats have been identified as a focus area in many post-Deepwater Horizon recovery documents (e.g., DWH Trustees 2016). However, marsh bird response to emergent marsh restoration efforts at the project scale or how populations respond at a regional scale is essentially unknown, particularly in the GoM (Woodrey 2017). Given the unprecedented scale at which marsh restoration will take place across the GoM in response to the Deepwater Horizon Oil Spill, the marsh bird working group identified the monitoring of marsh bird response to emergent marsh restoration as one of its highest priority management actions (Table 4.3). Response metrics associated with marsh restoration would be primarily aerial extent of marsh created

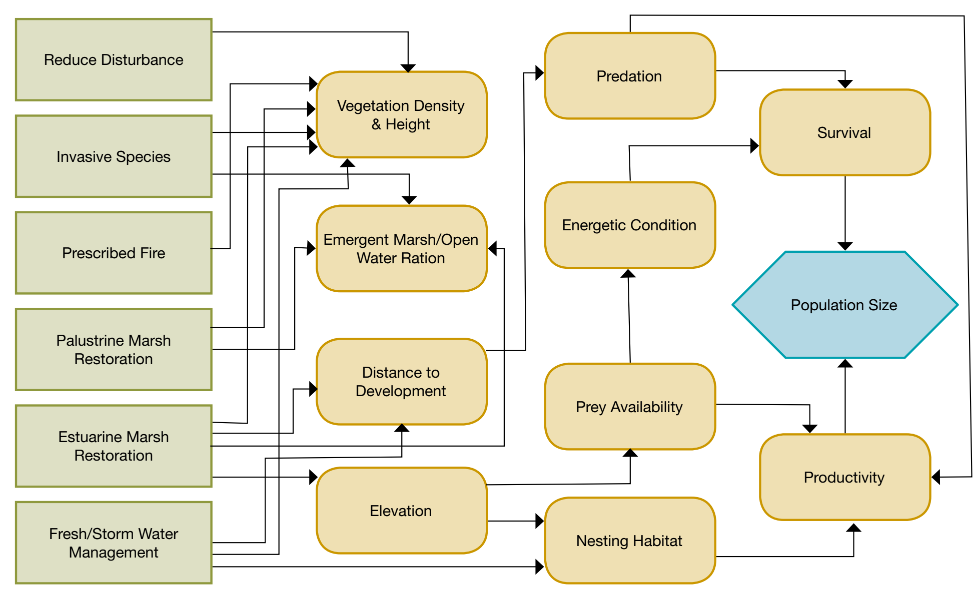

Figure 4.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Black Rail*** *(Laterallus jamaicensis) within the Gulf of Mexico Region.*

but should include marsh bird community assemblage and/or species-specific marsh bird abundance, depending on the project objective(s). Marsh restoration projects are typically of a smaller scale, limiting the opportunity for generating robust species abundance estimates. However, the use of community assemblages can allow for a robust evaluation of marsh creation projects. At the broader regional scale encompassing a collection of projects, species-specific abundance data can be used effectively to evaluate the cumulative effects of multiple restoration efforts across the region.

Freshwater management, defined as any management action that influences the amount of fresh water flowing into a system, including storm water, impacts marsh birds in several key ways. First, changing of salinity levels, via altered freshwater inflows, in a wetland system affects the plant communities and invertebrate prey available in that wetland. It can also change the sediment deposition rates in a wetland system, change the ratio of open to emergent marsh, and influence vegetation density and height. The major factors influencing marsh zonation patterns we see along the northern GoM, namely salinity and tidal regime, are well understood from a mechanistic perspective, yet little is known about how changes in salinity indirectly affect marsh bird populations via changes in plant community assemblages in coastal marshes. Given this relationship, priority should be given to reducing the uncertainty associated with vegetation assemblages and marsh bird populations where both plant assemblage and marsh bird abundance are monitored.

A more substantial uncertainty exists concerning the process of how salinity changes prey species abundance and diversity of marsh bird foods such as fiddler crabs (*Uca*. spp.), insects, benthic invertebrates, and plant seeds. Further, there is also uncertainty around the dietary plasticity of marsh birds as freshwater inputs influence salinity changes which in turn impact prey. Diet studies, such as those for Clapper Rail (Rush et al. 2010a), as well as ecological studies relating prey abundance and distribution to rail movements and nesting habits (Rush et al 2010b, c), are critical to reducing uncertainty. To better understand this relationship, studies should be rigorously designed to determine crab abundance across existing salinity gradients. In addition to fiddler crabs, the same approach and metrics would apply to reducing uncertainty surrounding the impacts of salinity for tidal marsh insects, benthic invertebrates, and seed abundances.

Table 4.3. *Uncertainties underpinning the relationship between management decisions and populations of marsh birds in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Marsh Birds All	Habitat and Natural Process Restoration (Habitat Restoration)	How does emergent marsh restoration influence marsh bird community assemblages and species-specific abundances?	Aerial extent of emergent marsh created; marsh bird community assemblage; marsh bird abundance	Marsh bird community assemblage and species-specfic abundance response to emergent marsh restoration.	High	High
Marsh Birds All	Habitat and Natural Process Restoration (Freshwater Management)	How do changes in salinity influence prey communities (e.g.,fiddler crabs, insects)?	Fiddler crab, insect abundance	Relationship between salinity and prey abundance (e.g., fiddler crabs, insect abundance).	High	High
Marsh Birds All	Invasive/ Problematic Species Control (Predator Management)	Is nest predation a significant source of low productivity?	Nest predation rates	Geographic variability highly uncertain; predator identity uncertain	High	Unknown
Yellow Rail Winter	Habitat and Natural Process Restoration (Freshwater Management)	How do hydrological changes to pine savanna change habitat suitability for wintering Yellow Rails?	Soil moisture, surface water depth	Uncertainty around seasonal/ annual changes in wet pine savanna hydrology in relation to Yellow Rail utilization.	High	Unknown
Black and Yellow Rail All	Habitat and Natural Process Restoration (Freshwater Management)	How do changes in the timing and extent of freshwater inputs change the plant community/structure?	Plant community assemblage	Extent of plant community assemblage change based on altered freshwater inflow and resulting changes in Black and Yellow Rail populations.	High	Unknown
Marsh Birds All	Habitat and Natural Process Restoration (Habitat Management-Prescribed Fire)	What are the long-term benefits of maintaining a marsh plant community assemblage with prescribed fire?	Plant commuity assemblage response; plant species-specific stem densities; percent dead herbaceous material	Whether changes in a marsh plant community due to prescribed fire will benefit marsh birds.	High	Unknown
Marsh Birds All	Site/Area Management (Freshwater Management)	Does storm water runoff negatively Impact survivorship and productivity of marsh birds?	Percent impervious surface; percent human development at landscape scale	Relationship between stormwater runoff and marsh birds.	Low	Unknown
Yellow Rail Winter	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	Does cultivated rice agriculture provide suitable stopover and possibly wintering habitat for Yellow Rails?	Aerial extent of second crop (i.e., ratoon crop) of cultivated rice; Yellow Rail abundance	Very high uncertainity associated with Yellow Rail abundance estimates and patterns of use in cultivated rice impoundments.	High	Unknown
Yellow Rail Winter	Habitat and Natural Process Restoration (Habitat Management-Prescribed Fire)	What is the relationship between prescribed fire (for management/restoration of wet pine savanna habitat) and Yellow Rail abundance?	Plant community assemblage, including structure; Yellow Rail abundance	Uncertainity exists regarding the population response of Yellow Rails to prescribed fire across the Gulf of Mexico region.	High	Unknown

Table 4.3 (continued).

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Black Rail All	Habitat and Natural Process Restoration (Habitat Management-Prescribed Fire)	What is the relationship between high marsh management management (i.e., prescribed fire) and Black Rail abundance?	Plant community assemblage, including structure; Black Rail abundance	Whether changes in high marsh plant community (i.e., species composition and structure) due to prescribed fire will affect Black Rail abundance.	High	Unknown
King Rail All	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	Does cultivated rice agriculture provide suitable habitat for breeding, migrating, and wintering habitat for King Rails?	Aerial extent of cultivated rice agriculture; King Rail abundance	High level of uncertainity surrounding King Rail abundance estimates and patterns of use in cultivated rice impoundment landscapes.	High	Unknown
Marsh Birds All	Site/Area Management (Freshwater Management)	How do changes in salinity influence plant communities?	Salinity regime, plant community assemblage	Relationship betweeen salinity and marsh plant species.	Low	High
Marsh Birds All	Invasive/ Problematic Species Control (Predator Management)	Is direct predation (raccoons, harriers, etc.) a significant source of mortality for adults and subadults?	Abundance of marsh bird predators (e.g., racoons, Northern Harriers)	Sources of mortality are unknown; precise estimates of mortality are unknown.	High	Low
Marsh Birds All	Invasive/ Problematic Species Control (Habitat Management-Invasive Plants)	What is the impact of invasive plant species on marsh bird comuunity assemblages, species-specific abundance, and demography?	Aerial extent of invasive plant species (e.g., Phragmites spp., Cogon grass, etc.); marsh bird community assemblage; marsh bird deomography	Marsh bird community assemblages and species-specific abundance and demography responses to various levels of invasive plant species.	High	Low

[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.

The effective management of wet pine savanna and high marsh habitats (defined as *Spartina patens* and *S. spartinae*-dominated transition zones at the ecotone of tidal marsh and pine forests) where Yellow and Black Rails have recently been found is virtually unknown, although the use of prescribed fire is beginning to be understood for the north-central regions of the Gulf (Morris et al. 2017, Soehren et al. 2018). Given the restricted geographic limits of these studies, a critical need for wintering marsh birds are survey and monitoring efforts focused on Yellow and Black Rails across the Gulf region. In addition to prescribed fire, freshwater inflows and hydrologic regime are two factors also thought to influence plant communities for these high marsh and pine savanna habitats, but these relationships are, for the most part, undescribed and understudied Thus, the GoMAMN marsh bird working group has prioritized monitoring efforts focused on tracking plant community assemblage and species-specific stem density in responses in these critical habitats to changes in freshwater hydrology for these two high priority species (Figure 4.1 and Appendix 4).

In the GoM region, nest predation appears to be the significant source of nest loss and resulting reduced productivity (Rush et al. 2010c; Lehmicke 2014). Although the specific species of predators are not known, it is hypothesized that mammalian predators are primarily responsible for the majority of nest loss in GoM tidal marsh systems. However, our certainty associated with this hypothesis is limited, due to the lack of nest monitoring data for breeding marsh birds. Thus, the marsh bird working group prioritized collecting nest predation rates across the Gulf region as part of local and regional projects. Further, monitoring marsh bird nest predation rates in areas where an integrated predator program is used for beach nesting birds would provide information regarding potential indirect benefits to birds nesting in the marsh near these beach habitats, an additional unknown which should be addressed across the Gulf region.

While the effects of prescribed fire are well studied in many upland systems, uncertainty remains around prescribed fire impacts on tidal marsh vegetation diversity and structure, wetland invertebrates, and the birds which depend on them, particularly in the unimpounded, natural marshes found along the Gulf coast. The most common questions members of the marsh bird working group hear from land managers revolve around the fire return interval for tidal marsh management. Unfortunately, there are little empirical data or published studies to provide guidance for the management community. Further, little is known regarding how changes in climate might impact land managers' ability to burn in the future. A focus on quantifying plant community response, including plant species assemblage, species composition, and species-specific stem densities, to prescribed fire is a significant priority for marsh bird monitoring. A focused evaluation of the long-term benefits of maintaining marsh plant communities via fire are critical to reducing uncertainty around marsh bird response to marsh management, and monitoring efforts should be undertaken to better understand regional differences in fire effects across the GoM region.

Many coastal wetlands, especially in Texas and Louisiana, have been converted into impounded wetland agricultural fields, often growing crops such as rice. Many rail species in North America are known to use these rice fields, along with several other species of marsh birds, though what kinds of rice agriculture are best for providing food, shelter, and wintering and/or breeding habitat is not well known (Eadie et al. 2008, Acosta et al. 2010).

For some species of birds, disturbance, especially during the breeding season, can have a large impact on the ability of birds to successfully fledge offspring. Disturbance during migration/winter can also cause birds to expend their limited energy reserves, as has been studied in several waterfowl species. Whether disturbance by humans impact the ability of marsh birds to successfully nest, or puts extra stress on their ability to survive during migration is unknown. Given winter ecology of marsh birds is not well known, little is known about the relative impacts that different types of disturbance might have. For example, what is the relative impact of a human near a nest, impacts of boat wake, or a person fishing several meters away in a boat?

Priority Status and Trends Assessments

Our highest priority is given to species with declining population trends and/or great uncertainty about their trend over long time spans and a broad geography (Figure 2.2, Table 4.1). We have included the population status of each of our marsh birds of conservation concern, as well as other marsh bird species considered potential monitoring targets (Table 4.1). These trends are from the Partners in Flight (2017) Species Assessment. For species which do not breed in the GoM and for which we do not know the relative proportion of the population wintering in the GoM (e.g., Yellow Rail), population level status and trends assessment in the GoM may not be appropriate. In those cases, trends of just the GoM wintering population may be useful. Population level status and trends assessment for a resident species such as Seaside Sparrow, are appropriate and should be given serious consideration.

Due to the lack of region-wide population estimatees and trend data for marsh birds, we value information related to the status and trends of our bird species of conservation concern that address both population-level and habitat (quantity and quality) over long time periods that span the entirety of the northern GoM. Because of their secretive nature, inaccessibility of their habitats, and relative paucity of information about them, we know very little about the status and trends of any of these marsh bird species of conservation concern. This information is vital for assessing/documenting changes in populations and their habitats, as well as to provide data to facilitate understanding of large-scale ecological processes such as sea-level rise and their impacts to birds and their habitats.

The highest monitoring priority is population-level trends over time, at a region-wide scale for breeding marsh bird species, collected in such a way as to inform the wider population trends for species that migrate to and through the GoM. Presently, there are no long-term avian monitoring programs in place and no restoration projects that collect marsh bird data across multiple states or over meaningful time scales. However, a robust marsh bird sampling framework is available (Johnson et al. 2009) and this sampling frame allows for the incorporation of historic data, thus taking advantage of the limited monitoring efforts to date.

Table 4.1 provides habitat associations for marsh bird species considered in this monitoring plan. Habitats are

Black Rail (*Laterallus jamaicensis*). Photo credit: Michael Gray.

prioritized in the same order as the priority species, because status and trends assessment is a two-pronged approach whereby we evaluated the status and trends of marsh birds of conservation concern and the habitats they use along the GoM. The long-term trends of marsh birds are best assessed by implementing a Gulf-wide monitoring program designed to estimate abundance using established point count monitoring protocol (Conway 2011) and sampling design (Johnson et al. 2009).

Priority Ecological Processes

Marshes and marsh birds are subject to a variety of ecological processes including, but not limited to hurricanes and other extreme weather events, changes in salinity, and predation (Day et al. 2013). By understanding these underlying processes, the bird conservation community of practice will be better prepared to understand marsh bird population changes, including the impacts of forces that can and cannot be managed. While there are many uncertainties about how marsh birds will be impacted by restoration techniques in wetland ecosystems, there are additional key uncertainties about related ecological processes (NASEM 2017).

The impacts on marsh birds of changing precipitation patterns, hydrological and fire regimes due to climate change and hurricane intensity and frequency are uncertain (Woodrey et al. 2012). Given these and other uncertainties identified by the GoMAMN Marsh Bird Working Group, the ecological process questions detailed in Table 4.4 were determined to be of the highest priority for better understanding marsh bird populations in the GoM.

The fragmentation of wetlands by human development has likely had impacts on the movement of organisms across the landscape, and even in some cases possibly at a local level. How this development impacts movement and other aspects of individual survival is not well known, and uncertainty about effects of different types of development on marsh bird ecology still exists.

There are several key areas of uncertainty around how hurricanes (and other named tropical storms) impact marsh birds (Table 4.4). First is the uncertainty around the short- and long-term effects on marsh bird communities, as well as the timing of the storms in relation to the breeding season. Storm surge, extensive rainfall and wind could all have detrimental impacts on individual marsh birds, their nests, and young, though how well individuals or their young are able to anticipate and respond to these impacts is not known. Long-term impacts of hurricanes could affect marsh birds through changes in the vegetation community from storm surge or other landform changes. This uncertainty is whether those changes to habitat impact marsh birds, and if they do, for how long a time period.

Marsh restoration is assumed to provide habitat for marsh birds, yet, we have little data to support this supposition (NASEM 2017). While there are many uncertainties about how marsh birds will be impacted by restoration techniques in wetland ecosystems there are additional key uncertainties about related ecological processes (NASEM 2017). For example, how do birds colonize these areas, and how is colonization affected by succession? Understanding individual bird movements would also allow us to assess the effects of human development and how it influences occupancy, as well as assessing the effects of fire on occupancy. In addition to assessing occupancy, telemetry data would be important because it allows for the study of movement and home range.

SUMMARY & MONITORING RECOMMENDATIONS

We see three main priorities for monitoring of marsh birds in the GoM:

★ Coordinated GoM-wide marsh bird monitoring is sorely needed. A robust framework exists for collecting data that can answer local and region wide questions and is already being successfully implemented in the north eastern US through the SHARP (Saltmarsh Habitat and Avian Research Program, tidalmarshbirds.org). The same

Table 4.4. *Uncertainties related to how ecological processes impact populations of marsh birds in the northern Gulf of Mexico.*

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Marsh birds All	Movement of Organisms	Does human development adjacent to wetlands influence the occupancy of marsh birds?	Occupancy; species-specfic marsh bird abundance	Whether human development of any kind has an impact; do certain kinds of development have more impact than others?	High	High
Marsh birds All	Natural Disturbance Regimes	Do hurricanes impact marsh bird abundance in the short- or long-term?	Species-specfic marsh bird abundance	Uncertainty about birds ability to move and avoid negative impacts; how hurricanes impact habitat quality and marsh bird survival.	High	Unknown
Marsh birds All	Natural Disturbance Regimes	Are there differential impacts of hurricanes on adult versus juvenile annual survivorship?	Adult and juvenile annual survivorship estimates	Uncertainty about adult vs juvenile ability to avoid natural disturbances.	High	Unknown

[a]Categories follow the classification scheme and nomenclature presented by Bennett 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.

sampling framework, and similar monitoring protocols should be implemented across all five northern GoM states, to allow us to estimate population size and trend, as well as address uncertainties associated with management actions and the impacts of ecological processes.

★ Monitoring of marsh bird response to various estuarine wetland restoration techniques is greatly needed, both to evaluate ongoing restoration work, and to inform future restoration efforts. Monitoring should seek to understand the impact of different restoration techniques, as well as the amount of time it takes marsh birds, and the vegetation/food resources they rely on, to respond to different techniques. In addition, the monitoring of the effects of prescribed fire in estuarine wetlands could have wide ranging implications for marsh birds, especially black rail, as well as other birds which use coastal wetlands such as waterfowl. Monitoring should seek to understand the effects of prescribed fire in different seasons, and with different intensities on the marsh bird community and the vegetation/food it relies on.

★ Sea-level rise is the ecological process we are most certain will influence marsh bird populations in the coming decades, though how it will impact all species is not well known. Additional work is needed to better predict how marshes will respond and/or move as sea levels rise, and what role extreme weather events such as hurricanes play in the short- and long-term survival of marsh bird species, especially earlier season tropical storms which could affect breeding birds.

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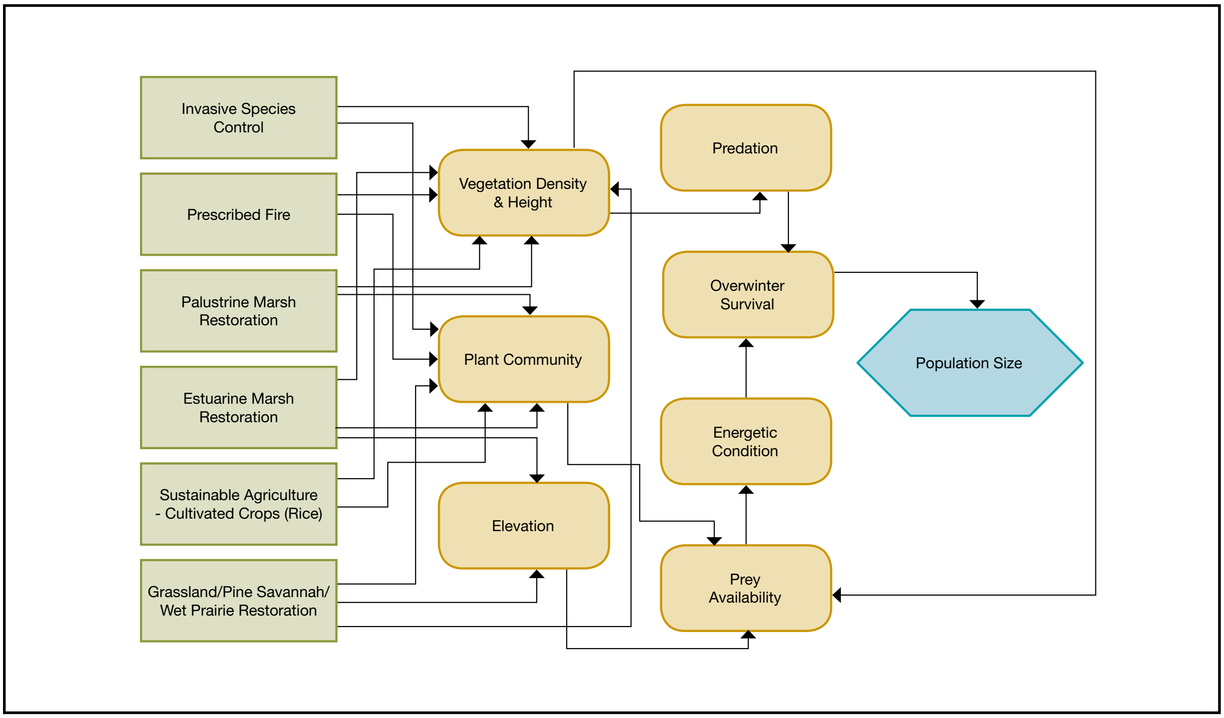
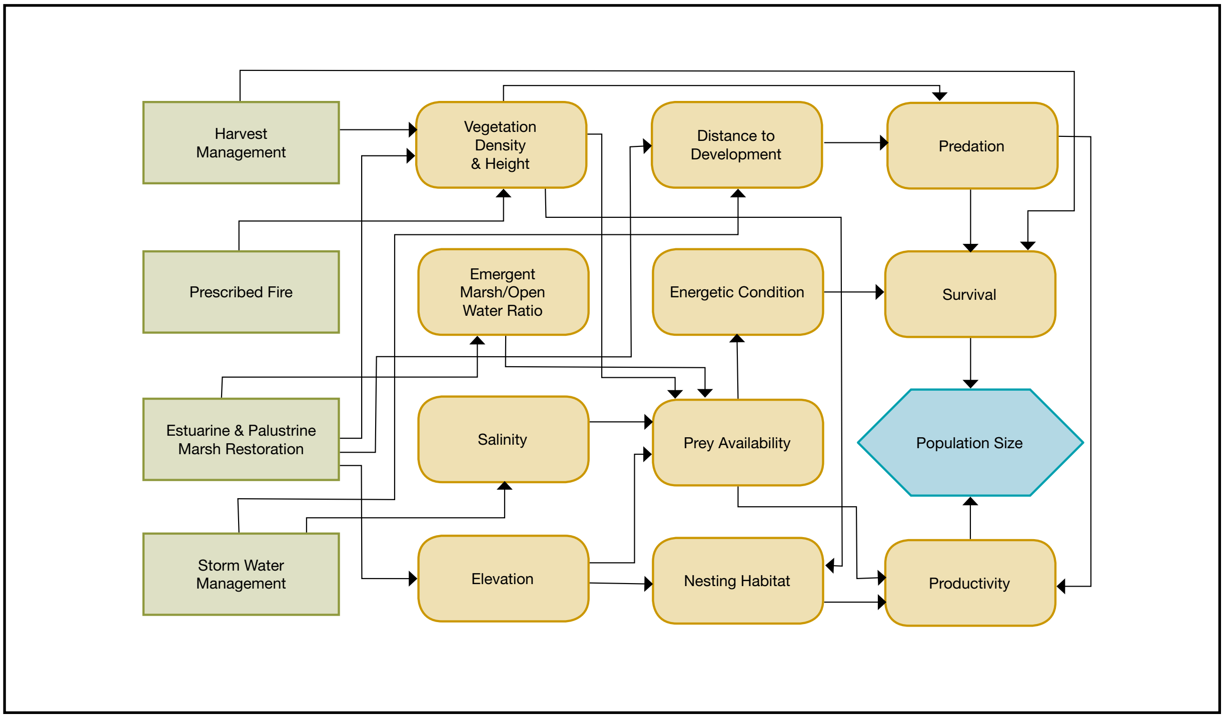
APPENDIX 4

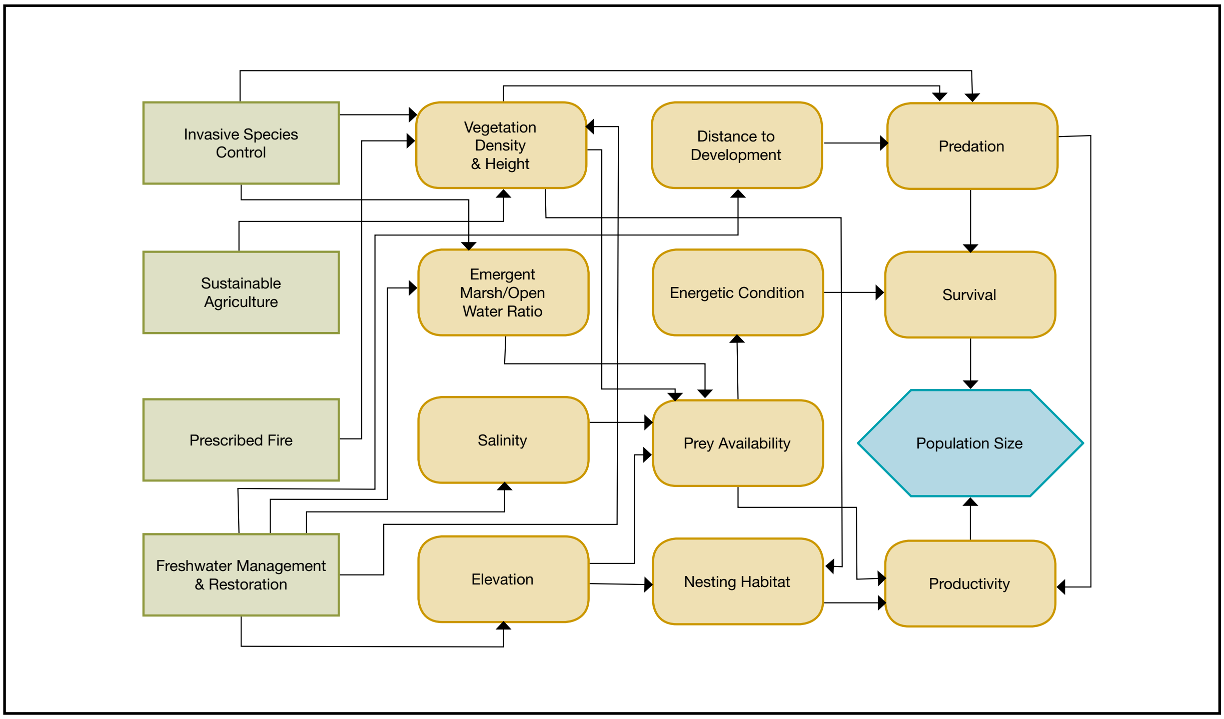
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of marsh birds.



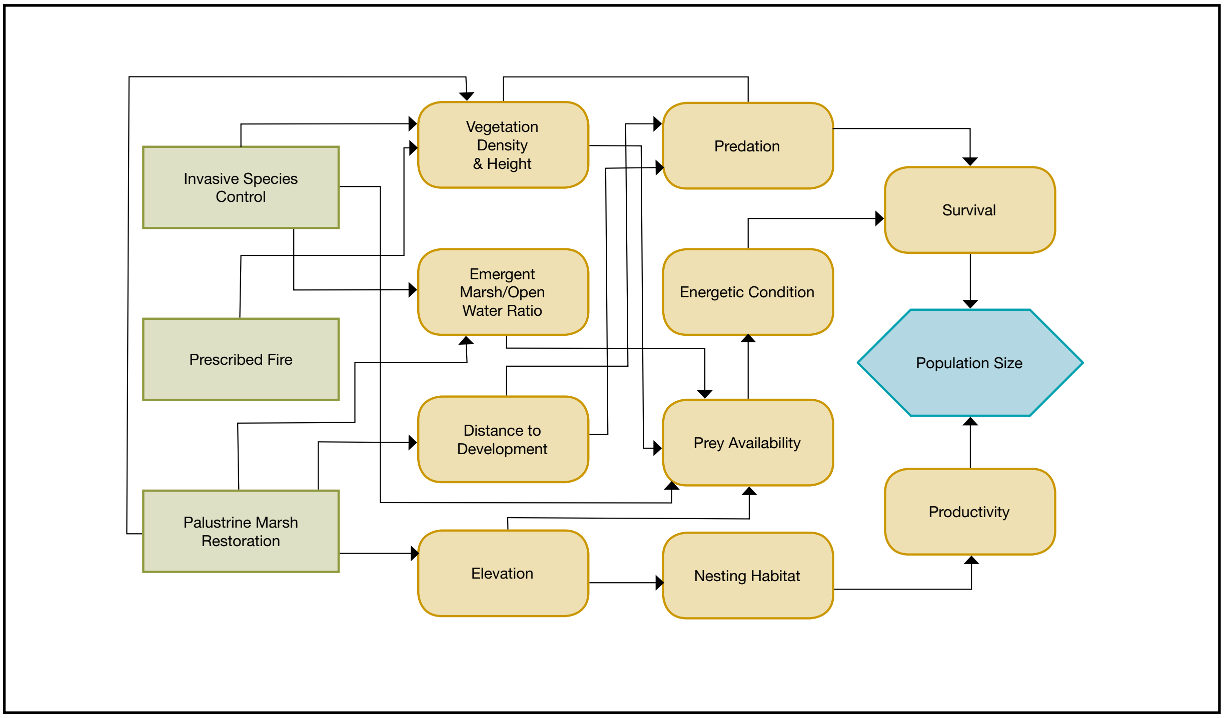
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Yellow Rail*** *(Coturnicops noveboracensis) within the Gulf of Mexico region.*



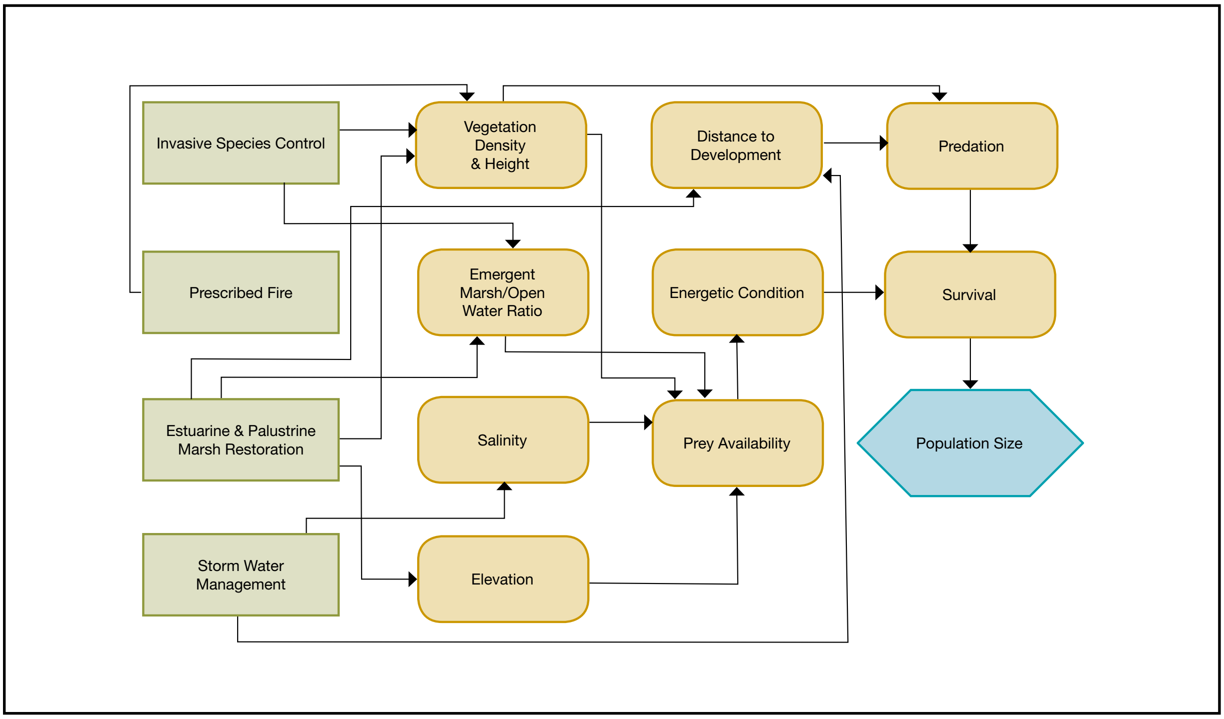
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Clapper Rail*** *(Rallus crepitans) within the Gulf of Mexico region.*



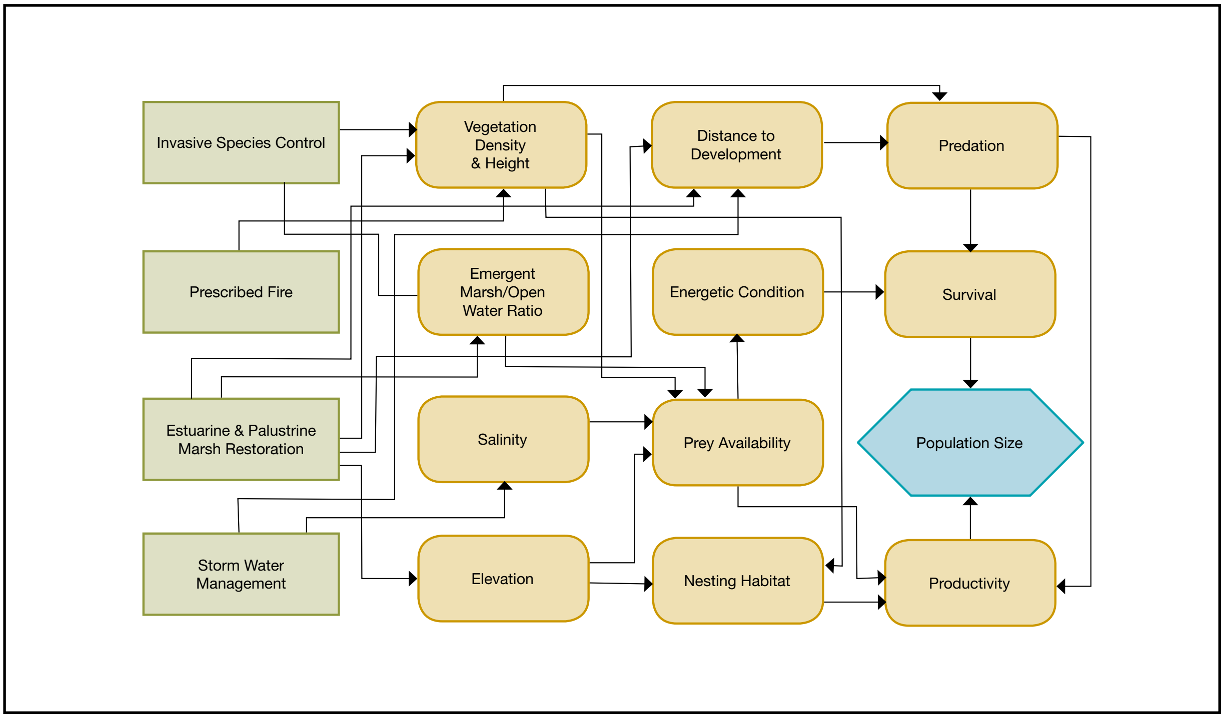
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***King Rail*** *(Rallus elegans) within the Gulf of Mexico Region.*



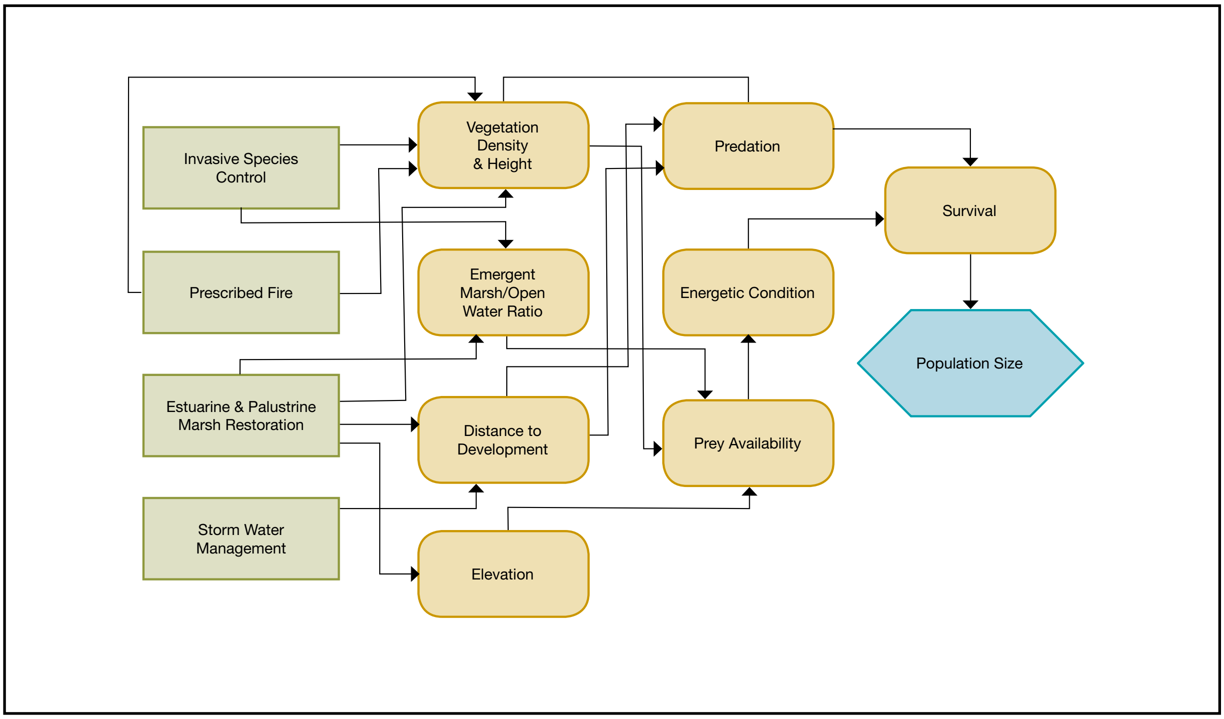
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Limpkin** (Aramus guarauna) within the Gulf of Mexico Region.*



*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **American Bittern** (Botaurus lentiginosus) within the Gulf of Mexico Region.*

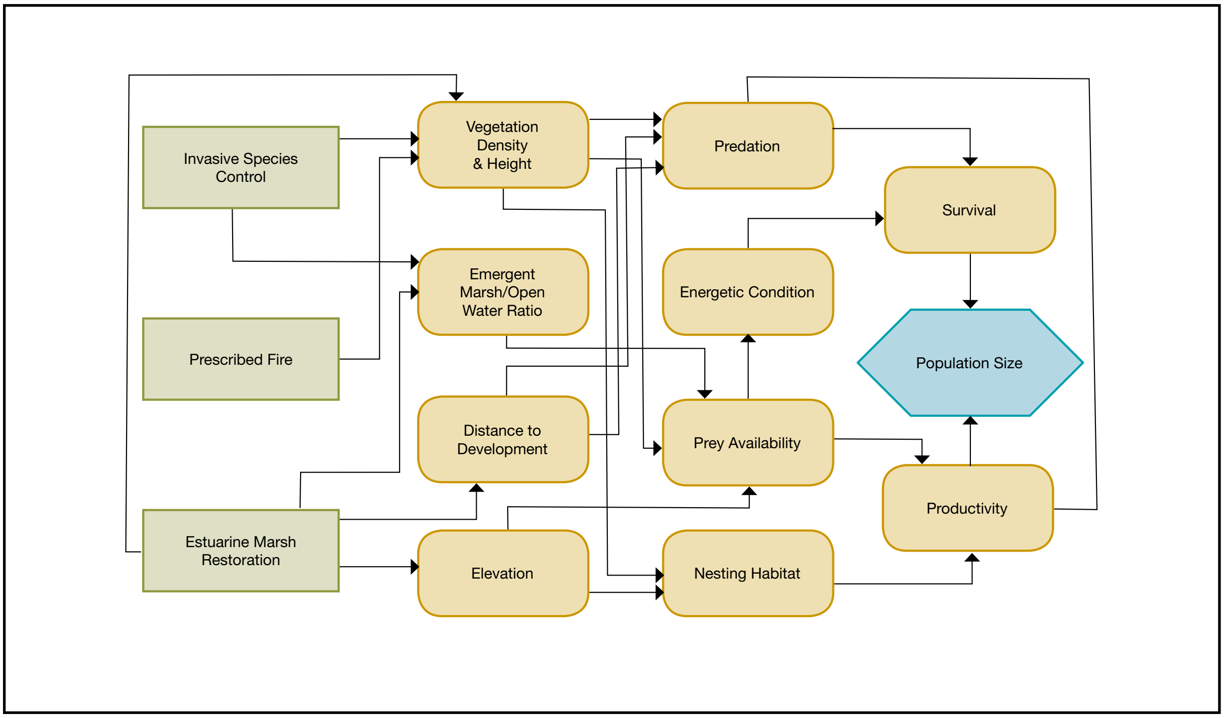


*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Least Bittern** (Ixobrychus exillis) within the Gulf of Mexico Region.*

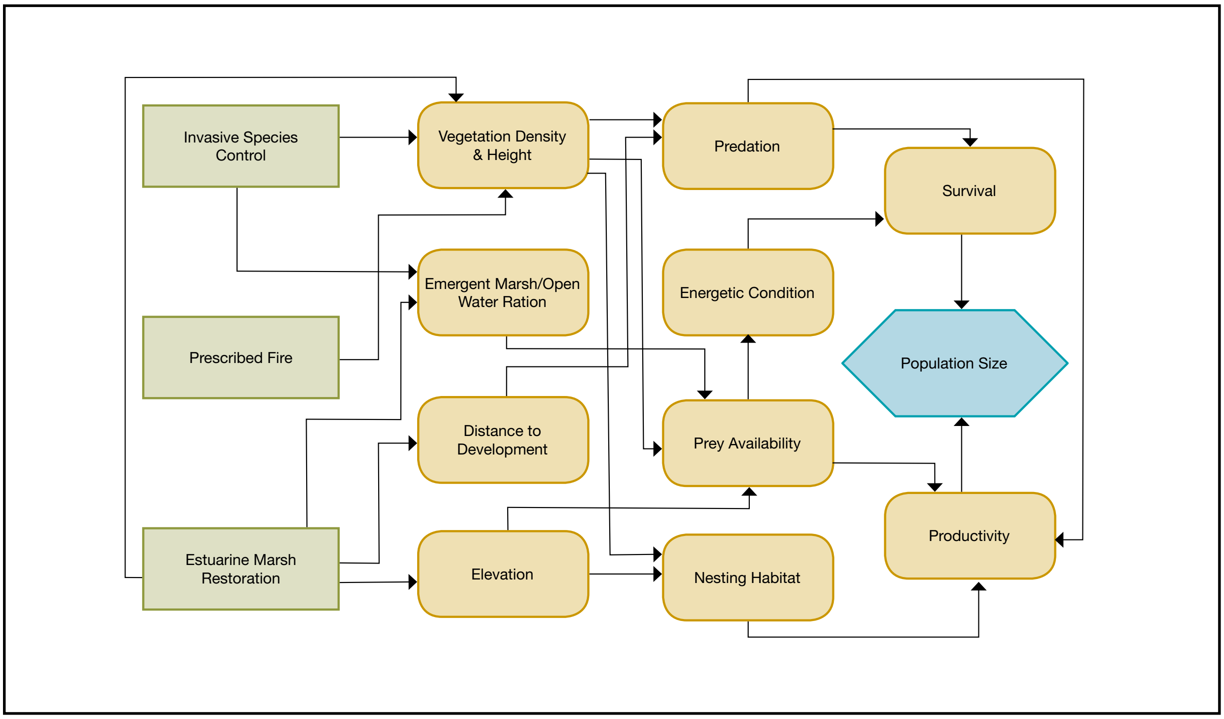


*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Marsh Wren** (Cistothorus palustris) within the Gulf of Mexico region.*

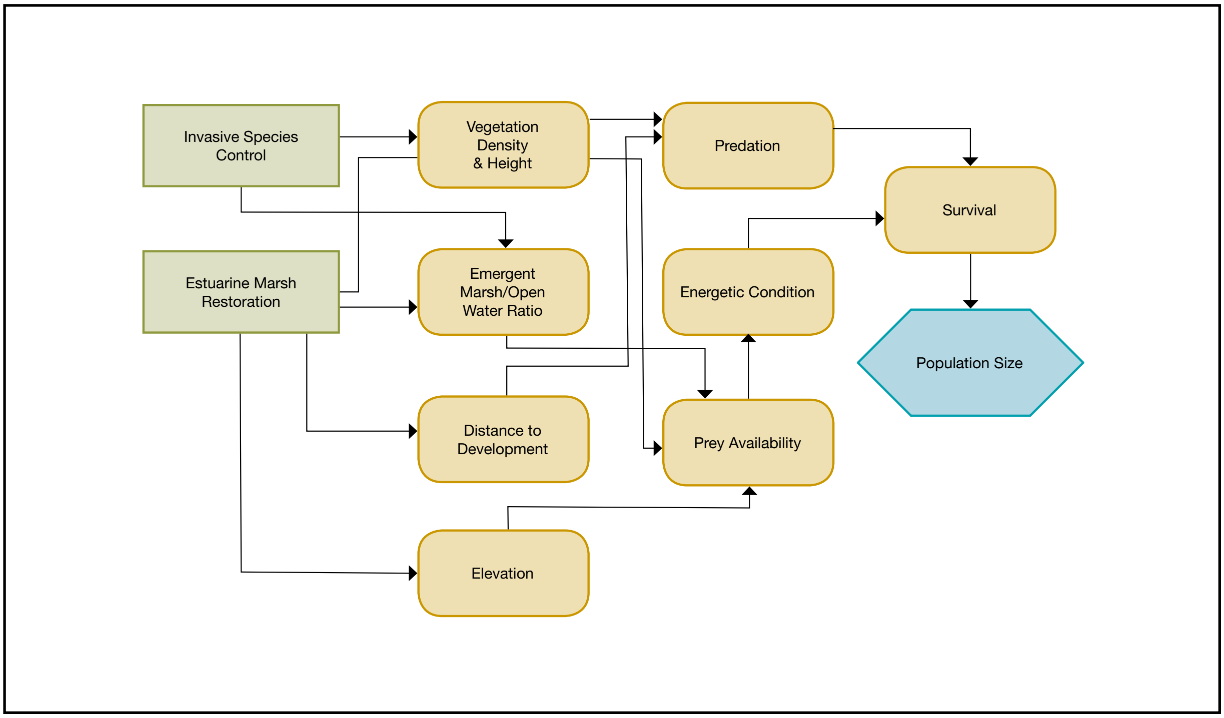
Marsh Birds



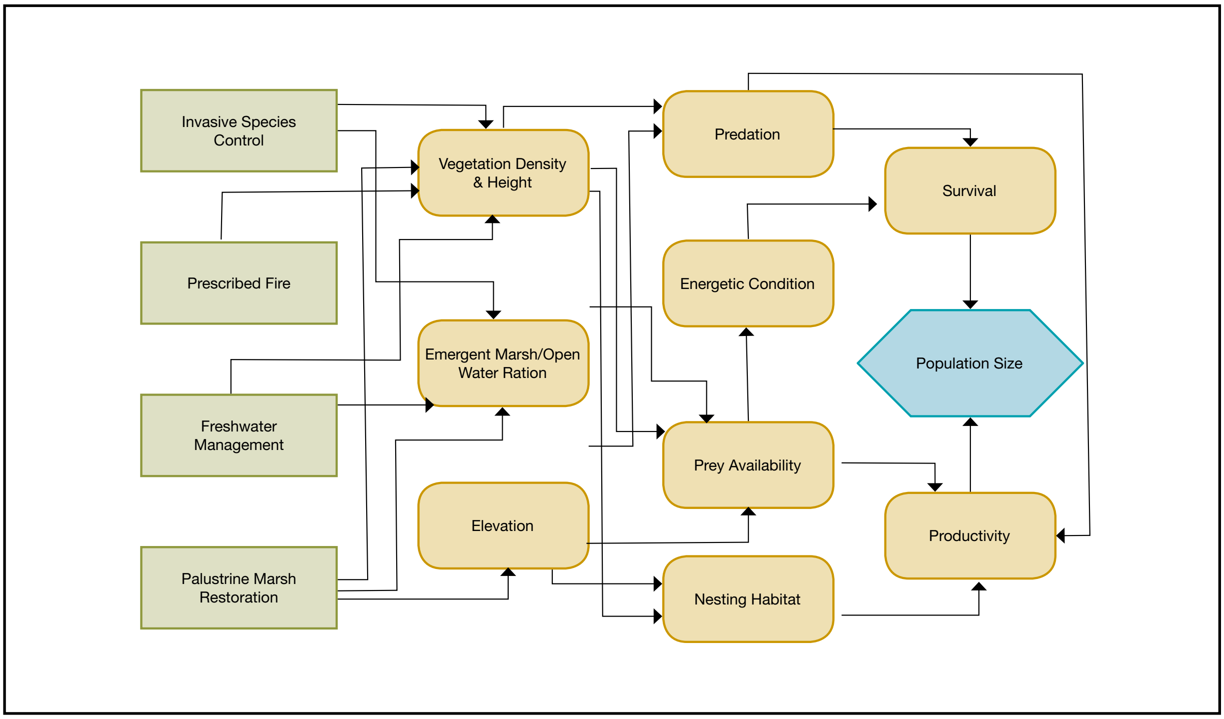
Influence Diagram of the relationship between Management Actions (Green Boxes), Intermediate Processes (gold boxes) and Population Size (Blue Hexagon) for the ***Mariah's Marsh Wren*** *(Cistothorus palustris marianae) within the Gulf of Mexico Region.*



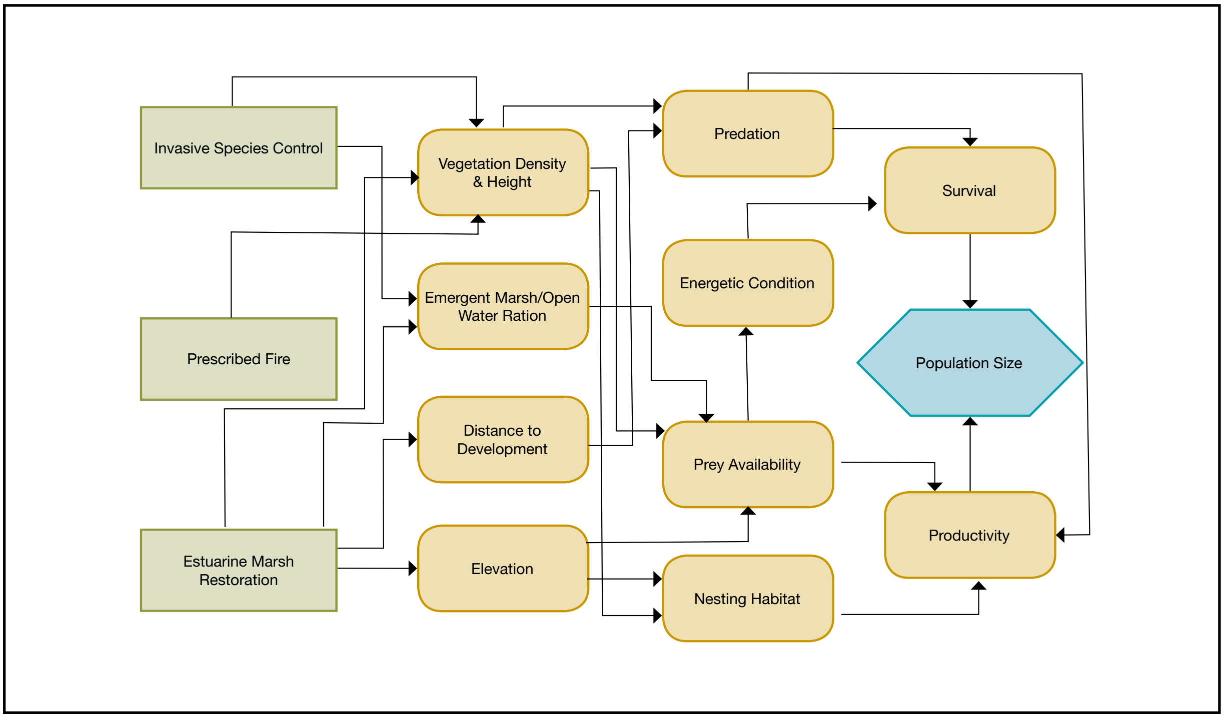
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Seaside Sparrow*** *(Ammospiza maritima) within the Gulf of Mexico region.*



*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Nelson's Sparrow** (Ammospiza nelsoni) 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 **Cape Sable Seaside Sparrow** (Ammospiza maritima mirabilis) 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 ***Texas Seaside Sparrow*** *(Ammospiza maritima sennetti) within the Gulf of Mexico region.*

5

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: RAPTORS

Authors:

Michael A. Seymour (1)

Jennifer O. Coulson (2*)

1. Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA
2. Orleans Audubon Society, Pearl River, LA

(*) Corresponding Author: **jacoulson@aol.com**

Osprey (*Pandion haliaetus*). Photo credit: George Gentry

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Chapter 5

GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: RAPTORS

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

Few groups of North American birds garner as much veneration as raptors. Members of this diverse group, from the diminutive American Kestrel (*Falco sparverius*) to the formidable Bald Eagle (*Haliaeetus leucocephalus*), have at least one thing in common: they actively hunt other animals, seizing prey with their feet. While the diurnal and nocturnal raptors share a common lifestyle, the hawks and eagles, the owls, and the falcons are only distantly related (Hackett et al. 2008). This divergent ancestry should be considered when threats arise, as responses may differ physiologically and behaviorally.

As apex predators, few adult raptor species need to worry about natural predators—unless a larger species of raptor lurks nearby. Cooper's Hawks (*Accipiter cooperii*), for example, are implicated as predators upon American Kestrels (Farmer et al. 2006), and Great Horned Owls (*Bubo virginianus*) will hunt virtually any species smaller than themselves (Artuso et al. 2013). But their position atop the food web comes at tremendous costs; as predators, raptors are often maligned by humans and, frequently, needlessly and erroneously targeted for destruction (Millsap et al. 2007). Although state and federal law now prohibits such wanton slaughter of wildlife, shooting and poisoning of birds of prey are still unfortunate realities (Harness 2007, Millsap et al. 2007).

Because of their position at the top of the food chain and their conspicuous nature, raptors can often act as sentries of environmental health (Bildstein 2001). When populations of large, predatory, meat-eating birds decrease dramatically in a short period of time, citizen scientists and others tend to notice and seek answers. One frequently cited example is that of the population decline of apex, predatory birds caused by their exposure to the pesticide DDT and its derivatives (Ratcliffe 1970, Grier 1982, Peakall 1987, Henny and Elliott 2007, Blus 2011). The toxins, particularly DDE, the result of degraded DDT, were bioaccumulated and biomagnified through the food web. When concentrated in the tissues of Brown Pelicans (*Pelecanus occidentalis*), Ospreys (*Pandion haliaetus*), Bald Eagles (*Haliaeetus leucocephalus*), Peregrine Falcons (*Falco peregrinus*), and others, DDE caused decreased deposition of calcium in the eggshells, which resulted in accidental breakage by incubating adults (Blus et al. 1971, Blus 2011). In what must be among the greatest conservation success stories of all time, after DDT was banned in 1972, population of pelicans and raptors showed almost immediate signs of a path to recovery (Grier 1982; Holm et al. 2003). In Louisiana, where Bald Eagles decreased to around five active nests by the early 1970s, eagles have now increased to more than 350 active nests as of 2015 (M. A. Seymour, unpublished data). In August 2007, the Bald Eagle was removed from the federal list of threatened and endangered species. In August 1999, the U.S. Fish and Wildlife Service (USFWS) removed the American Peregrine Falcon from the list of endangered and threatened species. Despite their substantial recovery, because many raptors feed on pest species, wildlife biologists must remain vigilant in monitoring raptor populations in case novel pesticides create novel consequences.

An active hunting lifestyle also makes many raptors particularly susceptible to injury and death from collisions and electrocution. Their proclivity to ride thermals and use prevailing winds renders them vulnerable to collisions with structures such as wind turbines and power lines (Pagel et al. 2013, Hunt et al. 2017). Their inclination to hunt along roadsides makes them susceptible to collisions with motor vehicles. Their attraction to roadsides and power line right-of-ways coupled with their tendency to hunt from dominant perches renders them susceptible to electrocution (Avian Power Line Interaction Committee 2006, Bierregaard et al. 2016). Larger species are more at risk of electrocution, because their extremities are more likely to make contact across wires, transformers, fuses, and other energized structures. As the human population grows and expands, so too must the power infrastructure to support it; increased risks of collisions and electrocutions are, therefore, likely without proper "siting and routing, improving line marking devices... and increasing awareness" (Avian Power Line Interaction Committee 2012).

Raptor diversity in the northern Gulf of Mexico (GoM) is high. Including new world vultures, osprey, kites, eagles, hawks, owls, and falcons, the bird checklists from the five states that rim the northern GoM contain 55 species, though several are represented by a handful or fewer records. Especially notable is the Mexican influence of birdlife in Texas, which lists 54 of the 55 species on its official state checklist (Texas Bird Records Committee 2018); Hook-billed and Double-toothed Kites (*Chondrohierax uncinatus* and *Harpagus bidentatus*), Crane and Roadside Hawks (*Geranospiza caerulescens* and *Rupornis magnirostris*), and Collared Forest-Falcons (*Micrastur semitorquatus*), and others are not likely encountered elsewhere within the GoM region. Louisiana and Florida have both recorded 36 species of raptors, and Mississippi and Alabama have both recorded 33 species of raptors (Louisiana Bird Records Committee 2016, Florida Ornithological Society 2016, Mississippi Ornithological Society Bird Records Committee 2015, Alabama Ornithological Society and Alabama Wildlife and Freshwater Fisheries Division 2017). State wildlife action plans from the

Table 5.1. *Raptor species of greatest conservation need as assigned by GoM State Wildlife Action Plans (Texas Parks and Wildlife Department 2012, Florida Fish and Wildlife Conservation Commission 2012, Alabama Department of Conservation and Natural Resources 2015, Holcomb et al. 2015, Mississippi Museum of Natural Science 2015)*

Raptor Species of Greatest Conservation Need from State Wildlife Action Plans						
Common Name	**Latin Name**	**Texas**	**Louisiana**	**Mississippi**	**Alabama**	**Florida**
Osprey	*Pandion haliaetus*		x	x		x
White-tailed Kite	*Elanus leucurus*		x			x
Hook-billed Kite	*Chondrohierax uncinatus*	x				
Swallow-tailed Kite	*Elanoides forficatus*	x	x	x	x	x
Golden Eagle	*Aquila chrysaetos*	x		x	x	
Northern Harrier	*Circus hudsonius*	x				
Bald Eagle	*Haliaeetus leucocephalus*	x	x	x		x
Mississippi Kite	*Ictinia mississippiensis*	x				x
Snail Kite	*Rostrhamus sociabilis*					x
Common Black Hawk	*Buteogallus anthracinus*	x				
Harris's Hawk	*Parabuteo unicinctus*	x				
White-tailed Hawk	*Geranoaetus albicaudatus*	x				
Gray Hawk	*Buteo plagiatus*	x				
Red-shouldered Hawk	*Buteo lineatus*	x				
Broad-winged Hawk	*Buteo platypterus*					x
Short-tailed Hawk	*Buteo brachyurus*					x
Swainson's Hawk	*Buteo swainsoni*	x				
Zone-tailed Hawk	*Buteo albonotatus*	x				
Ferruginous Hawk	*Buteo regalis*	x				
Barn Owl	*Tyto alba*			x		
Eastern Screech-Owl	*Megascops asio*					x
Ferruginous Pygmy-Owl	*Glaucidium brasilianum*	x				
Burrowing Owl	*Athene cunicularia*	x				x
(Mexican) Spotted Owl	*Strix occidentalis lucida*	x				
Short-eared Owl	*Asio flammeus*	x	x	x	x	x
Crested Caracara	*Caracara cheriway*		x			x
(Southeastern) American Kestrel	*Falco sparverius paulus*	x	x	x	x	x
Merlin	*Falco columbarius*					x
Aplomado Falcon	*Falco femoralis*	x				
Peregrine Falcon	*Falco peregrinus*	x	x	x		x

Raptors

GoM region include 30 species (Texas Parks and Wildlife Department 2012, Florida Fish and Wildlife Conservation Commission 2012, Alabama Department of Conservation and Natural Resources 2015, Holcomb et al. 2015, Mississippi Museum of Natural Science 2015; Table 5.1). From this list of species of greatest conservation need (SGCN), six species were chosen by the Raptor Working Group of the GoMAMN: an obligate fish-eater (Osprey); an acrobatic, aerial forager (Swallow-tailed Kite; *Elanoides forficatus*); a formidable predator and occasional scavenger (Bald Eagle); a crepuscular marsh and grassland dweller (Short-eared Owl; *Asio flammeus*); a strikingly dimorphic, cavity-nester (Southeastern American Kestrel; *F. s. paulus*); and a hard-hitting, aerial assailant (Peregrine Falcon). These six eclectic birds represent the Raptors of Conservation Concern on which to concentrate efforts to reduce uncertainty of the ecological processes and the management actions that affect our GoM raptors (Table 5.2).

Breeding season

Forty species of raptors have been known to nest in the five states of the GoM region. Of those forty species, approximately 26 species nest within the GoMAMN boundary. In general, 13 of the 26 species nest in forested landscapes, while the other 13 prefer grasslands for nesting. However, several species nest in trees, but require open forest or grassland for foraging (e.g., Swallow-tailed Kite and American Kestrel), which makes this generalized classification less clear. An increase in open habitats such as agriculture and pastureland has likely fueled the expansion of traditionally grassland species further east; Swainson's Hawk (*Buteo swainsoni*) and Crested Caracara (*Caracara cheriway*), for example, have rapidly expanded their breeding ranges from southwestern through the south-central regions of Louisiana within the last two decades (Morrison and Dwyer 2012; M. A. Seymour, unpublished data). Other species have benefited from anthropogenic habitat disturbances as well, often at the expense of other native birds. Great Horned Owls readily use sparsely wooded neighborhoods, which when adjacent to upland pine and bottomland hardwood forests, create conflict with nesting Swallow-tailed Kite, a Raptor of Conservation Concern. Like the presumed depredation of American Kestrels by Cooper's Hawks (Smallwood et al. 2009), a species that has also increased in abundance in the region, loss of kites to Great Horned Owls may be a factor in continued declines of these imperiled birds (Coulson et al. 2008).

A cosmopolitan species, found on every continent except Antarctica, the piscivorous Osprey nests throughout the GoMAMN focal area in estuarine and palustrine forested wetlands and emergent wetlands (Bierregaard et al. 2016). Nests are often constructed at the tops of standing snags, cypresses, mangroves, telephone poles, electrical transmission towers, telecommunication towers, and nesting platforms; ground-nesting may occur in areas without suitable vertical structure and without mammalian predators (Bierregaard et al. 2016). Because Ospreys are piscivorous, nests are almost always close to waterbodies and are often built atop structures in water such as standing boles of baldcypress (*Taxiodium distichum*). The breeding season in Texas through central Florida begins in February (early) or March (more likely), with the earliest nesting occurring in south Florida beginning in late November (Florida Fish and Wildlife Conservation Commission 2003, Tweit 2006b, Bierregaard et al. 2016). The Osprey is a rare nester in Texas, with possible, sporadic nesting at Port Isabel through Matagorda Bay up to approximately Port Arthur. Elsewhere within GoMAMN, the Osprey is a common nester, with concentrations in Louisiana in the lower Atchafalaya River, Mississippi River, and Pearl River drainages; in Mississippi, in the barrier islands, lower Pascagoula River and Escatawpa River drainages and Grand Bay National Estuarine Research Reserve; in Alabama, in the barrier islands and Mobile Bay; and in Florida, along the Gulf Coast through the Florida Keys. Recovery of Osprey populations following the DDT era was greatly enhanced by provisioning artificial nesting platforms (Houghton and Rymon 1997). Three thousand or more nesting pairs of Ospreys occur within the five GoM states (Bierregaard et al. 2016).

Like nests of the Osprey, those of the Bald Eagle, a North American endemic, are most often found near permanent waterbodies, particularly within palustrine forested wetlands (Buehler 2000). Nests are constructed upon similar substrates as those of Osprey. However, due to the large size and the substantial mass of nests, Bald Eagle nests are rarely constructed atop pole-like structures. Instead, eagles tend to use strong crotches of large trees such as baldcypress. However, where access to large trees is limited, mangroves, electrical transmission towers, telecommunication towers, and nesting platforms may be used (Buehler 2000). In fact, in many areas of the GoMAMN geography, particularly where baldcypress or other suitable trees are scarce or compromised by saltwater intrusion, Bald Eagles are increasingly found nesting on manmade structures. Where vertical structures are scarce, ground-nesting may occur (Buehler 2000). Bald Eagles typically build alternate nests within their territories; such nests may remain unoccupied for several years before becoming active again. This behavior of maintaining multiple, serviceable nests has led to the protection of all eagle nests, whether active or inactive, under the Federal Bald and Golden Eagle Protection Act. Because Bald Eagles have a more varied diet than Ospreys, eagles may frequently nest in large,

Table 5.2. *Raptor species to be considered for monitoring programs at multiple geographic scales across the northern Gulf of Mexico. Table includes species residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).*

Common Name	Latin Name	Breeding	Winter	Migration	Landcover Association(s)[a]	Trend Score	Continental Concern Score
Osprey	*Pandion haliaetus*	X	X		Palustrine Emergent Wetland, Palustrine/Riverine Forested Wetland, Lacustrine Forested Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Estuarine-Tidal Riverine Open Water	1	7
Swallow-tailed Kite	*Elanoides forficatus*	X		X	Palustrine Forested Wetland (bottomland hardwoods), Lacustrine/Riverine, Estuarine Forested Wetland, Upland Evergreen Forest (Wet Longleaf and Slash Pine Flatwoods & Savannas), Grassland (including pasture), Cultivated (row crops)	3	12
Bald Eagle	*Haliaeetus leucocephalus*	X	X		Palustrine Emergent Wetland, Palustrine/Riverine Forested Wetland, Lacustrine Forested Wetland, Estuarine Forested Wetland, Estuarine-Tidal Riverine Open Water	1	9
Short-eared Owl	*Asio flammeus*		X		Grassland, Upland Scrub/Shrub, Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Xeric Longleaf Pine Barrens), Beach/Dune, Cultivated (rice), Palustrine Emergent Wetland, Estuarine Emergent Wetland	5	12
(Southeastern) American Kestrel	*Falco sparverius paulus*	X	X		Grassland (including pasture), Upland Scrub/Shrub, Upland Evergreen Forest (Dry & Mesic Longleaf Flatwoods, Xeric Longleaf Pine Barrens), Upland Mixed Forest	4	11
Peregrine Falcon	*Falco peregrinus*		X	X	Grassland, Palustrine Emergent Wetland, Palustrine/Riverine Forested Wetland, Lacustrine Forested Wetland, Estuarine Forested Wetland, Estuarine Shrub/Scrub Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Beach/Dune, Urban, Cultivated (rice)	2	10

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

isolated trees within agricultural landscapes where they feed on waterbirds and carrion. In fact, the southern Bald Eagle is primarily a winter nester—likely taking advantage of the exceptional waterfowl abundance that occurs during winter. The nesting season extends from September through July (J. O. Coulson, unpublished data), with "occasional second clutching" in Florida (Florida Fish and Wildlife Conservation Commission 2003). Confirmed nesting of Bald Eagles extends discontinuously from the coastal bend of Texas through the Florida Keys; the species is an uncommon nester in coastal Mississippi, Alabama, and much of the Florida Panhandle until approximately Tallahassee, Florida (Turcotte and Watts 1999, Florida Fish and Wildlife Conservation Commission 2003, Tweit 2006a, Alabama Ornithological Society 2009; M. A. Seymour, unpublished data). Bald Eagle populations have continued to recover from the DDT era, when 417 breeding pairs were estimated in the contiguous U.S.A. in 1963 (Buehler 2000); by 2007, almost 10,000 pairs were estimated across the same area, 35 years after the ban of DDT (USFWS 2009). More than 1,900 pairs of eagles currently

Bald Eagle (*Haliaeetus leucocephalus*). Photo credit: Dave Menke

nest from Texas to Florida (Turcotte and Watts 1999, Tweit 2006a, Alabama Ornithological Society 2009, Zimmerman et al. 2017; M. A. Seymour, unpublished data). The spectacular recovery of the Bald Eagle was aided by state and federal wildlife agencies, who reintroduced eagles throughout their former range and mounted effective environmental education efforts.

Another species found in palustrine forested wetlands, the Swallow-tailed Kite once nested in as many as 21 states in the U.S.A. (Meyer 1995). The dramatic population decline and range reduction that occurred from 1880 to 1940 may have been due to large-scale logging of nesting habitat. Now regularly breeding in only seven southeastern states, this aerial forager is, nevertheless, conspicuous and unmistakable where found (Meyer 1995). Swallow-tailed Kites are early returnees from wintering grounds in South America to their breeding grounds in the Southeast, arriving as early as late February. Nesting begins almost immediately, with egg-laying in March through May and with nests typically placed high in the fork of an emergent tree, often a pine species (*Pinus*), baldcypress, Eastern cottonwood (*Populus deltoides*), or sweetgum (*Liquidambar styraciflua*)(Meyer 1995, J. O. Coulson, unpublished data). Vertebrate prey items like frogs, lizards, and nestling birds are gleaned from trees; but Swallow-tailed Kites also frequently forage over agricultural lands and other open grasslands where they hunt insects and other small organisms (Meyer 1995). Although the U.S.A. population of Swallow-tailed Kites appears stable or slightly increasing in the core of its range, active management needs to be maintained or increased to create suitable nesting habitat, particularly uneven or all-aged forests with live, emergent trees. Only 1,200 or so nesting pairs are extant in the U.S.A., and most of those occur within the GoMAMN geography—demonstrating the responsibility of our region to the persistence of this rare species. Moreover, the U.S.A. breeding population is disjunct; it is geographically separated from the next nearest breeding subpopulation by most of Mexico.

The American Kestrel, a small, brightly colored falcon, is one of the most abundant raptors in the USA with an estimated population of 2.5 million (Partners in Flight 2017). Despite its abundance, there is growing concern that the species is declining throughout its range (Smallwood et al. 2009). Although the species generally responds well to human encroachment, the southeastern subspecies of American Kestrel (*F. s. paulus*) has failed to rebound from the widespread harvest of pines in its native habitat, the longleaf pine (*Pinus palustris*) savanna. In the GoMAMN geography, the Southeastern American Kestrel occurs from east Texas (Seyffert 2006) to most of Florida (Florida Fish and Wildlife Conservation Commission 2003), but exact distribution, especially throughout its life cycle, is still unresolved. This cavity nester relies on woodpeckers to create natural cavities in trees and is a permanent resident in our region where it can be found in open pine habitats and adjacent grasslands (Smallwood and Bird 2002). American Kestrels also readily accept manmade nest boxes, and provisioning such artificial cavities in suitable habitat has been shown to be an effective conservation measure for the southeastern subspecies (Smallwood and Collopy 2009). The breeding season extends from March to July through most of the Southeast. Kestrels prey on a variety of small animals from invertebrates like grasshoppers to small vertebrates like lizards, mice, and birds, most of which are captured by sitting-and-waiting hunting. The species' hunting style and food preference necessitate open habitats for successful foraging (Smallwood and Bird 2002). Open pine habitats and other grassland types in the Southeast were historically maintained by natural fires; the exclusion of fire in these systems, coupled with incompatible natural resource usage, has greatly decreased available nesting and foraging habitats in our region, likely the main factor in the decline of the southeastern subspecies. Like the Swallow-tailed Kite, almost the entire breeding range of the southeastern subspecies of American Kestrel occurs within the GoMAMN boundary; monitoring of the species and reducing uncertainty of the interactions of various life history parameters and drivers are the responsibility of our region. Mcclure et al. (2017) provides commentary on elucidating the kestrel's decline.

Two of the six GoMAMN Raptors of Conservation Concern, Peregrine Falcon and Short-eared Owl, do not nest in the GoMAMN geography, instead utilizing the region during migration and nonbreeding (winter) months (White et al. 2002, Wiggins et al. 2006). A powerful and agile raptor, the Peregrine Falcon is a cosmopolitan species, occurring on all continents except Antarctica (White et al. 2002). Apparently, Peregrine Falcons never nested in the GoMAMN geography, and within the five GoM states, it currently only nests in the western Rio Grande Joint Venture region in Brewster Co., Texas (McKinney 2006). The Short-eared Owl breeds in open habitats on five continents (all except Antarctica and Australia) where it preys mostly on small mammals and the occasional bird. The species does not nest in the GoMAMN geography or within any of the states along the Gulf Coast (Wiggins et al. 2006).

Spring and autumn migration seasons

Raptor abundance and distribution in North America change with seasonal migration. These movements most often result from changes in the seasonal distribution and abundance of food resources. Peregrine Falcons, for example, fly south in autumn to hunt shorebirds and waterfowl, which are more abundant and concentrated during that season and during winter. Of 26 raptor species that breed within the GoMAMN geography, four species mostly or entirely leave the region during late summer and autumn, returning to breed the following spring: Swallow-tailed and Mississippi Kites and Broad-winged and Swainson's Hawks; small numbers of the latter two species remain in the region in south Texas; the Bird's Foot Delta, Louisiana; and peninsular Florida in winter. As primarily winter nesters, southern Bald Eagle exhibit an unusual migratory pattern, flying north in spring after nesting, and often covering substantial distances as evidenced by satellite telemetry studies (Mojica et al. 2008, Smith et al. 2017). However, a small proportion of the southern Bald Eagle population can be found in the GoM region at any time of the year (J. O. Coulson, unpublished data).

Birds of prey frequently use visual cues such as rivers and coastlines for navigation, refueling, and resting at stopover sites along the route (Goodrich and Smith 2008). The geography of most of the GoM region precludes a funneling effect of migrant raptors in spring, but circum-Gulf migrants are readily observed along the Gulf Coast as they travel through Texas and Florida. Unlike many migratory landbirds, which frequently migrate at night, raptors, excluding owls, are primarily diurnal, or daytime, migrants. Daytime flights are facilitated by deflection and thermal updrafts and allow diurnal raptors to more readily find prey species, which often feed or loaf during the day (Goodrich and Smith 2008). A species' habitat use during migration is similar to that of its breeding season, although as migrating individuals begin to encounter conspecific, resident birds, migrants may be forced into habitats of lesser quality or appropriateness. Of the six GoMAMN Raptors of Conservation Concern, only the Swallow-tailed Kite completely leaves its North American breeding grounds during nonbreeding. Conversely, the Southeastern

American Kestrel is "essentially resident" within its range in the southeastern U.S.A. (Smallwood and Bird 2002).

Several raptors, including the Swallow-tailed Kite, congregate before or during migration, which allows biologists to count a large proportion of the populations of some species. The formation of pre-migration, communal roosts in late summer by Swallow-tailed Kites has allowed researchers to collaborate on a region-wide, synchronous survey; this ability to survey an almost entire population at once provides an exceptionally rare opportunity for biologists (Meyer 1994). Ospreys congregate in the thousands in Cuba each spring before migrating north across the Gulf of Mexico (Goodrich and Smith 2008). Large numbers of migrating hawks can be readily observed in the GoM in both spring and autumn. In spring, the GoM geography and the direction of migration make for a weaker funneling effect of migrants, but autumn flights can be spectacular, particularly for species that migrate over land (i.e., circum-Gulf) to regions south of the GoM. Hawkwatch sites, where observers count migrating raptors, in the GoMAMN geography have tallied almost a quarter of a million individuals (Corpus Christi, TX), but the majority of sites along the GoM report thousands to tens of thousands of hawks each autumn. Hawkwatchers in Veracruz, Mexico, tally 4-6 million raptors of potentially 30 or more species, including some GoMAMN Raptors of Conservation Concern, each autumn (Goodrich and Smith 2008). Regardless of whether diurnal raptor surveys are site counts or "censuses," data should, at least, allow indices of abundance and trend (Bednarz et. al 1990, Bildstein 2001, McCarty and Bildstein 2005).

Due to their cryptic nature, migration of owls is very poorly understood. In fact, what is known about the migration of the Short-eared Owl, a GoMAMN Raptor of Conservation Concern, is currently restricted to recoveries of previously banded birds and anecdotes (Wiggins et al. 2006). Short-eared Owls are able to "migrate over vast expanses of oceans" (Wiggins et al. 2006) and have been recorded from offshore oil platforms in spring and autumn (Russell 2005).

Nonbreeding season

Although most breeding species of raptors occur year-round to some degree in the GoM, populations of several species show marked changes during the nonbreeding season (winter for most North American raptors). For example, the relative abundance of the easily observed Red-tailed Hawk increases >500% from breeding season to nonbreeding season in the five GoM states (eBird 2017). American Kestrel (subspecies pooled) relative abundance may increase >2500% over the same seasons in the same geography (eBird 2017). Two species of raptors are absent from the GoM entirely during nonbreeding—Swallow-tailed Kite, a Raptor of Conservation Concern, and Mississippi Kite. In the United States, small numbers of Broad-winged and Swainson's Hawks, both of which form spectacular migratory flocks, are restricted to south Texas, the Bird's Foot Delta region of Louisiana, and peninsular Florida during winter, most of their populations having migrated to Central and South America. With the exception of southern peninsular Florida, most of the GoM Ospreys are apparently migratory, with the relative abundance in the five Gulf states roughly doubling in winter (eBird 2017), augmented by northern breeders (Bierregaard et al. 2016). Two Raptors of Conservation Concern—Short-eared Owl and Peregrine Falcon—do not occur in the GoMAMN region in breeding season, instead utilizing the area during migration and nonbreeding; conservation actions, therefore, would need to be tailored to these species during nonbreeding in this geography.

Unlike the other GoMAMN Raptors of Conservation Concern that nest in spring and summer, the Bald Eagle nesting season occurs in fall and winter in the GoM region. Although the species may be found throughout the year in the five Gulf states, relative abundance generally decreases 50% outside of nesting season (eBird 2017). After winter nesting in the southern United States, most Bald Eagles migrate north in spring, traveling as far away as Canada (Mojica et al. 2008, Smith et al. 2017). Bald Eagles observed in the GoM during summer may be post-breeding, northern breeders or southern breeders that have remained behind. Immature eagles are more likely to restrict their movements to local areas rather than migrate (Buehler 2000). Within the GoM during nonbreeding season, Bald Eagles tend to occur in habitats similar to that of breeding birds (e.g., palustrine forested wetlands). Habitats or systems targeted for restoration for Bald Eagles, therefore, would benefit birds year-round.

Neither of the two remaining GoMAMN Raptors of Conservation Concern that occur in the GoM during both breeding and nonbreeding seasons—Osprey and Southeastern American Kestrel—exhibits a significant shift from those habitats used during breeding season, although they may widen the breadth of habitat utilization. Throughout the year, Ospreys are obligates of open water where ample surface-dwelling fishes exist (Bierregaard et al. 2016). The more generalist kestrel, however, readily diversifies. For example, resident kestrels nesting in open pine forest may continue to occupy that habitat in winter or may increase their use of more disturbed habitats such as agricultural fields. Wintering migrant kestrels likewise occupy similar habitats, but sexual segregation occurs such that females, which arrive earlier than males, tend to use more open, often higher quality, habitat than males (Smallwood 1987, Smallwood and Bird 2002).

Short-eared Owl (*Asio flammeus*). Photo credit: Krista Lundgren

Kestrel sexual segregation, particularly when associated with habitat quality, may have management implications.

The Short-eared Owl, a species that does not breed in the GoMAMN geography, winters in open areas, particularly grasslands including estuarine and palustrine emergent wetlands, coastal prairies and agricultural fields (Wiggins et al. 2006, Booms et al. 2014). On the western edge of the GoM region, the species is regularly observed in rice country, where they roost and feed upon small vertebrates in the crop or in the stubble after harvest. Although often difficult to detect due to their crepuscular habits (Clark 1975), fields heavily favored by Northern Harriers often coincide with the presence of Short-eared Owls, as the two species occupy similar dietary niches but forage at different times of the day. The distribution of Short-eared Owls across the GoMAMN region is discontinuous, with the species more commonly observed in coastal Texas, Louisiana, and peninsular Florida (eBird 2017).

Because Peregrine Falcons have such a varied diet, the species is able to make use of many different habitat types with varying levels of human disturbance, ranging from riverine forests to agricultural lands, and from remote beaches and barrier islands to urban environments (White et al. 2002). In winter, waterfowl and shorebirds are abundant in grasslands, particularly coastal prairie and working wetlands (e.g., rice fields and crawfish aquaculture) and on beaches, making these areas especially attractive as hunting grounds for Peregrine Falcons. In cities, these falcons make use of tall manmade structures like buildings and bridges as hunting perches. Despite the many dangers of urban life (e.g., collisions with windows or vehicles), the species can find copious food resources like Rock Pigeons (*Columba livia*), feral waterfowl, and bats (White et al. 2002).

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

Throughout much of U.S.A. history, raptors were maligned, often without merit, as killers of livestock, beloved pets, gamebirds and other wildlife. Such perceived assaults on these resources resulted in wanton slaughter of thousands of raptors, particularly at migration bottlenecks where large numbers of birds are constricted to a small geographic area (Bildstein et al. 2007, Harness 2007). This level of destruction was unsustainable and led to drastic losses in the populations of several species. Although perhaps not as vilified as they once were, raptors, nonetheless, experience direct and indirect negative, anthropogenic impacts. Mortality of raptors by shootings and poisonings, both intentional and unintentional, is still a concern, particularly among larger or more conspicuous species such as Bald Eagles, Ospreys, and Swallow-tailed Kites. Even American Kestrels may be targeted due to their preference for open habitats and use of prominent perches (Smallwood and Bird 2002).

In general, intentional take of these species has declined dramatically in the last several decades—likely the result of federal laws (Bald and Golden Eagle Protection Act, the Endangered Species Act, and the Migratory Bird Treaty Act) and their enforcement, as well as successful education of the public regarding the benefits of such birds. Persecution of raptors remains, however—frequently a result of poor observational skills and assumptions by the persecutor or careless and illegal use of pesticides. Poison-laced carcasses targeting coyotes and other predators and scavengers invariably kill nontarget species like eagles, vultures, hawks, and, even, owls (M. A. Seymour, personal communication). One of the most frequent concerns from members of the public is that of pet safety when any sort of predatory bird is observed on their property; with increasing popularity of backyard poultry and "toy" breeds of dogs, perceived or actual conflicts will, certainly, increase. In perhaps the most egregious example, a Swallow-tailed Kite, one of a mated pair, was shot in central Louisiana in the early 2000s, because the shooter believed the kite would kill doves in his yard; the doves were believed to be Eurasian Collared-doves (*Streptopelia decaocto*), an invasive, exotic species (M. A. Seymour, personal communication). Contemporary shooting of most raptor species, including the GoMAMN Raptors of Conservation Concern, likely does not cause population level impacts (Meyer 1995, Smallwood and Bird 2002, Wiggins et al. 2006, Bierregaard et al. 2016). Nevertheless, more critically imperiled or localized breeders like the Swallow-tailed Kite may be disproportionately affected, particularly if the individual killed is important to the social unit (J. O. Coulson, personal communication).

Shootings may be among the most readily identifiable sources of anthropogenic mortality of raptors, but, like most wildlife, alteration of habitat, which impacts the birds' access to food and clean water and roosting and nesting areas, is the primary threat to GoMAMN's Raptors of Conservation Concern. Although these species vary in habitat requirements, anthropogenic threats that potentially negatively impact raptor communities include (Figures 5.1 and Appendix 5):

1. climate change and sea-level rise,
2. altered hydrology,
3. contaminants,
4. agriculture,
5. land development,
6. disturbance,
7. biological resource use,
8. energy transmission,
9. transportation corridors,
10. wind energy, and
11. invasive species and biotoxins.

Climate change, coupled with sea-level rise, may have a significant impact to raptors and their habitats (Langham et al. 2015), especially in the GoM region where coastal habitats may receive greater impact. The influence diagrams for most of the Raptors of Conservation Concern include "climate change" and its associated impacts (Figures 5.1 and Appendix 5). In the southern U.S.A., modeled future climate scenarios suggest rising temperatures and decreasing available moisture, for no matter how much precipitation may increase or decrease in these scenarios, "rising temperatures and increasing evapotranspiration will more than offset any increase in precipitation" (Kunkel et al. 2013, Holcomb et al. 2015). Changes in temperature and available moisture will cause habitat migration as conditions become less favorable for

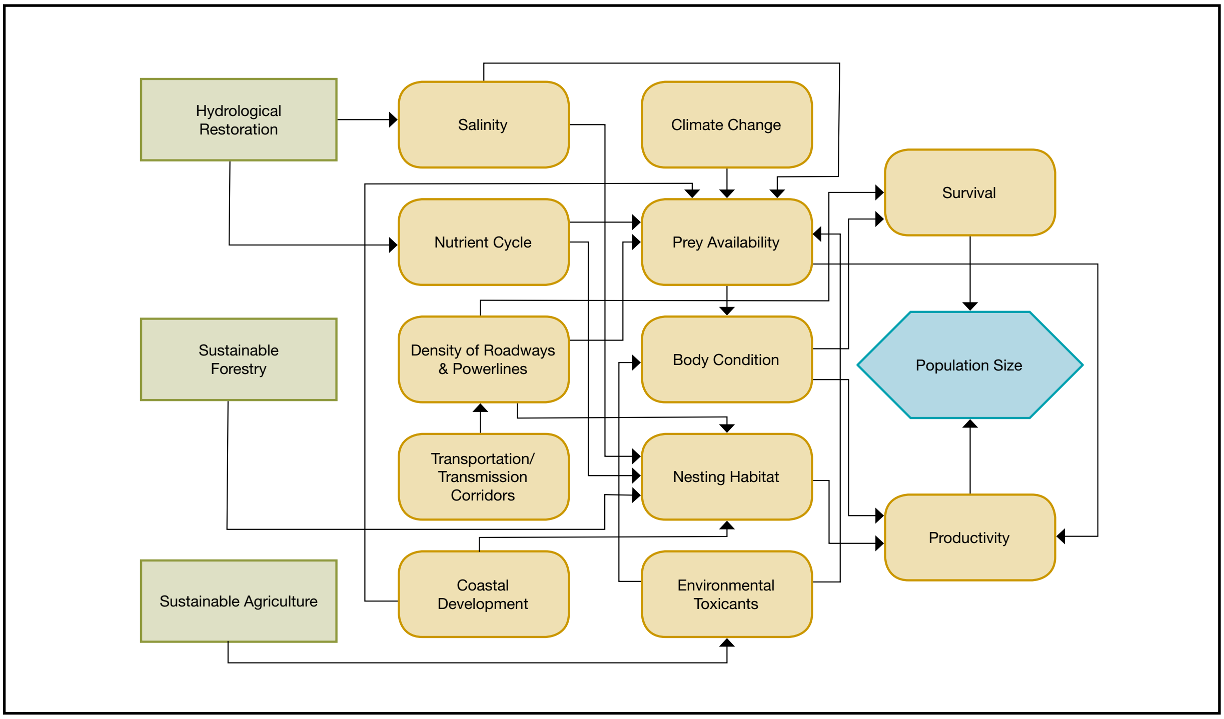

Figure 5.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Osprey*** *(Pandion haliaetus) within the Gulf of Mexico Region.*

some plants but more favorable for others. Coastal habitats will be doubly taxed as sea-level rise, accelerated by climate change, will exacerbate land loss, because habitat migration may not be able to keep pace with sea-level rise. In addition, particularly in coastal Louisiana, subsidence, or the sinking of the land, will further decrease available terrestrial habitat (Yuill et al. 2009); lack of natural sediment and fresh water influx from spring floods due to the leveeing of the Mississippi River further decreases likelihood of recovery. Increased frequency and intensity of tropical cyclones in the Gulf may lead to increased mortality of trans-Gulf migrants like Swallow-tailed Kites.

Sea-level rise and the decrease in available moisture, which results in less recharge of aquifers with fresh water, allow saltwater intrusion into coastal communities. Altered hydrology that prevents flushing of wetlands with fresh water also allows increased salinities and can alter food resources of piscivores. Plants intolerant of increased salinities and lacking nutrients transported by freshwater inflow may be killed, and loss of their anchoring roots intensifies land loss. In the southeast, hundreds of hectares of forested wetlands have been killed by increased salinities (Conner and Inabinette 2005, White and Kaplan 2017); Bald Eagles and Ospreys build nests atop the standing snags, but the decreased longevity of the dead trees likely results in more nest structure (and nest) failures than live trees. Prone to exploit manmade structures such as telecommunication towers and tall power line transmission towers, loss of natural nesting substrates may increase conflicts among Bald Eagles, Ospreys, and humans.

Raptors are susceptible to secondary poisoning through consumption of contaminated prey. The plight and subsequent highly successful recovery of Osprey, Bald Eagle, and Peregrine Falcon populations after years of exposure to DDT and its derivatives is well documented (Ratcliffe 1970, Grier 1982, Peakall 1987, Henny and Elliott 2007, Blus 2011). Briefly, by consuming prey items that had bioaccumulated and biomagnified DDE (the product of DDT decomposition), these predators produced unusually thin eggshells, which were easily crushed under the weight of incubating birds. Although DDT may no longer be a serious concern in the U.S.A., the pesticide was still available (and likely stockpiled) in many Latin American countries at least until the 2000s, making the potential of continued exposure possible for some migrant raptors (van den Berg 2009). Because birds of prey sit atop the food chain, introduction of new pesticides must be carefully scrutinized, and effects on the productivity and survivorship of these birds should be monitored (Buehler 2000).

Despite a ban on the use of lead shot for waterfowl hunting in 1991, use of lead ammunition is still common in other forms of hunting. Scavenging raptors like Bald Eagles may uptake lead fragments from gut piles or unrecovered carcasses of hunter-killed deer, hogs, and coyotes; lead sinkers used in fishing may also contribute to these poisonings (Buehler 2000). Lead poisoning causes severe neurological complications and depresses the functions of several organs resulting in reduced fitness and almost certain death (Henny and Elliott 2007). Population level impacts of lead and pesticide poisonings are not well resolved and clearly warrant surveillance (Henny and Elliott 2007).

Several anthropogenic threats result in direct loss of habitat or habitat quality; the decrease in availability of suitable habitat may be the most pervasive and persistent threat faced by the Raptors of Conservation Concern. Land development for residential communities is particularly prevalent in upland areas of the GoMAMN geography; loss of open pine woods such as longleaf pine savanna reduces available nest cavities for Southeastern American Kestrel (see Appendix 5). Encroaching civilization in these systems frequently precludes the use of prescribed fire to maintain the necessary early seral stage preferred by the kestrels. Similarly, inappropriate and incompatible forest management practices can create unsuitable habitat and possible population sinks throughout the Gulf states. For example, in parts of the Gulf Coast Joint Venture geography, when forests traditionally occupied by Swallow-tailed Kites are overly thinned, Great Horned Owls invade. These owls are important predators of the imperiled Swallow-tailed Kite, honing in on nests with young and also depredating adult kites (Coulson et al. 2008). Localized, but potentially substantial, losses may result; when adults or multiple nests are depredated, kites may abandon nesting neighborhoods altogether (J. O. Coulson, unpublished data). Swallow-tailed Kites and Bald Eagles tend to nest in emergent trees, those that penetrate the canopy of the forest, and, consequently, forestry practices that encourage growth of all-aged or uneven-aged forests are preferable for these nesters. Mature trees are also used by roosting flocks of migrating raptors like Swallow-tailed Kites; such roosts should be protected from human disturbance.

Fragmentation of habitat can cause otherwise high-quality habitat to become unsuitable, particularly during nesting periods. As forest patches are harvested or cleared, the landscape becomes more open and forest patches smaller, allowing two apex predators, Great Horned Owls and Red-tailed Hawks, to occupy previously unsuitable habitat (Bosakowski and Smith 1997, Smith et al. 1999). Fragmentation also increases edge effects increasing risks of exposure and predation. When fragmentation is caused by transmission and transportation corridors, direct mortality may be magnified. For larger birds of prey like Bald Eagles and, less commonly, Ospreys, electrocutions may result from interaction with power lines (Avian Power Line Interaction Committee 2006, Loss et al. 2014, Bierregaard et al. 2016). Collision with power lines is also a leading cause of anthropogenic mortality in birds, although the extent to which this impacts bird populations is not well established (Manville 2005, Avian Power Line Interaction Committee 2012, Loss et al. 2014). Species that hunt along roadways are prone to vehicle strikes, especially those that scavenge roadkill. Of the Raptors of Conservation Concern, Bald Eagle, a scavenger, is a common victim of vehicle strike (Buehler 2000). Traveling to and from foraging grounds, Ospreys, Short-eared Owls, and American Kestrels may be struck by vehicles while crossing roads or bridges (Smallwood and Bird 2002, Wiggins et al. 2006, Bierregaard et al. 2016). Although not known, the crepuscular nature and low level flights of Short-eared Owls could place them at a greater risk for vehicle strike. Establishment of wind energy turbines, necessarily constructed in large open spaces, fragments the landscape and creates physical obstructions to flight (Manville 2005, Loss et al. 2013, American Wind Wildlife Institute 2017). In the GoMAMN region wind turbines are already situated along beaches and in agricultural fields, coincidentally the same habitats used by shorebirds and waterfowl, prey species that may draw raptors into wind farms. Large birds like eagles may be disproportionately susceptible to collision with turbines, but carcasses of large birds are also more likely to be detected (Arnett et al. 2007, Smallwood 2007, Pagel et al. 2013).

Invasive, exotic species of organisms can lead to severe consequences to native species. Intuitively, invasive plants may alter habitat structure, which may impact animal communities. In the southern U.S.A., highly invasive, freshwater, aquatic weeds such as *Hydrilla verticillata* can quickly form dense mats of vegetation. This abundant substrate allows a cyanobacterium (*Aetokthonos hydrillicola*) to thrive (Wilde et al. 2014). Cyanotoxins produced by the cyanobacterium are inadvertently eaten by herbaceous waterbirds, especially American Coots (*Fulica americana*). Bioaccumulation of the toxin in the coots causes the birds to suffer neurological issues, which makes them easy prey for Bald Eagles, which then develop neurological symptoms as well and, ultimately, perish. Avian vacuolar myelinopathy (AVM), the disease caused by the neurotoxic cyanotoxin, was only just discovered in 1994 (Birrenkott et al. 2004). Increased temperatures associated with climate change may increase the geographic range of hydrilla (Maki and Galatowitsch 2008), possibly aiding the spread of *A. hydrillicola* and AVM.

Collectively, birds of prey are well-studied, largely due to their conspicuous and charismatic nature, but also because of their interactions with humans. The ancient sport of falconry has greatly advanced both the study of raptors and their conservation (Kenward 2009). Conversely, the persecution of raptors and their subsequent population declines produced one positive consequence: Osprey, Bald Eagle, and Peregrine Falcon are among the most studied birds in North America. In fact, monitoring of the latter two species was mandated due to federal requirements as formerly endangered species. Nonetheless, continued monitoring of raptor populations is essential, as some species act as sentinels for ecosystem health (Bildestein 2001). Monitoring of Short-eared Owls has been limited to breeding areas, and improvement of population monitoring has been identified as a "pressing conservation [priority]" for the species (Booms et al. 2014, Miller et al. 2016, Hawkwatch International 2017).

Monitoring is vital to conservation, as these data, when collected over many years, may be used to estimate status and trends in populations (McCarty and Bildstein 2005). Equally important, however, is the disentangling of the effects of ecological processes from those of management actions. Targeted, question-based monitoring will be required to decrease uncertainty in order to develop Best Management Practices (BMPs) to ensure continued population recovery or population stabilization. As climate change and habitat loss continue to threaten these species, the avian conservation community must remain nimble in its response.

IDENTIFICATION OF PRIORITIES

The avian conservation community must act immediately to address existing data gaps and uncertainties in the degree of impact of both anthropogenic and natural processes. Data gaps and uncertainty hinder our ability to make informed conservation decisions and can lead to delayed actions, a lag that permits further loss of diversity and unchecked habitat alteration and loss. Although the breadth of data gaps are not consistent across the GoM region, nor among the Raptors of Conservation Concern, GoMAMN identified three overarching objectives (discussed in Chapter 2; Figure 2.2):

1. Maximize our understanding of management actions (How do our actions intentionally and unintentionally affect raptors?)
2. Maximize our understanding of status and trends (How are raptor populations and their required habitats doing?), and
3. Maximize our understanding of ecological processes (How are large-scale ecosystem processes impacting raptors?).

These three objectives help define the priority foci necessary to better affect raptor conservation in the GoM.

As a generally well-studied taxon, raptors have been the topic of numerous study designs from monitoring of breeders to migrants. Less common is monitoring during the nonbreeding season (Andersen 2007); nonbreeding species-specific protocols will need refinement. The GoMAMN Raptor Working Group values projects that include investigation of impacts to juveniles, subadults, and adults and both sexes. Existing evidence suggests habitat usage, timing of migration, and geographic endpoints are linked to age- and/or sex-specific survival rates for several species (Smallwood 1987, Buehler 2000, Mueller et al. 2000, Martell et al. 2001). In addition to the sections below, avian biologists interested in raptor monitoring would be wise to review *Raptor Research and Management Techniques* (Raptor Research Foundation 2007), which includes comprehensive coverage of all aspects of raptor science.

Priority Management Actions

The bird conservation community through GoMAMN (see Figure 2.2) has demonstrated its values through the objectives hierarchy. Part of the objectives hierarchy refers specifically to management actions, showing that we value projects that (1) affect many priority species, (2) have a large spatial scope, (3) reduce uncertainty about the impact of management action(s) on raptors, (4) address management actions that are in common use as part of Gulf of Mexico restoration activities, and (5) use an adaptive management framework to answer questions about management actions.

Priorities for management actions can be found in Table 5.3. Actions that were scored as high priorities were ranked as such: (1) because the effect size of that action was unknown or, if known, suspected of impacting large portions of raptor populations and (2) because uncertainty in that effect size was higher than others. Although many priority management actions will likely benefit several species, others may be negatively impacted. For example, replanting a former agricultural field with hardwoods in the Mississippi Alluvial Valley may eventually provide nesting substrate for eagles, but planting trees will render the site unsuitable for wintering Short-eared Owls. In addition, documenting duration and seasonality of actions (e.g., harvesting timber in winter to avoid colonial waterbirds, but ignoring nesting Bald Eagles) may be critically important to addressing impacts.

The selection of management actions that benefit the GoMAMN Raptors of Conservation Concern necessitates evaluation of the impacts and applicability to all raptors within the GoMAMN geography. Management actions expected to impact raptors in the GoMAMN geography include hydrological restoration (to minimize saltwater intrusion and permit nutrient flow); promotion of sustainable forestry (e.g., retention of mature trees and snags); promotion of sustainable agriculture (to minimize pesticide loads and to maintain acreage of rice, crawfish, and other working agriculture); minimization of development and disturbance within key breeding and roosting areas; promotion of prescribed fire; restoration of marshes, beaches, and barrier islands; sustainable harvest management (to minimize lead in the environment); and removal of invasive species (to minimize negative trophic impacts and biotoxins). Figure 5.1 and Appendix 5 demonstrate the influence of these actions on raptor productivity and survivorship.

In general, management actions of greatest priority are those listed on the Raptors of Conservation Concern Influence Diagrams (Figure 5.1 and Appendix 5) as well as the actions listed in Table 5.3. Priority management actions include promotion of sustainable agriculture and forestry management. Sustainable agriculture was included on all of the diagrams. Historic efforts to minimize or eliminate nontarget impacts and other unintended effects of dangerous pesticides (e.g., DDT), coupled with the commonality of pesticide impacts on the diagrams, demonstrates the persistent uncertainty of their impacts, especially those of novel pesticides. Bald Eagles, Short-eared Owls, and Peregrine Falcons use rice fields for foraging and/or roosting (Short-eared Owl only). A reduction in the market value of rice could cause farmers to shift to crops of less wildlife value. Given the loss of natural grassland habitats, retention of rice acreage may be an essential management technique. In forested landscapes, promotion of raptor-friendly management to retain snags and tall canopy trees and to prevent an even-aged forest could be highly beneficial to all forest nesting species. The magnitude of impact on productivity and survivorship from reduced habitat suitability caused by unsustainable forestry warrants more study.

Other actions were found to be more specific to one or two species of Raptors of Conservation Concern; however, omission of these actions from other species' influence diagrams does not imply that the actions are not expected to affect those species—only that the action is not believed to be as impactful to those species as the other listed actions. For example, restoration of hydrology clearly impacts food resources and nest sites of Ospreys, Bald Eagles, and Swallow-tailed Kites, but other actions simply ranked higher for Swallow-tailed Kite such as maximizing sustainable forestry, which increases nest tree availability and potentially decreases nest predator abundance. Additional management actions specific to Bald Eagles include regulation of lead (i.e., to prevent lead ammo fragment uptake by scavenging birds) and removal of invasive species (i.e., to prevent a trophic cascade that poisons eagles). Uncertainty persists in the

Table 5.3. *Uncertainties underpinning the relationship between management decisions and populations of raptors in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Osprey and Bald Eagle Breeding, Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Freshwater Management)	Do altered/reduced fish populations due to reduced freshwater inflow significantly impact piscivorous raptor species?	Productivity; Adult/Juvenile Survivorship	Unknown magnitude and spatial extent	High	Low
Osprey and Bald Eagle Breeding, Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Forestry)	Do timber harvests reduce habitat quality and quantity and productivity of Ospreys and eagles?	Productivity; Adult/Juvenile Survivorship	Unknown magnitude and duration of impact	High	Low
Osprey, Swallow-tailed Kite, Bald Eagle, Short-eared Owl, American Kestrel, Peregrine Falcon Breeding, Non-breeding, Migration	Species Management (Contaminants)	To what magnitude do stockpiled DDT inventories or novel pesticides impact productivity and survivorship of apex raptors?	Productivity; Adult/Juvenile Survivorship	Unknown unknowns	High	Unknown
Swallow-tailed Kite Breeding, Migration	Site Area/ Management (Disturbance)	To what magnitude does human disturbance of communal roosts impact kite fitness? Does it impact juveniles differently from adults?	Adult/Juvenile Survivorship	Unknown magnitude and whether age classes affected equally	High	Low
Swallow-tailed Kite Breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Forestry)	Do timber harvests reduce habitat quality and quantity for nesting and roosting kites?	Productivity; Adult/Juvenile Survivorship	Unknown magnitude and duration	High	Low
Swallow-tailed Kite Breeding	Habitat and Natural Process Restoration (Habitat Management-Forestry)	Will the increase in Great-horned Owls and Red-tailed Hawks in traditional kite neighborhoods impact kites long term?	Productivity; Adult/Juvenile Survivorship	Unknown magnitude and duration	High	High
Bald Eagle Breeding, Non-breeding, Migration	Species Management (Contaminants)	How widespread and to what degree is continued use of lead ammunition for big game and lead sinkers for fishing affecting eagle survivorship and productivity?	Productivity; Adult/Juvenile Survivorship	Unknown magnitude and spatial extent	High	Unknown

Table 5.3 (continued).

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Bald Eagle Breeding, Non-breeding, Migration	Invasive/ Problematic Species Control (Habitat Management-Invasive Plants)	How widespread is the cyanobacterium that causes Avian Vacuolar Myelinopathy and is removal of invasive aquatic plants a viable option to disrupt the pathway to eagles?	Adult/Juvenile Survivorship	Unknown magnitude and spatial extent	High	Unknown
Short-eared Owl Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	To what extent will conversion of rice agriculture have on nonbreeding Short-eared Owls?	Population Density	Unknown unknowns, unknown magnitude and extent of impacts	High	Unknown
Short-eared Owl Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Restoration)	Does restored marsh provide similar amounts of prey and roost sites for Short-eared Owls to natural marsh?	Small Mammal Density; Population Density	Unknown magnitude of impacts	High	Unknown
Short-eared Owl Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Prescribed Fire)	What fire interval produces the highest quality of habitat for roosting and feeding Short-eared Owls?	Small Mammal Density; Population Density	Unknown magnitude of impacts	High	Unknown
(SE) American Kestrel Breeding, Non-breeding	Habitat and Natural Process Restoration (Habitat Management-Forestry)	Do timber harvests reduce habitat quality and quantity for nesting kestrels?	Small Mammal, Herp, and Invertebrate Density; Population Density; Productivity; Adult and Juvenile Survivorship	Unknown magnitude and duration	High	High
(SE) American Kestrel Breeding, Non-breeding	Site Area/ Management (Land Use)	To what extent will encroaching residential areas impact the ability to maintain kestrel habitat via fire?	Small Mammal, Herp, and Invertebrate Density; Population Density; Productivity; Adult and Juvenile Survivorship	Unknown extent	High	Low
Peregrine Falcon Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Management-Agriculture)	To what extent will conversion of rice and crawfish agriculture/ aquaculture have on nonbreeding Peregrine Falcons?	Population Density	Unknown unknowns, unknown magnitude and extent of impacts	High	Unknown

Table 5.3 (continued).

Species Season(s)	Management Category[a]	Question	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Peregrine Falcon Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Restoration)	Does coastal restoration maximize benefit to prey species of Peregrine Falcon and how does that translate to benefits to falcons?	Shorebird Density; Population Density	Unknown magnitude and duration	High	High
Peregrine Falcon Non-breeding, Migration	Habitat and Natural Process Restoration (Habitat Restoration)	Does restored marsh provide similar amounts of prey for Peregrine Falcons to natural marsh?	Waterfowl and Shorebird Density; Population Density	Unknown magnitude of impacts	High	High

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

extent to which populations are currently impacted especially within the geographic distribution of those threats.

Restoration and maintenance of beaches and barrier islands, as well as that of grasslands like marsh, coastal prairie, and pine savanna, would benefit Short-eared Owls, American Kestrels, and Peregrine Falcons. In particular, prescribed fire should be utilized where and when appropriate. Maintenance of anthropogenic habitats like rice fields and other moist soil units should also benefit these species, as these habitats act as foraging or roosting grounds. To what magnitude and extent in our inability to perform prescribed fire due to encroaching human settlements affect open pine species like American Kestrels warrants attention. Restoration of coastal habitats like beaches and barrier islands must include an evaluation on the restoration's impact to the local food web (e.g., deposit of dredge material on to a beach may impact forage for shorebirds, which impacts prey resources to falcons).

The GoMAMN's primary goal is to reduce uncertainty in how management actions and ecological processes drive the population dynamics of birds in order to better inform conservation. Monitoring programs should attempt to minimize the uncertainty of priority management actions listed above (see also Table 5.3). Because of the somewhat eclectic nature of the Raptors of Conservation Concern, multiple projects would need to be devised to successfully study these management actions. Ideally, monitoring programs that investigate the effects of management actions should do so under a framework of adaptive management; that is, the results of monitoring should allow practitioners to determine if a management action is providing a desired outcome (Franklin et al. 2007). If the action does not, then it should be corrected.

In order to maximize our understanding of management actions and how they impact bird populations, monitoring programs must be rigorously designed to capture relevant data. Avian response variables, those dependent upon the actions of management or ecological processes (see Priority Ecological Processes below), must be clearly defined and appropriate to the question. For management questions (e.g., Can we increase survivorship of Bald Eagles if we minimize *Hydrilla*, an invasive aquatic plant that provides substrate upon which a deadly biotoxin-producing cyanobacterium grows?), population size, survivorship, reproduction, and movement could be valid response variables.

Key to any monitoring program is the ability to quantify the population responses of the study organism using sound methods. For example, abundance, or the total number of individuals in a given area at one point in time, can be a metric to gauge success of a management action. Density of a population can also be used, and, intrinsically, this value is created when an abundance measure is made. For example, fixed transects to survey for active eagle nests would enumerate the number of nests and provide the area surveyed. Although most land managers will want to measure changes in abundance, density, etc., and link those changes to local conditions created through habitat management, carryover effects (e.g., productivity at breeding grounds) may not be evident on-site. Because Short-eared Owls and Peregrine Falcons nest outside the GoM, monitoring of productivity, obviously, would have to occur outside our region. Nonbreeding surveys of Short-eared Owls would likely be occupancy only (a boolean measure of presence) that, while useful, especially for cryptic species, is of less value than abundance and density. In addition, Efford and Dawson (2012) note that occupancy may be "confounded with home-range size or detection distance."

As undeniably important as a measure of population size is, the data can be of limited value when collected alone. Although population size may provide trend information, it does not explain that trend. It is, therefore, advisable to measure other response variables in combination with abundance and density. One such variable, survivorship, must take into account the age and sex of the bird, as age- and sex-biased mortality has been documented in birds, including raptors (Ferrer and Hiraldo 1992, Dwyer and Mannan 2007). Differential mortality can be due to a variety of factors such as sexual segregation within habitats, differences in parental roles and behaviors, and the reverse sexual dimorphism exhibited in most species of raptors. Existing and emerging technologies such as increasingly smaller radio transmitters may assist in measuring survival as long as those methods themselves do not significantly impact survivorship.

Reproductive success, like survivorship, helps explain trends and, historically (e.g., during the pesticide era of the mid-1900s), population level effects were found to occur during nesting. The age of first breeding can be delayed in many raptors, particularly the larger species; thus, the magnitude of impact of a management action (or an ecological process) may vary with age (Millsap et al. 2004). In many species of raptors, fecundity is relatively low, compensated for by a longer lifespan. Delayed breeding and longer lifespan, therefore, may necessitate the monitoring of multiple ages of cohorts. Several parameters are important to measure during bird reproduction including clutch size, brood size, nest success, and fledging success.

Some raptor nests can be relatively easily surveyed, especially if they occur in emergent trees and if aircraft are available or if the species are nest box users. Species that create prominent nests—large in size and in emergent or isolated trees—can be effectively monitored via aerial surveys (Carrier and Melquist 1976, Ewins and Miller 1994, Andersen 2007). The kestrel's inclination to use nest boxes assists in monitoring of productivity and can assist in capture for instrumenting (Katzner et al. 2005, Bloom et al. 2007). Others, like grassland nesters, may be more challenging (Larson and Holt 2016). Brown et al. (2013) discuss the advantages and limitations of using apparent nest success to gauge reproductive success in raptors. Monitoring parameters of reproductive success are necessarily time consuming and often costly. However, to properly understand impacts to raptors, one must accept the challenges. Steenhof and Newton (2007) provide standardization of various parameters used in determining nest success and productivity and discuss survey methodologies.

Movement can also provide valuable information on management success. For example, if birds instrumented with tracking devices unexpectedly move out of an area that has been managed, land managers could focus on where the birds went and why and, possibly, could then replicate those conditions at the managed site. Please see the Priority Status and Trends Assessments section below for a more in-depth treatment on "movement."

Clearly, the importance of measuring the proper avian response variables cannot be overstated, but to provide an answer for why they have responded, one must also consider non-avian covariates. Measuring the impacts of these covariates is absolutely essential to disentangling the effects of management actions and ecological processes on populations, particularly if there are confounding variables. Local conditions should be included in monitoring projects, especially basic habitat measures, weather, etc. For example, salinity, density of aquatic vegetation, water turbidity and temperature, prey fish distribution, etc., may impact piscivorous raptors. Prey abundance may impact behaviors, as well, and might be beneficial to monitor in conjunction with bird abundance, survivorship, etc. The number of hunters using lead ammunition, in part, describes the poisoning risk that eagles and other scavengers may face. Distance to human settlement(s) may dictate timing of prescribed fires, which may impact food and habitat resources. Depth of dredge materials placed during beach nourishment may prevent feeding by shorebirds, affecting the food resource of Peregrine Falcons. Selection and measurement of non-avian covariates can be complicated and time-consuming, but models may be improved (i.e., better explain results) with inclusion of proper covariates.

Additional and up-to-date information on current management practices and activities can be found through the Deepwater Horizon Project Tracker Database (http://www.dwhprojecttracker.org/).

Priority Status and Trends Assessments

The GoMAMN's objectives hierarchy (Figure 2.2) demonstrates what the avian community believes is most critical for maximizing the usefulness of monitoring data collected to address questions on status and trends. The community places the most value on projects that 1) evaluate species that are experiencing the greatest declines, 2) evaluate species for which trends are highly uncertain, 3) cover the greatest geographic extent, and 4) include mechanisms to ensure the monitoring is long-term. The GoMAMN recognizes that annual monitoring may be excessive for many species; continuity of data may include intervals of no surveys, but gaps in surveys ideally should be based on life history of the species and be consistent (e.g., surveys occur year 1, 3, 5, etc.).

The population status and trend estimates for each species of Raptor of Conservation Concern may be found in (Table 5.2). The Partners in Flight (2017) Avian Conservation Assessment Database (PIF ACAD) was used to populate Continental Population Trend (PT-c in PIF ACAD) and maximum Continental Concern (CCSmax in PIF ACAD) scores (see Panjabi et al. 2017 for context) for each species. Raptors for which PT-c is more or less stable or highly uncertain or highly variable received a score of 3. Species with a score < 3 are of less concern, whereas those with a score > 3 are of greater concern. CCSmax scores are the maximum value calculated between breeding and nonbreeding season: the higher the number, the greater concern.

The GoMAMN Raptor Working Group established the following status and trends priorities for the Raptors of Conservation Concern in the Gulf of Mexico. Whereas, all raptor species in Table 5.2 are priorities, these species were further ranked by a composite score calculated by the species' PT-c and CCSmax scores from the Partners in Flight Avian Conservation Assessment Database (2017).

- **Priority 1** – Short-eared Owl
- **Priority 2** – Southeastern American Kestrel and Swallow-tailed Kite
- **Priority 3** – Peregrine Falcon, Bald Eagle, and Osprey

The bird community's history of determining bird trends has relied heavily on the venerable USGS Breeding Bird Survey (BBS), which is a defensible and repeatable methodology of monitoring many bird species (Sauer and Droege 1990). However, due to timing of the BBS season (e.g., mostly outside southern Bald Eagle nesting season), the time of day (i.e., mostly diurnal species detected), species' detectability, species' rarity coupled with a clustered distribution (e.g., Swallow-tailed Kite) and others, this survey may not best represent actual trends of some species (Sauer and Droege 1990). Targeted monitoring, therefore, may be a necessity for several birds like Osprey, Bald Eagle, Short-eared Owl, and many others. Seasonality may impact survey design, and counts on breeding grounds may be preferable to those on nonbreeding grounds. Short-eared Owls, for example, are likely most detectable during breeding season display flights; the species' nomadism and more crepuscular behavior in winter make detection during that season difficult (Miller et al. 2016). Bird behavior during migratory periods such as kettling (i.e., flocking of soaring, migratory birds) may facilitate abundance estimates. At the most basic level, counts of migrating raptors at geographic bottlenecks is one way to measure abundance, and such data may inform population indices (Bednarz et al. 1990, Farmer and Smith 2010).

Population trends of several raptor species have been estimated. According to the BBS (Sauer et al. 2017), in the U.S.A. between 2005 and 2015, the Osprey population experienced an annual increase of approximately 4.9%. According to the BBS (Sauer et al. 2017) Swallow-tailed Kites increased 5.5% annually in that same time frame, but this species may be less suited to BBS analyses due to its rarity and patchy distribution. Bald Eagle populations increased approximately 12.4% annually (Sauer et al. 2017). Trends for Short-eared Owls and American Kestrels appear to show declines, but the data are inconclusive in the U.S.A. (Sauer et al. 2017). In Canada, Short-eared Owls declined approximately 16.5% annually between 2005 and 2015 (Sauer et al. 2017). These percentages are provided with the caveat that no species' population trend above was estimated without some level of uncertainties in the sample (e.g., credibility measure, sample size indicator, etc.). PIF (2017) suggests that Short-eared Owl and American Kestrel may be experiencing significant declines (Table 5.2). Despite the trend information for many raptors, it is important to note that the longevity of the applicability of data to inform status and trends is finite. In other words, despite most GoMAMN Raptors of Conservation Concern actually showing possible population increases according to BBS data (Sauer et al. 2017), without frequent monitoring to obtain up-to-date counts, trends may quickly lose relevance.

Although trends are extremely important in determining the trajectory of a population and conceptually simple, status is multifaceted—taking into account a mixture of habitat availability, total population size (i.e., relevant to persistence), scope and persistence of threats, fecundity, and other variables. Status of species necessitates evaluation of environmental conditions such as changes in habitat quantity or quality. Resolution or scale of habitat measurements will vary based on study design, but the GoMAMN suggests that programs collect habitat data over the long-term. Habitat associations of the Raptors of Conservation Concern are included in Tables 5.1 and 5.2. The GoMAMN uses the Coastal Change Analysis Program (C-CAP) habitat classes in this document. C-CAP information is available at NOAA's Office for Coastal Management Digital Coast's website (http://coast.noaa.gov/digitalcoast).

One positive result of the historic and precipitous population declines of the Bald Eagle and the Peregrine Falcon was that periodic surveys were required to monitor recovery (USFWS 2003, 2009, 2016; Green et al. 2006). Most monitoring occurs during the breeding season to capture productivity, which is important when assigning status. Surveys for nesting eagles occur periodically in the Gulf states with only Florida having a specific action plan for the species (Florida Fish and Wildlife Conservation Commission 2017). In addition, Audubon Florida (2016) also promotes project EagleWatch, a citizen science project that monitors eagles. Louisiana collected Bald Eagle nest data, including productivity, most recently in the 2017/2018 nesting season (M. A. Seymour, unpublished data). USFWS performed region-wide surveys during the 2017/2018 nesting season similar to those performed by USFWS in 2009.

Counts of migrating raptors can be useful for population indices and, in very rare circumstances, may allow almost complete censusing of a population. Hawk-watchers across the U.S.A. gather at migration bottlenecks to count migrating raptors and report those counts to the Hawk Migration Association of North America, which maintains a list of sites (www.hawkcount.org). The most productive sites (e.g., Veracruz, Mexico) are outside the GoMAMN geography.

Communal, pre-migration roosting of Swallow-tailed Kites allows avian biologists to conduct extensive surveys that capture nearly the entire U.S.A. population of the species. Carefully timed, synchronous, aerial surveys from Texas to Florida minimizes double-counting and maximizes comparability state-to-state. Region-wide surveys were most recently conducted in 2013 (Coulson and Seymour 2014). No targeted, region-wide monitoring effort in the Gulf exists for Ospreys, Short-eared Owls, American Kestrels, or Peregrine Falcons, although the non-breeders—Short-eared Owls and Peregrine Falcons—may be best monitored for status and trends on breeding grounds further north (outside the GoMAMN geography).

Determination of migratory routes, stopover sites, duration of stays, etc., of several Raptors of Conservation Concern have rapidly advanced by use of emerging technologies (Martell et. al 2001, Walls and Kenward 2007, Mojica et al. 2008, Watts et al. 2011, Martell et al. 2014, Stupik et al. 2015, Smith et al. 2017). Because migration is one of the most dangerous periods in the avian life cycle, the avian conservation community desires to understand movement of raptors at multiple scales. Such movement may be monitored several different ways such as banding and auxiliary marking (e.g., alphanumeric leg bands, patagial wing markers, feather dyeing, imping, etc.), each with their own strengths and weaknesses (Varland et al. 2007). Many tracking technologies are currently available for monitoring movement of raptors, with larger species like eagles, ospreys, kites, and larger falcons having solar powered, satellite transmitters and GPS trackers available in addition to traditional VHF tags. Smaller species such as the American Kestrel may be best tracked by light-sensitive geolocators, coded VHF tags, or by stable isotopes (Walls and Kenward 2007, Hobson et al. 2009). Bird Studies Canada's Motus Wildlife Tracking System, an international collaboration, has been well-received throughout North America and beyond, making passive (and inexpensive) VHF tracking of migratory birds a reality. Motus-compatible receiver stations are located throughout the GoM region with many more planned in the near future. The Louisiana Statewide Passive Detection for Organismal Research (SPDOR) VHF network expects to maintain 30 or more such stations in coastal Louisiana by autumn of 2020 (M. A. Seymour, personal communication). Tracking birds to identify stopover sites used by long-distance migratory species may be critical and should be priority.

Due to the spatial and temporal dependency on the validity of status and trends, the maintenance of a monitoring program for priority species is imperative. In fact, development of sound, baseline status and trend values may be the single most important responsibility of bird scientists in the GoM. Without these values, the other key pieces of monitoring—understanding management and ecology of species—cannot be fully realized. For example, success of the restoration of Swallow-tailed Kite neighborhoods (this species is a semi-colonial nester) cannot be determined without knowledge of nesting density and success, productivity, and survivorship benchmarks upon which the restoration can be compared. Similarly, if the baseline (i.e., background) levels of environmental pollutants and their derivatives in the blood of Bald Eagles or Ospreys are not established, the conservation community must wait until another indicator signals such impacts—potentially population level impacts like widespread reproductive failure.

For additional details on how the collection of relevant metrics of bird life history or habitat and other non-avian covariates affects our ability to conserve birds, see Priority Management Actions (above) and Priority Ecological Processes (below), as well as the *Raptor Research and Management Techniques* (Raptor Research Foundation 2007).

Priority Ecological Processes

The GoMAMN Raptor Working Group developed the Ecological Processes table (Table 5.4) through literature review and consultation with species experts across the U.S.A. To prioritize these processes, we used the ecological process objective hierarchy values which emphasize 1) relevance to our Raptors of Conservation Concern, 2) reduction of uncertainty in how ecological processes influence population dynamics, and 3) the maximization of our ability to predict those dynamics (Figure 2.2). Like management actions, ecological processes are best studied over a long term, if possible. Influence diagrams were used to illustrate the connectivity between ecological processes and population dynamics (Figures 5.1-5.6).

Like the other GoMAMN taxa working groups, the Raptor Working Group ranked a set of questions about how ecological processes impact our species of Conservation Concern. We considered two scoring criteria—effect size (where Unknown > High > Low) of the ecological process of interest and the uncertainty (High > Low) of that effect size. Once scored, prioritization was as follows, with a score of one being the highest priority: 1 = Unknown, High, 2 = Unknown, Low, 3 = High, High, 4 = High, Low, 5 = Low, High, and 6 = Low, Low (Effect size, uncertainty). Questions for the same species with the same rank have the same composite score of effect size and uncertainty and were not further ranked.

Many ecological processes act synergistically and often impact the magnitude of one another (e.g., climate change and sea-level rise). As a GoMAMN rule, ecological processes with direct links to management action(s) are treated in Priority Management Actions. For example, although saltwater intrusion into coastal marsh is an ecological process, the magnitude of impact may be mitigated by anthropogenic actions like freshwater diversions. That being said, concessions had to be made regarding whether or not anthropogenic climate change and its associated impacts were best ascribed to Management Action or Ecological Process; GoMAMN has chosen the latter. Similarly, our monitoring questions could affect categorization. For example, our question regarding the likelihood of spread of an AVM causing cyanobacterium is more appropriately linked to ecological process (Table 5.4); whereas, the question regarding disruption of the AVM pathway via invasive plant removal is clearly management related (Table 5.3). In addition, toxicants and harmful heavy metals released into the natural environment may affect several trophic levels, resulting in trophic cascades. Cascading effects may impact the function of entire systems (treatment of these threats may be found above). Ecological processes like animal movements and interactions may also be affected by the creation of travel and transmission corridors, wind farms, and subsidized native and introduced species; those anthropogenic impacts are discussed in Primary Threats and Conservation Challenges.

The reality of climate change and its potential impacts to GoM wildlife, fisheries, and habitats cannot be ignored. Depending on the modeled scenario and the location in the region, habitats (and their associated denizens) may be greatly degraded or eliminated altogether (Watson et al. 2015). Whether habitats will be able to migrate quickly enough is uncertain, but in some portions of the region, effects of subsidence and sea-level rise are already destroying vast acreages of marsh and other coastal habitats. Beaches and barrier islands are eroding and disappearing. Saltwater intrusion continues to make habitat inhospitable for some raptors, likely reducing available natural nest sites for Ospreys and eagles or killing active nest trees and making them unstable. Climate change may disproportionately impact trans-Gulf migrating Swallow-tailed Kites, because the birds may experience greater mortality due to an increase in storm frequency and intensity. Climate change will also affect sea temperature, which could cause decreased fitness, survival, and productivity in Peregrine Falcons on their breeding grounds, because the seabirds on which they feed will be negatively impacted by the potential loss of forage fish caused by rising temperatures (North American Bird Conservation Initiative, U.S. Committee 2010; Young et al. 2012).

The actions of ecological processes are equal in neither time nor space, requiring project managers to evaluate their effects at appropriate spatial and temporal scales. Because these processes may impact species through different mechanisms and may vary in intensity throughout seasons and life cycles, biologists should be mindful when designing projects. For example, will rising temperatures from climate change increase the depth of Ospreys' preferred fish species and will that behavior exert a greater impact during nesting season leading to decreased productivity (Table 5.4)?

SUMMARY AND MONITORING RECOMMENDATIONS

The decisions to implement conservation actions, especially those that have the potential to impact large portions of bird populations, do not and should not occur in a vacuum. Our ability to positively impact those populations relies upon the conservation community's understanding of how and why birds react to environmental conditions. Our capacity to make informed decisions requires "separating signal from noise" (P. Frederick, personal communication)—in our case, determining what patterns in the data actually drive population dynamics versus red herrings. To accomplish this, we must disentangle the effects of management from those ecological processes.

The GoMAMN Raptor Working Group recognizes the need to address several data gaps, that when filled, will greatly enhance our understanding of raptor populations in the GoM region. Data gaps include 1) demographic parameters such as productivity, nest success, survivorship of adults and juveniles and males and females, movement, and others;

Table 5.4. *Uncertainties related to how ecological processes impact populations of raptors in the northern Gulf of Mexico.*

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Osprey Breeding, Non-breeding, Migration	Climatic Processes	Will increased water temperatures impact food availability?	Productivity; Adult/Juvenile Survivorship; Nest Success	Unknown magnitude of effects on fitness, reproduction	High	High
Swallow-tailed Kite Migration	Natural Distburance Regimes	To what magnitude do tropical cyclones and other extreme weather impact age classes of kites?	Adult/Juvenile Survivorship	Unknown magnitude and impacts to age classes	High	Unknown
Swallow-tailed Kite Breeding	Climatic Processes	How will climate change impact the distance, distribution, quality, and quantity of kite foraging and nesting grounds?	Productivity; Adult/Juvenile Survivorship; Population Density	Unknown to what extent climate change will occur or to what extent its impacts will be	High	High
Bald Eagle Breeding	Climatic Processes	To what extent will sea-level rise impact quantity and quality of eagle nesting and foraging grounds?	Productivity; Adult/Juvenile Survivorship; Population Density	Unknown magniture and extent	High	High
Bald Eagle Breeding	Hydrological Processes	Do saltwater intusion-killed trees impact productivity and survivorship of eagles?	Productivity; Adult/Juvenile Survivorship	Unknown impact to nesting birds	High	Low
Bald Eagle Breeding, Non-breeding, Migration	Interactions Between Organisms	What is the liklihood of spread of Avian Vacuolar Myelinopathy into novel parts of the range?	Invasive aquatic plant density; Adult/Juvenile Survivorship	Unknown magnitude of impact to populations and liklihood of spread	High	Unknown
Peregrine Falcon Non-breeding, Migration	Climatic Processes	How will climate change impact the abundance and distribution of falcon food resources?	Shorebird and Waterfowl Densities; Adult/Juvenile Survivorship	Unknown to what extent climate change will occur or to what extent its impacts will be	High	High

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

2) baselines and benchmarks for birds (e.g., abundance and distribution) and their environment (e.g., environmental pollutants, invasive species abundance, available natural and manmade habitat, etc.); 3) effectiveness of management treatments and habitat delivery and how to best utilize an adaptive framework for their success; and 4) magnitudes of impact and duration of ecological processes on bird populations and how to plan for uncertainties in our changing climate (e.g., increased temperature, aridity, and sea level).

The GoMAMN Raptor Working Group identified the following as priority actions requiring immediate attention:

★ Development of a monitoring program to evaluate background levels of pollutants and biotoxins in the environment with linkages to raptor population dynamics. Apex raptors like Ospreys, Bald Eagles, and Peregrine Falcons are particularly susceptible to bioaccumulated and biomagnified contaminants.

★ Creation of a question-based monitoring program to determine impacts of timber harvest on breeding and migrating raptors. Results of this monitoring should include development of Best Management Practices to guide conservation practitioners. Within the GoMAMN region, natural nest and roost sites may be limiting factors for Ospreys, Bald Eagles, Swallow-tailed Kites, and American Kestrels.

★ Evaluation of the impacts of saltwater intrusion and reduced freshwater inflow (and nutrients) on the habitats and birds of coastal marshes and forested wetlands. Saltwater intrusion and decreased freshwater inflow alter vegetation composition and structure and may change fish and aquatic insect prey communities. These changes may threaten nest tree persistence and the nesting success and productivity of the birds that rely on them. In addition, survivorship and productivity of piscivorous raptors like Ospreys and Bald Eagles may be impacted by changes in fish assemblages.

★ Development of region-wide monitoring programs that target effective surveillance of population abundance and distribution of GoMAMN's Raptors of Conservation Concern in order to better understand their status and trends. Generally, Ospreys, Swallow-tailed Kites, Bald Eagles, Short-eared Owls, American Kestrels, and Peregrine Falcons are not well monitored by existing programs such as the USGS Breeding Bird Survey. Instead, survey methodologies must be implemented that address both the spatial and temporal aspects of the species' unique life cycles. In particular, we need to a) determine distribution and abundance of the Southeastern American Kestrel throughout its life cycle, including the ratio of abundance of this subspecies to others where ranges overlap and b) develop a viable method of long term monitoring for nonbreeding Short-eared Owls.

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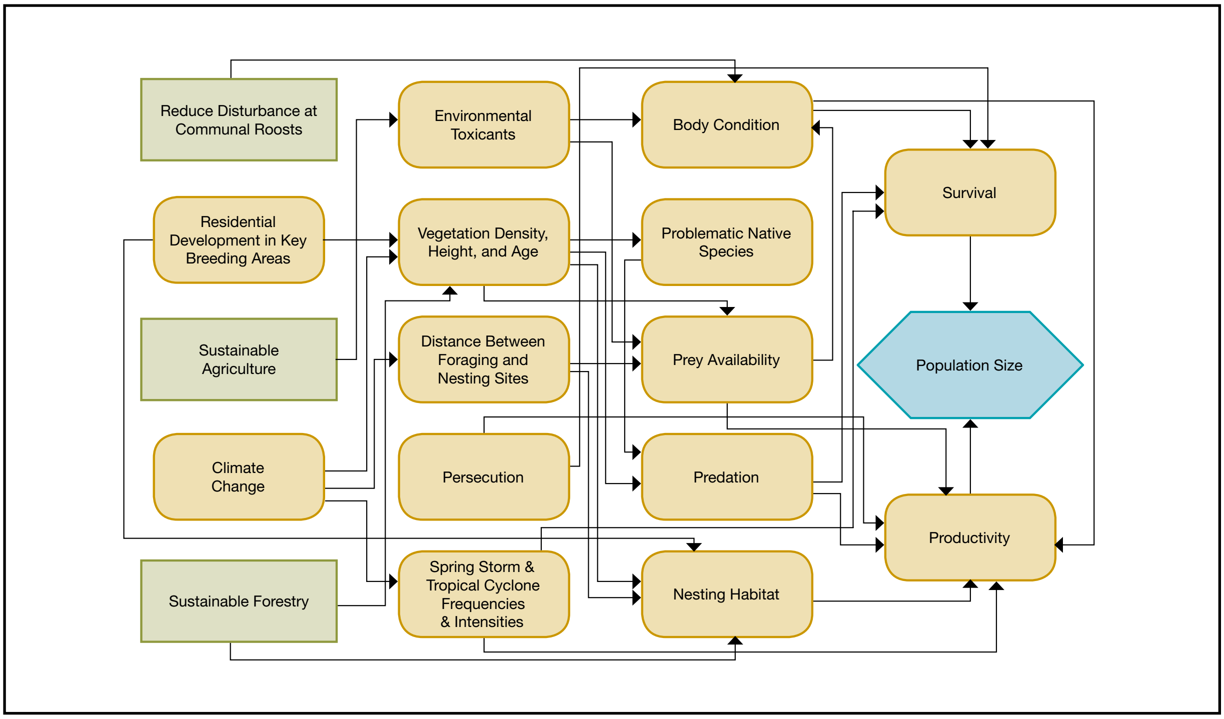
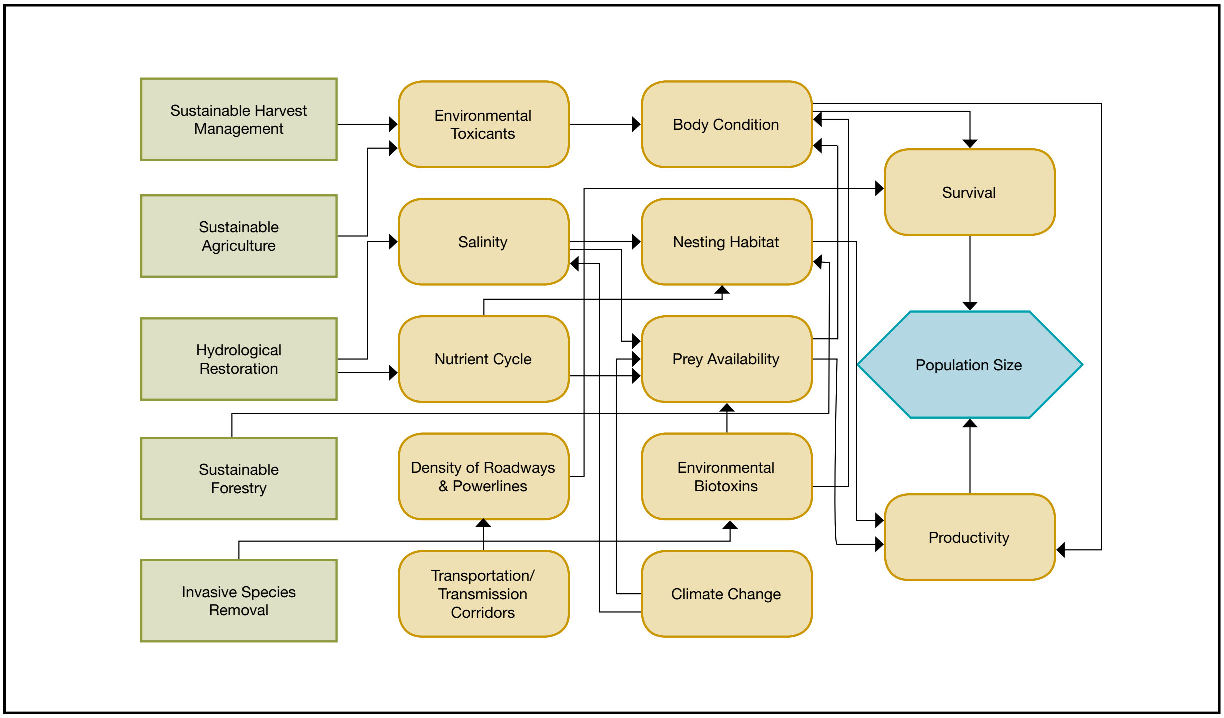
APPENDIX 5

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

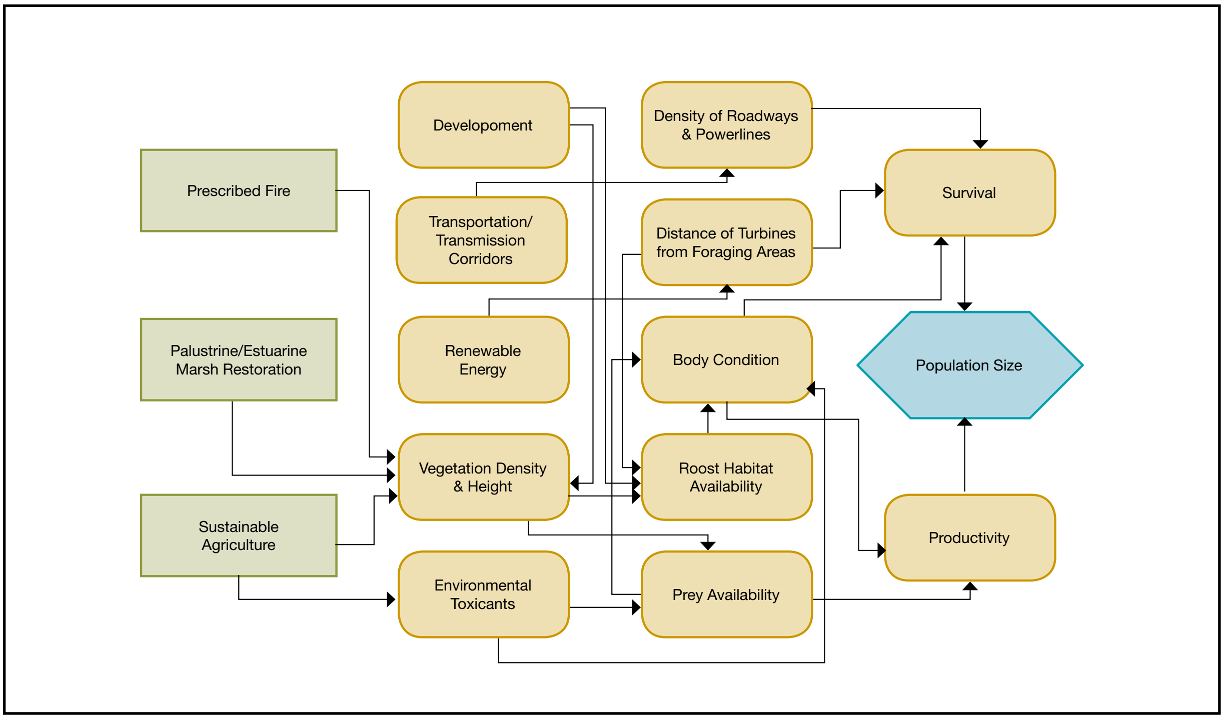


Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Swallow-tailed Kite*** *(Elanoides forficatus) within the Gulf of Mexico Region.*

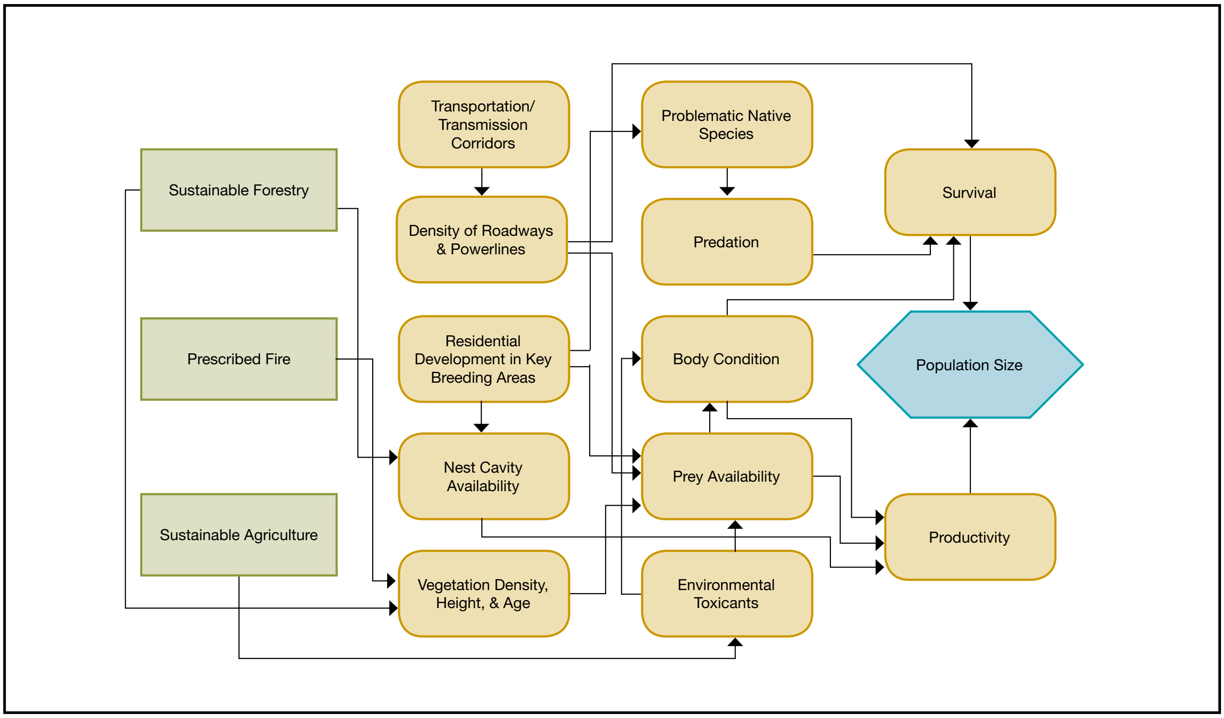
Raptors



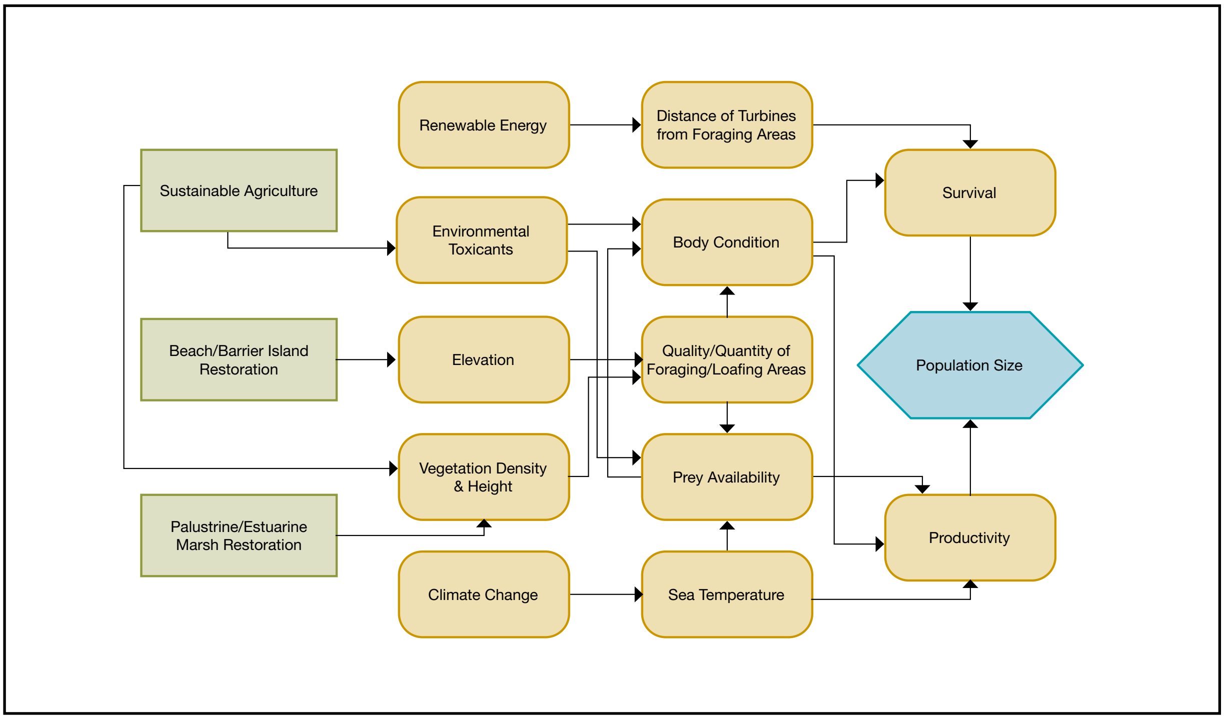
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Bald Eagle*** *(Haliaeetus leucocephalus) within the Gulf of Mexico Region.*



Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Short-eared Owl*** *(Asio flammeus) 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 **American Kestrel** (Falco sparverius) 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 **Peregrine Falcon** (Falco peregrinus) within the Gulf of Mexico Region.*

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6

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SEABIRDS

Authors:

Patrick G. R. Jodice (1*)
Evan M. Adams (2)
Juliet Lamb (3,4)
Yvan Satgé (3)
Jeffrey S. Gleason (5)

1. U.S. Geological Survey South Carolina Cooperative Fish & Wildlife Research Unit, and Department of Forestry and Environmental Conservation, Clemson University, Clemson, South Carolina
2. Biodiversity Research Institute, Portland, ME
3. Department of Forestry and Environmental Conservation, and South Carolina Cooperative Fish & Wildlife Research Unit, Clemson University, Clemson, South Carolina
4. Current Address: Department of Natural Resource Science, University of Rhode Island, Kingston, Rhode Island
5. U.S. Fish and Wildlife Service, Gulf Restoration Office, Chiefland, Florida

(*) Corresponding Author: **pjodice@g.clemson.edu**

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 (*Thalasseus 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

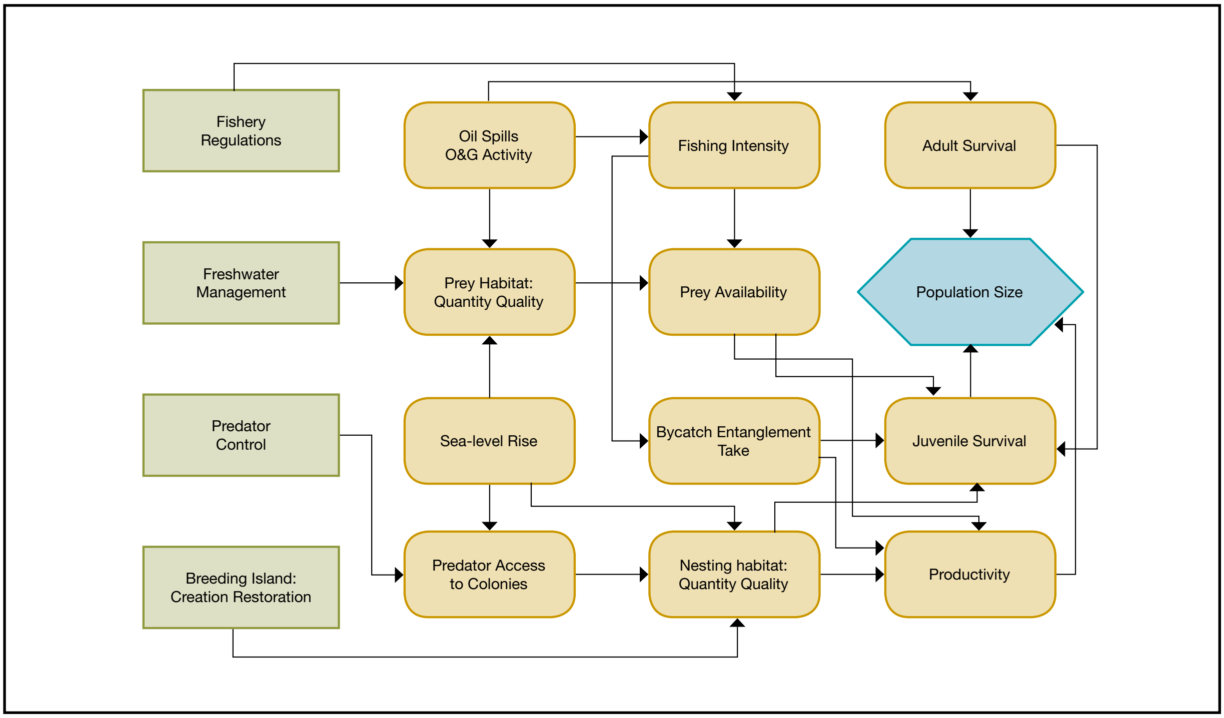

Figure 6.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Brown Pelican*** *(Pelecanus occidentalis) within the Gulf of Mexico Region.*

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

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

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.

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 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 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 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 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 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 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 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 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 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 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 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 Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
All Seabirds 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 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 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 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 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 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 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 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 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 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 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 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 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 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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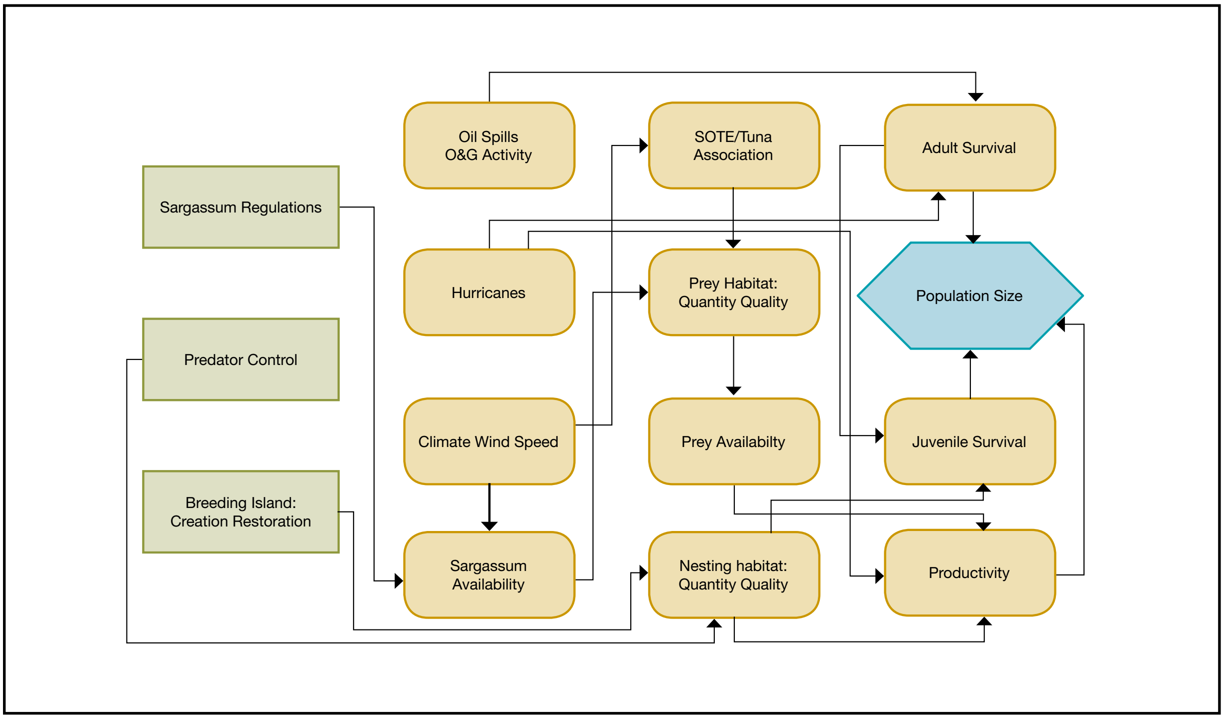
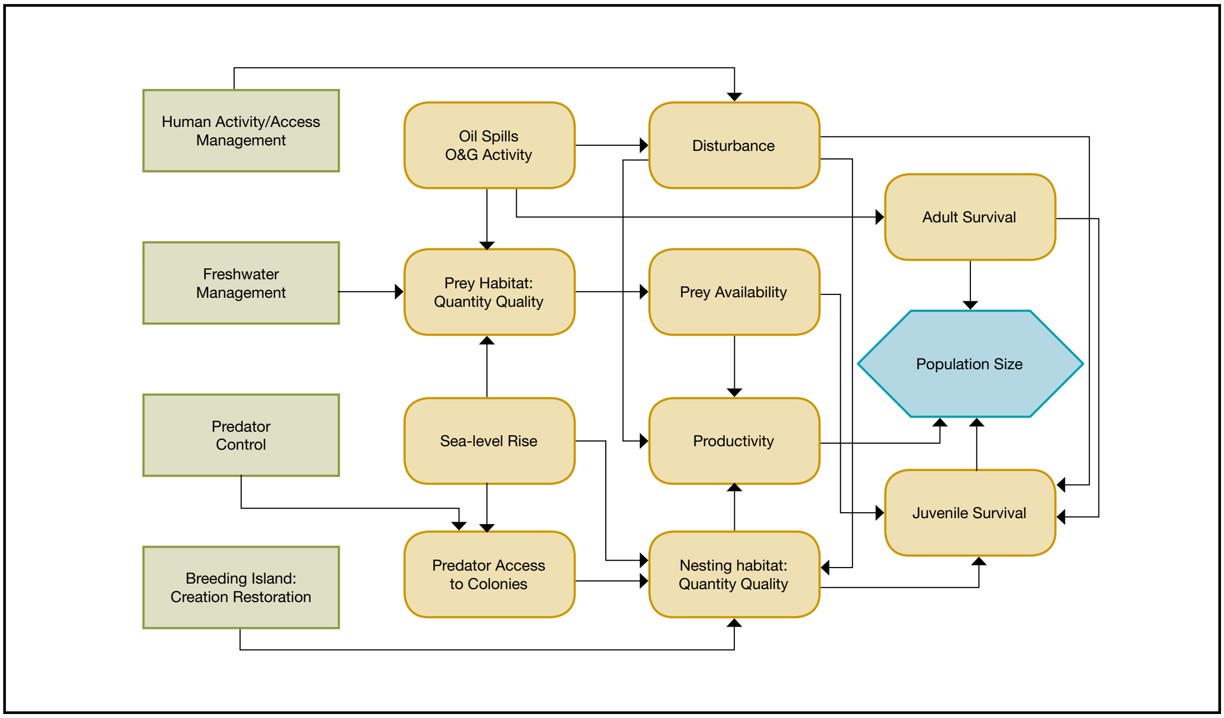
APPENDIX 6

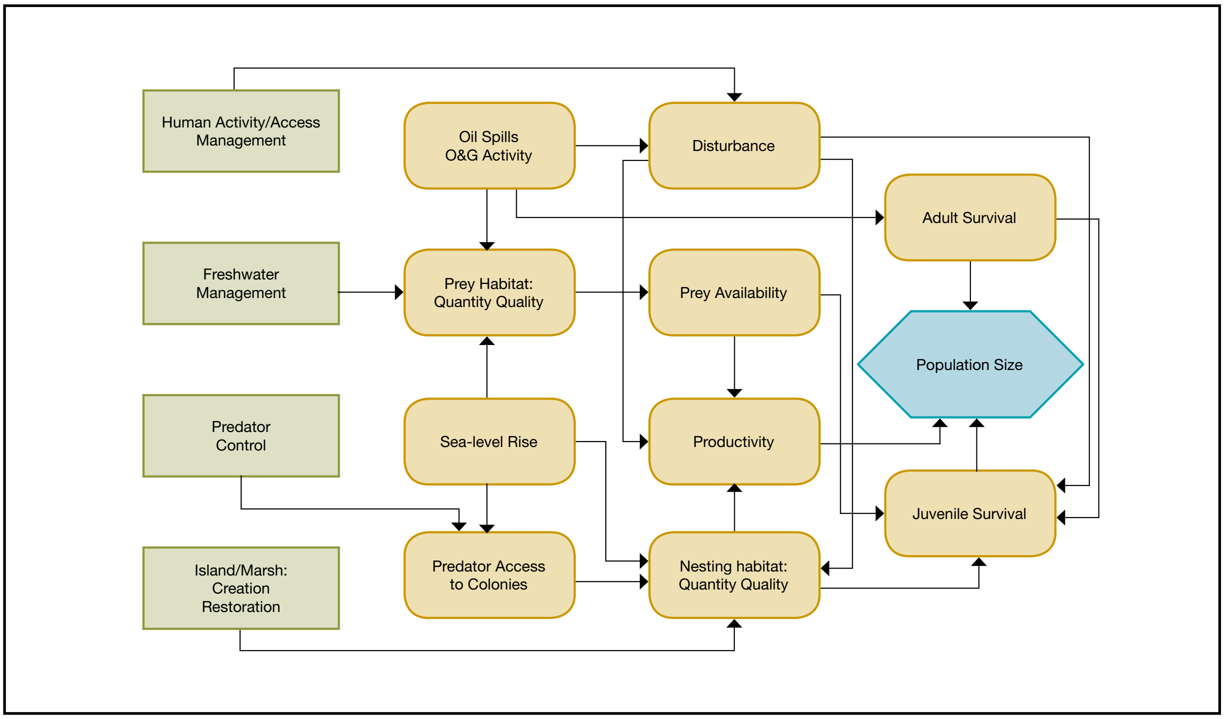
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of seabirds.



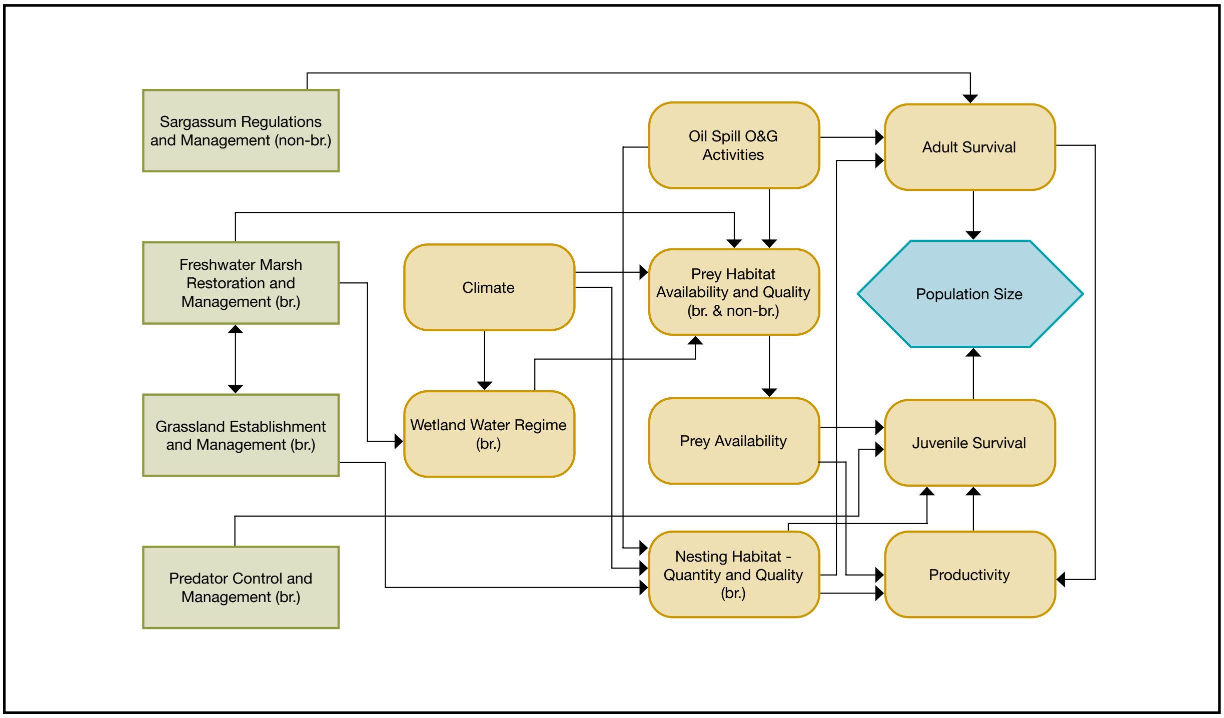
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Sooty Tern*** *(Onychoprion fuscatus) within the Gulf of Mexico Region.*



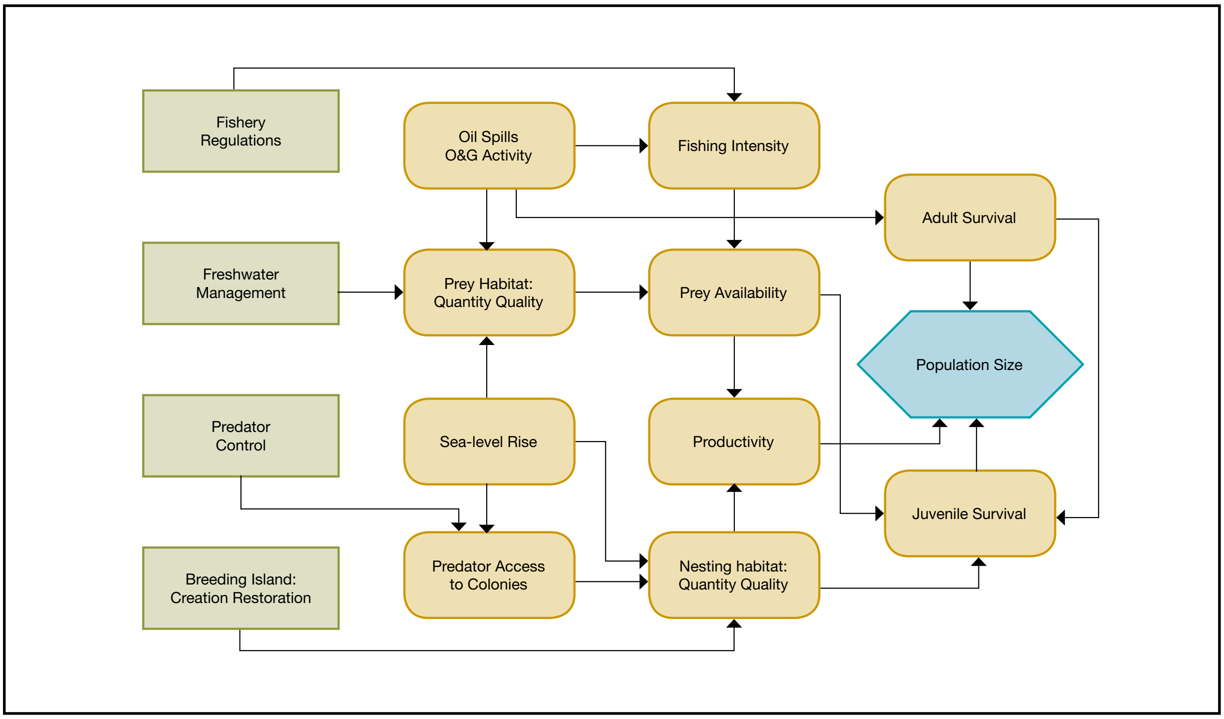
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Least Tern** (Sternula antillarum) within the Gulf of Mexico Region.*



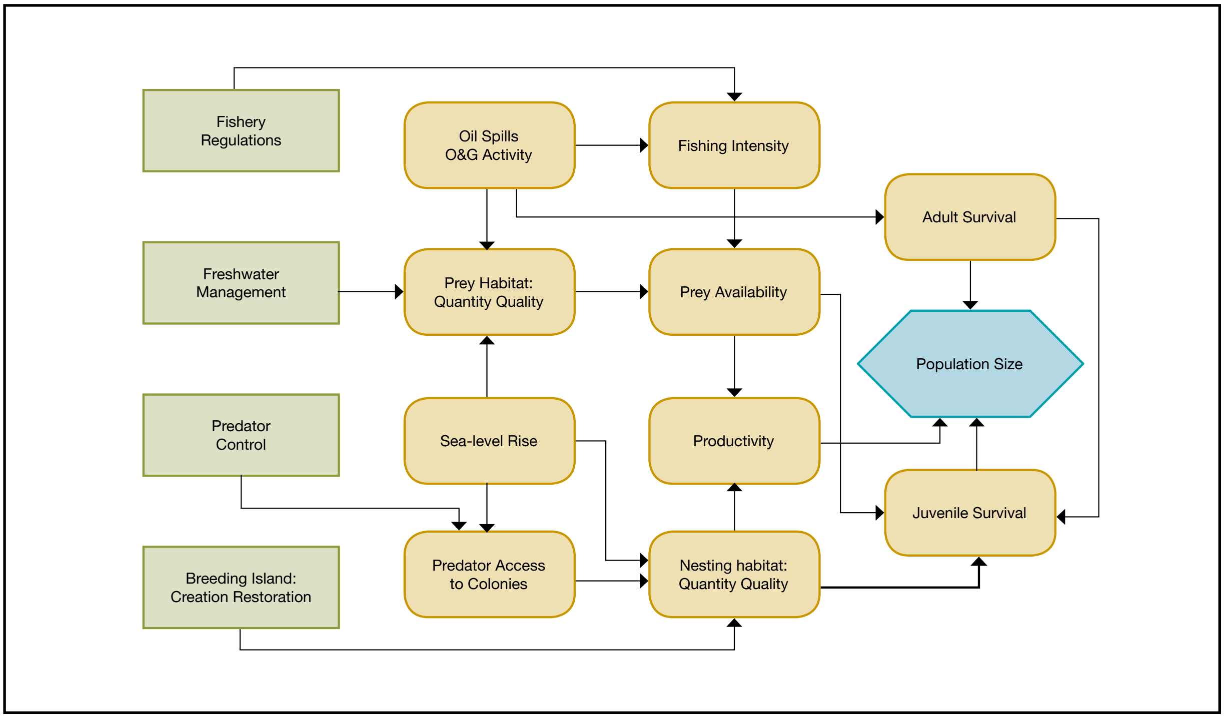
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Gull-billed Tern** (Gelochelidon nilotica) within the Gulf of Mexico Region.*



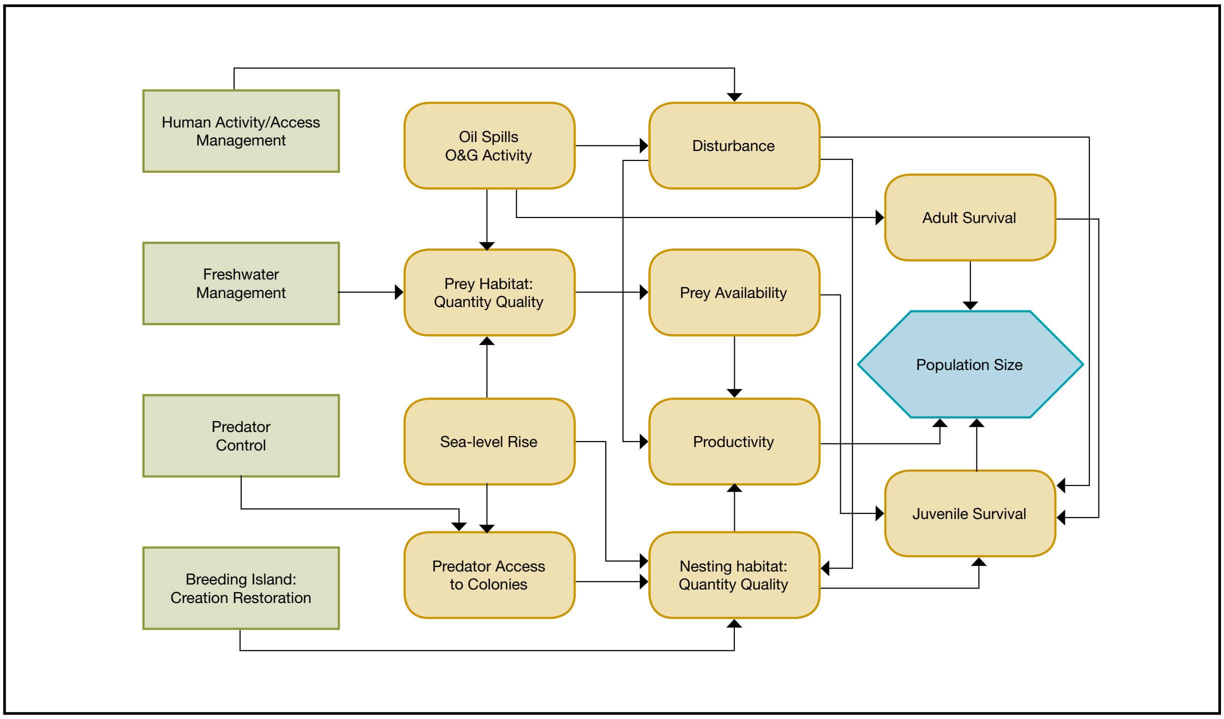
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Black Tern*** *(Chlidonias niger) within the Gulf of Mexico Region.*



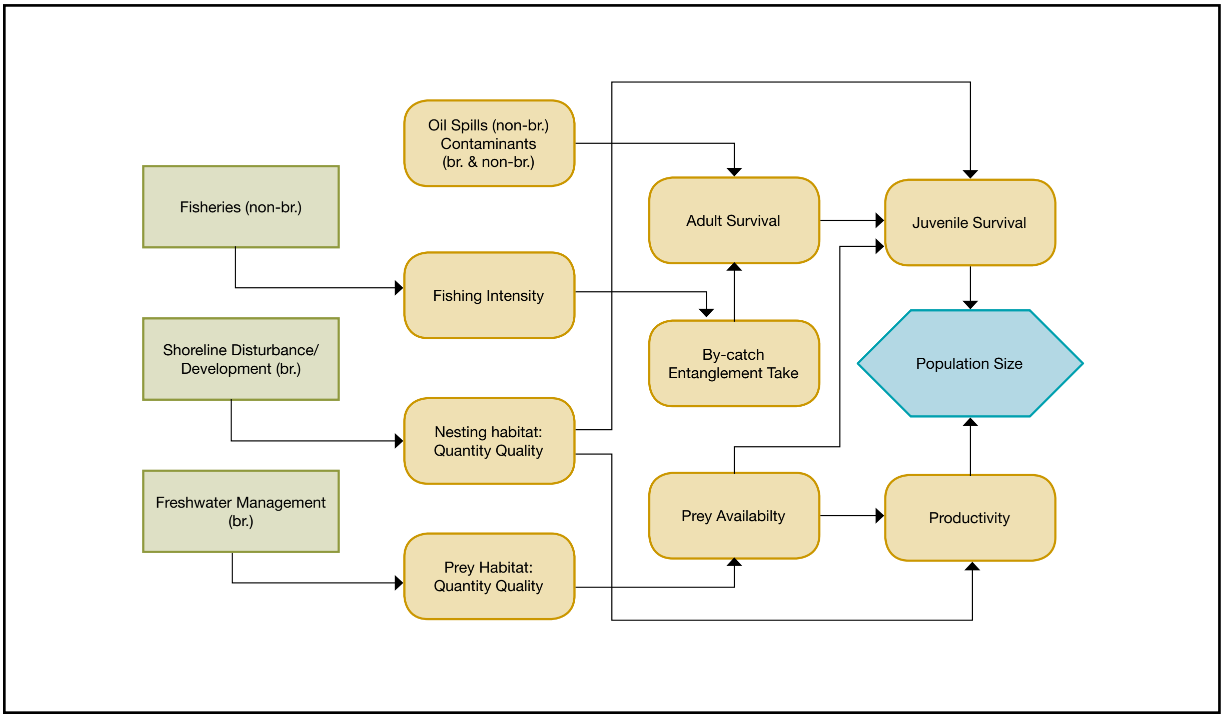
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Royal Tern*** *(Thalasseus maximus) within the Gulf of Mexico Region.*



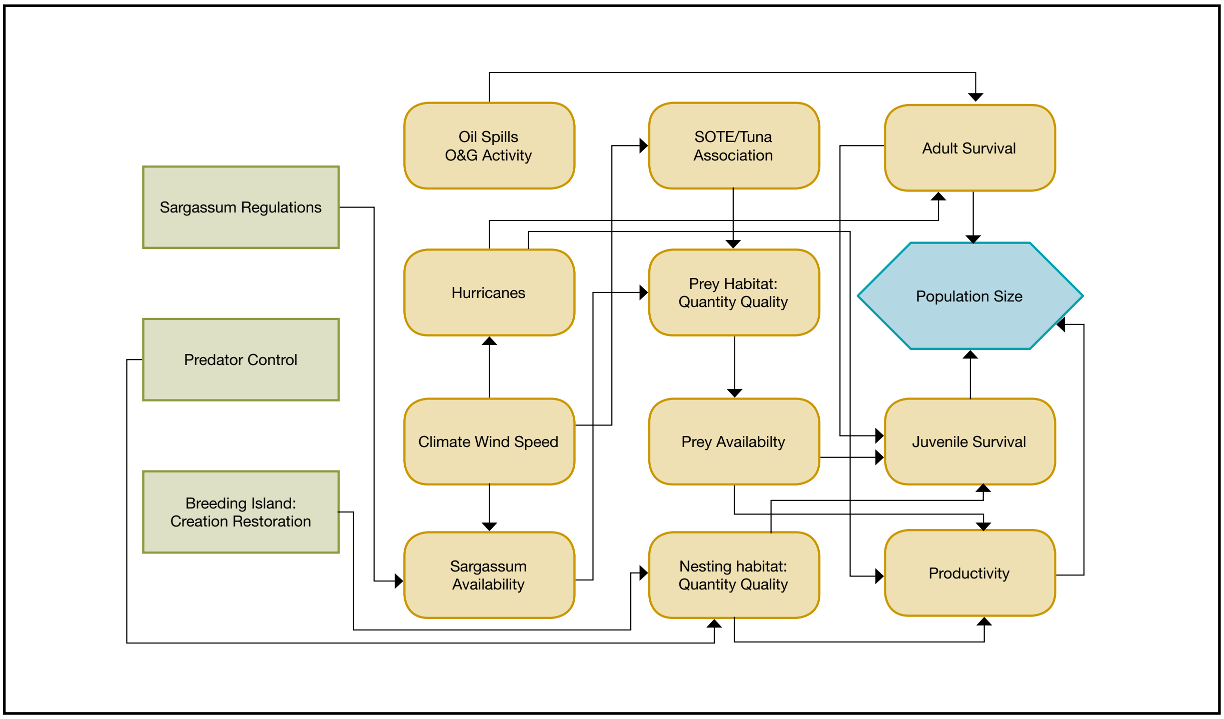
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Sandwich Tern*** *(Thalasseus sandvicensis) within the Gulf of Mexico Region.*



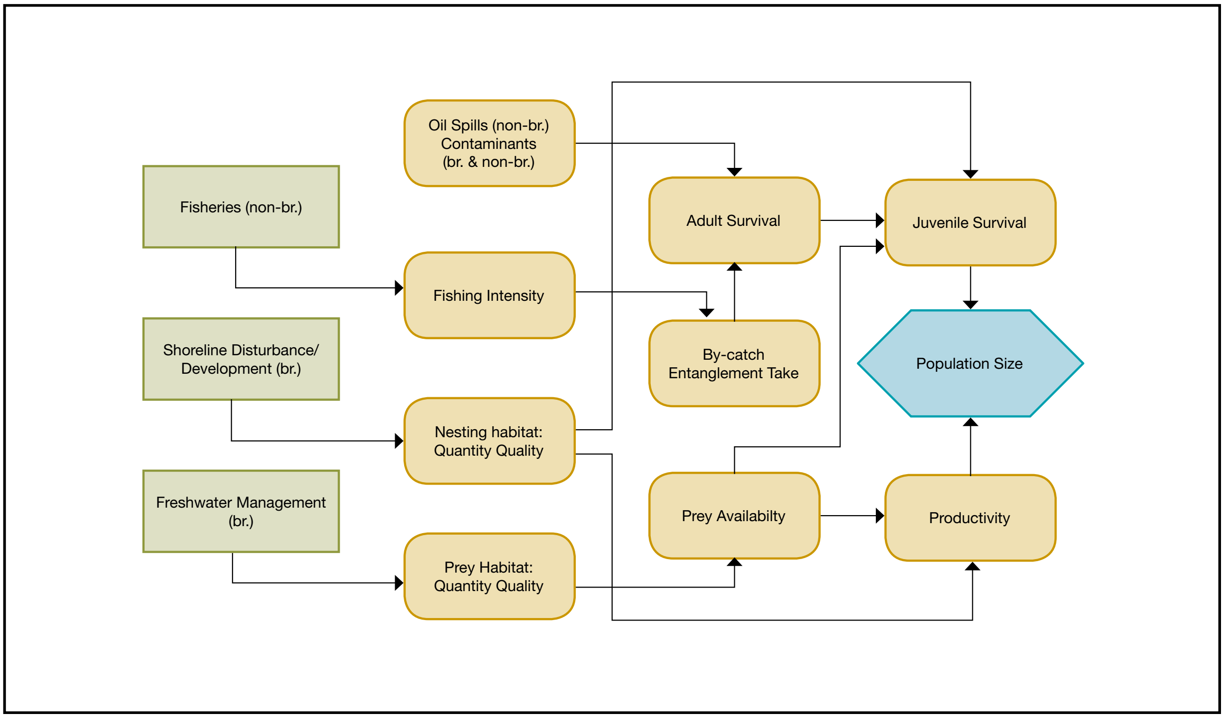
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Black Skimmer*** *(Rynchops niger) within the Gulf of Mexico Region.*



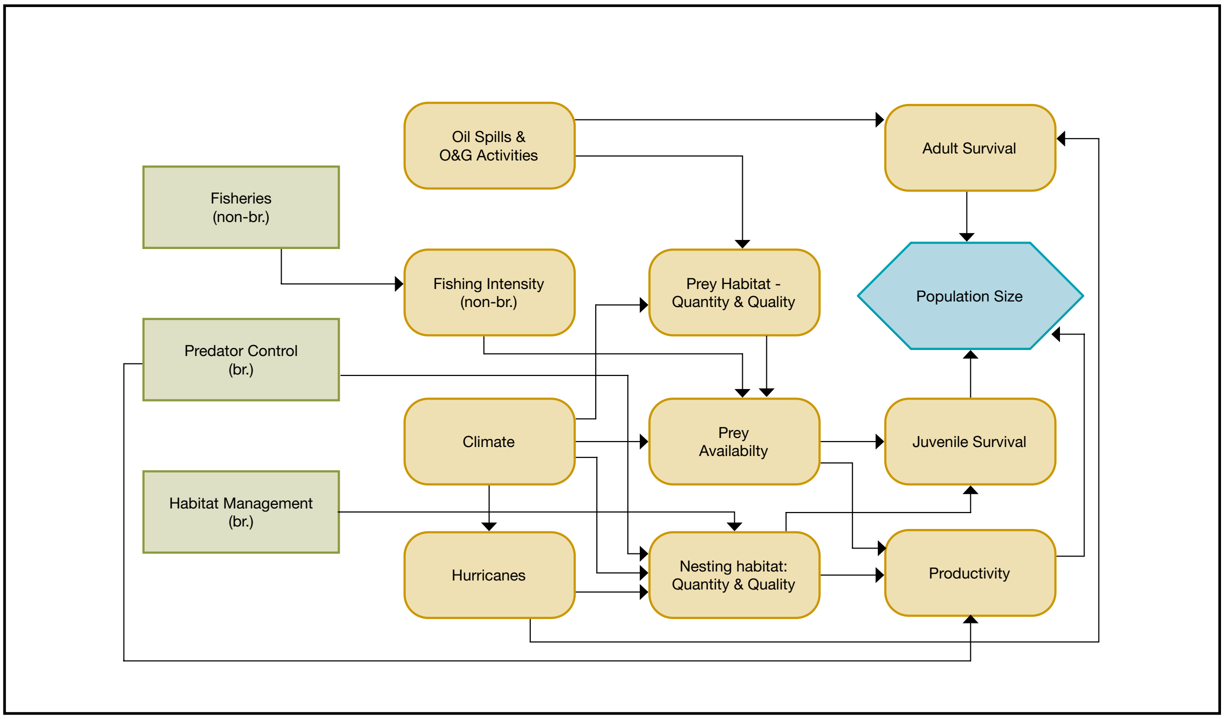
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Common Loon** (Gavia immer) within the Gulf of Mexico Region.*



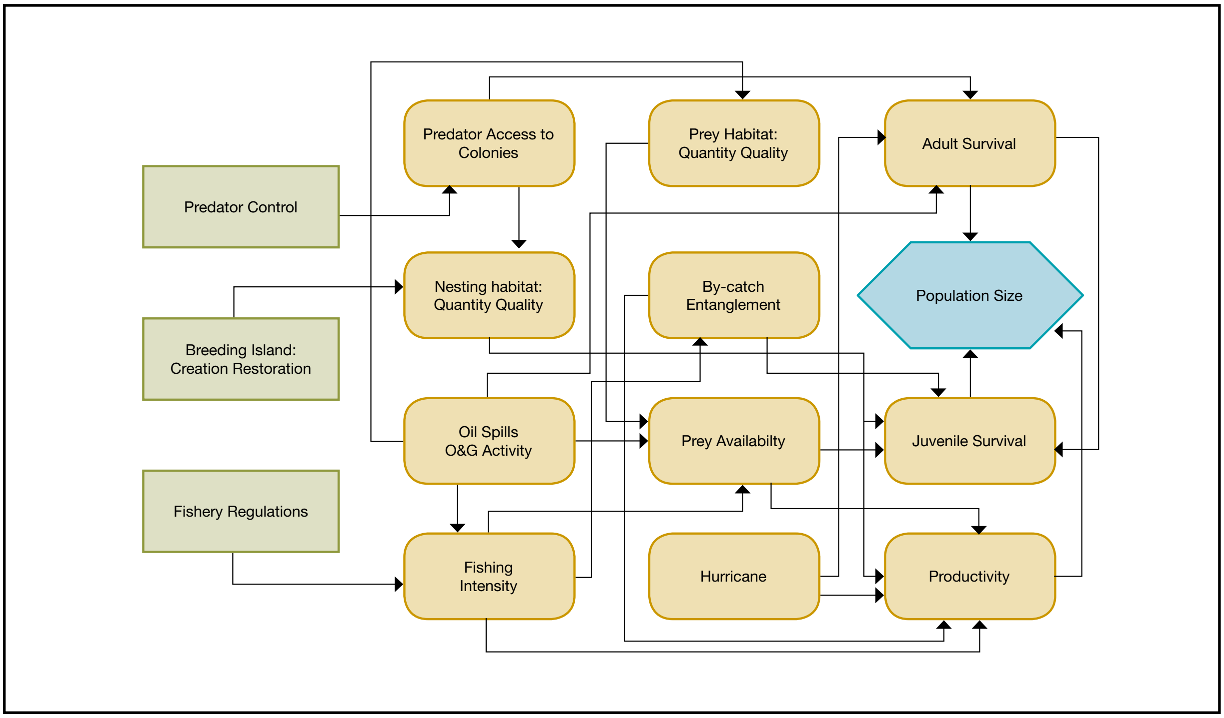
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Audubon's Shearwater** (Puffinus lherminieri) within the Gulf of Mexico Region.*



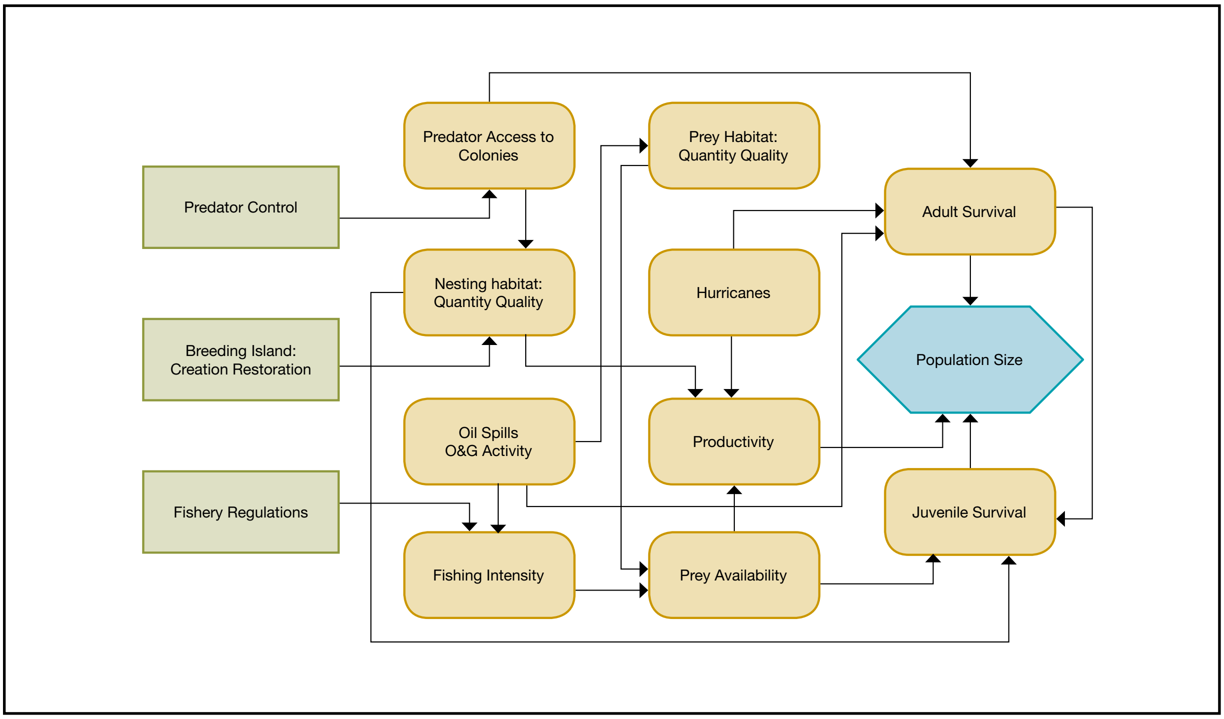
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Band-rumped Storm-Petrel** (Oceanodroma castro) within the Gulf of Mexico Region.*



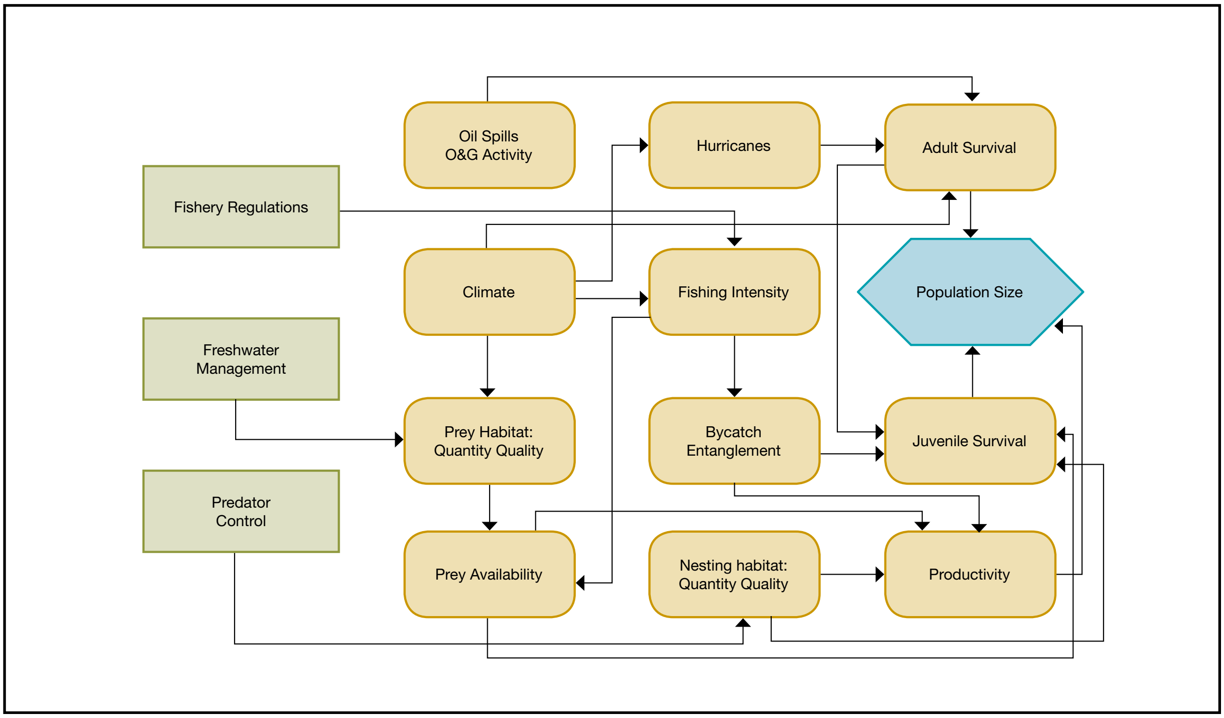
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Black-capped Petrel** (Pterodroma hasitata) within the Gulf of Mexico Region.*



*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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7

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SHOREBIRDS

Authors:
Janell M. Brush (1*)
Raya A. Pruner (2)
Melanie J. L. Driscoll (3)

1. Lovett E. Williams Wildlife Research Lab, Florida Fish and Wildlife Conservation Commission, Gainesville, FL
2. Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, Panama City, FL
3. Phoenix Rising, L.L.C., Baton Rouge, LA

(*) Corresponding Author: **Janell.Brush@myfwc.com**

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

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Chapter 7

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: SHOREBIRDS

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

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

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

Breeding Season

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

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

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

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

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

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

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

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

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

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

Spring and Autumn Migration Seasons

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

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

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

Winter Season

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

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

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

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

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

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

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

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

Shorebirds

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

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

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

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

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

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

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

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

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

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

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

Framing the Uncertainty – Influence Diagrams

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

IDENTIFICATION OF PRIORITIES

Priority Status and Trend Assessments

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

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

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

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

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

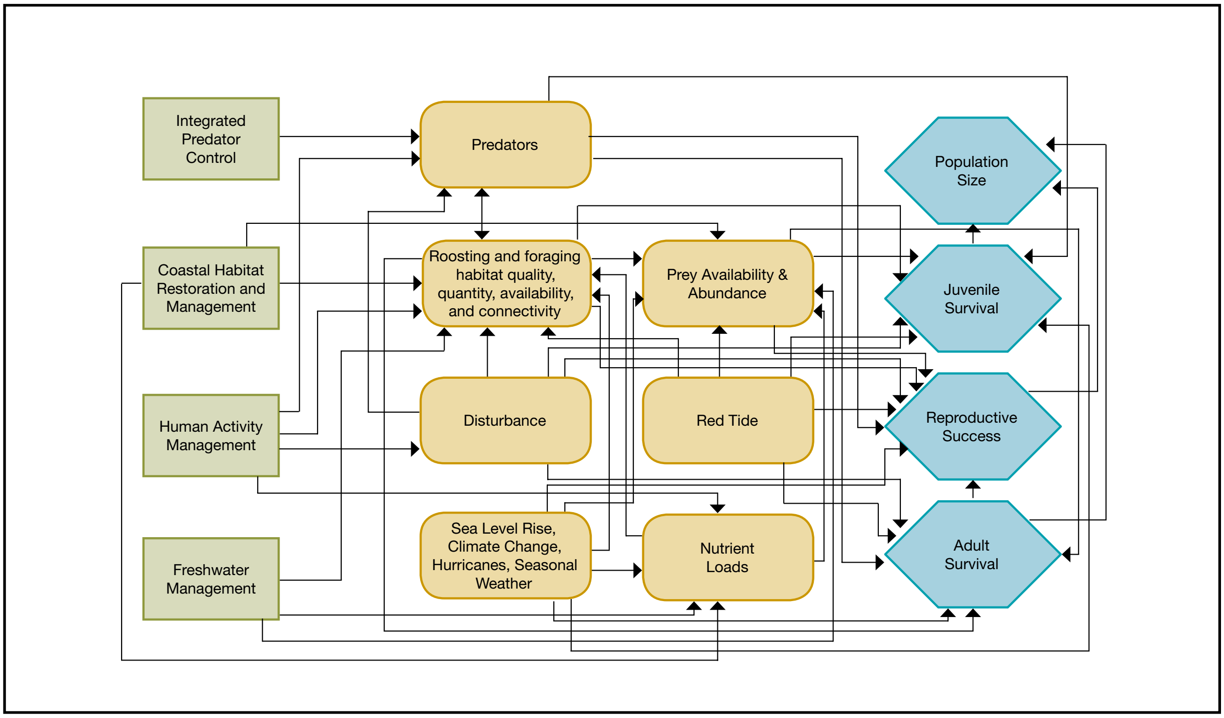

Figure 7.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the* ***American Oystercatcher*** *(Haematopus palliatus) within the Gulf of Mexico Region (see Appendix 7 for additional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

Shorebirds

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

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

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

Priority Management Actions

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

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

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

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

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

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

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

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

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

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

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

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

Table 7.2 (continued).

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

Shorebirds

Table 7.2 (continued).

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

Table 7.2 (continued).

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

Shorebirds

Table 7.2 (continued).

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

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

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

Priority Ecological Processes

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

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

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

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

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

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

Table 7.3 (continued).

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

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

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

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

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

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

SUMMARY & MONITORING RECOMMENDATIONS

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

Monitoring priorities:

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

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

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

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

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

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

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

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

★ Establish or expand on existing studies designed to monitor change and loss of coastal habitat through management/restoration, vegetation succession, or ecological processes, focusing on shorebird foraging, roosting, and breeding habitats to determine impacts to shorebird survival, reproductive success, and population size.

★ Evaluate the importance of site fidelity in breeding and nonbreeding shorebirds and incorporate site specific variables to determine rates of mortality and emigration.

★ Establish a monitoring program that allows rapid assessment of the effects of natural or man-made perturbations including episodic coastal oiling, red tide, or similar events on shorebird survival and health. This program may extend to tracking of survival of impacted birds as well as the tracking of birds in the area that were not impacted.

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

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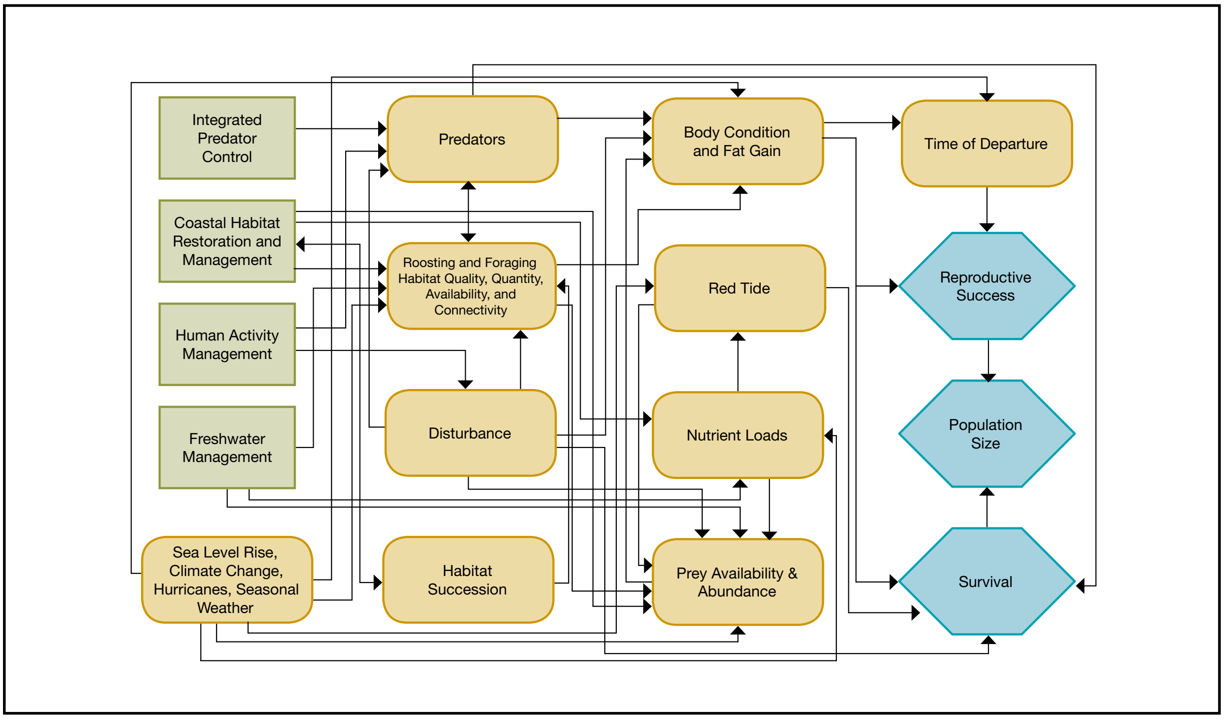
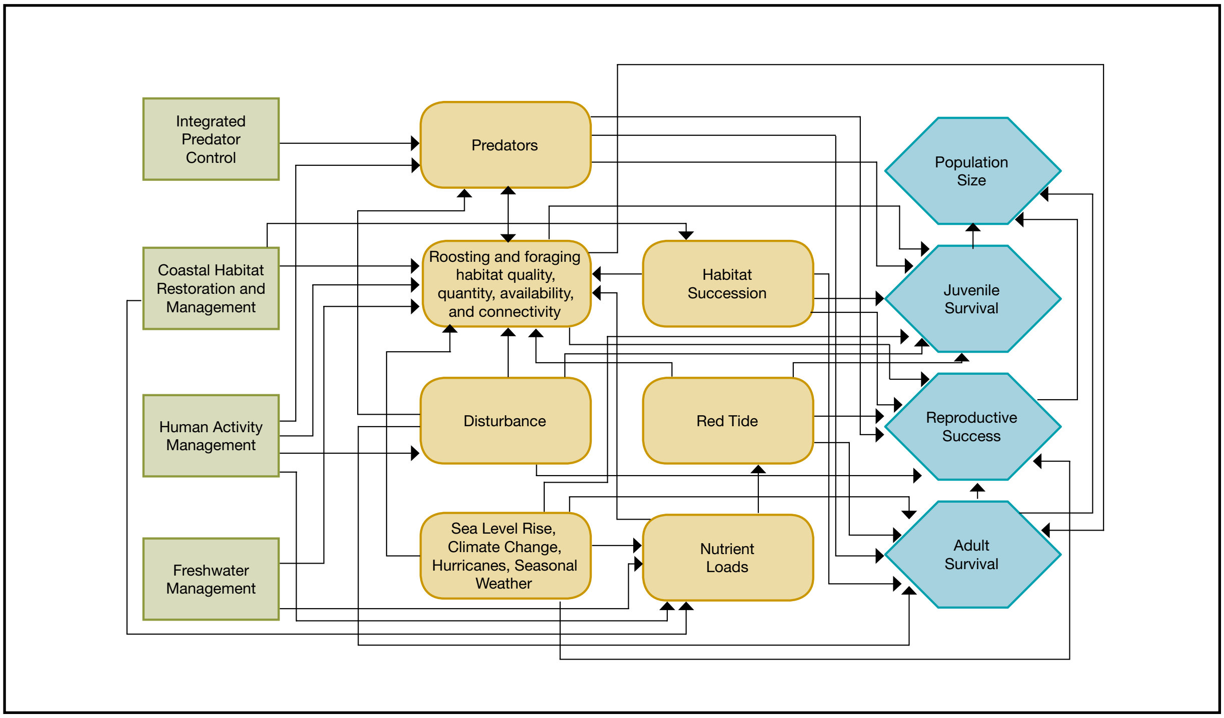
APPENDIX 7

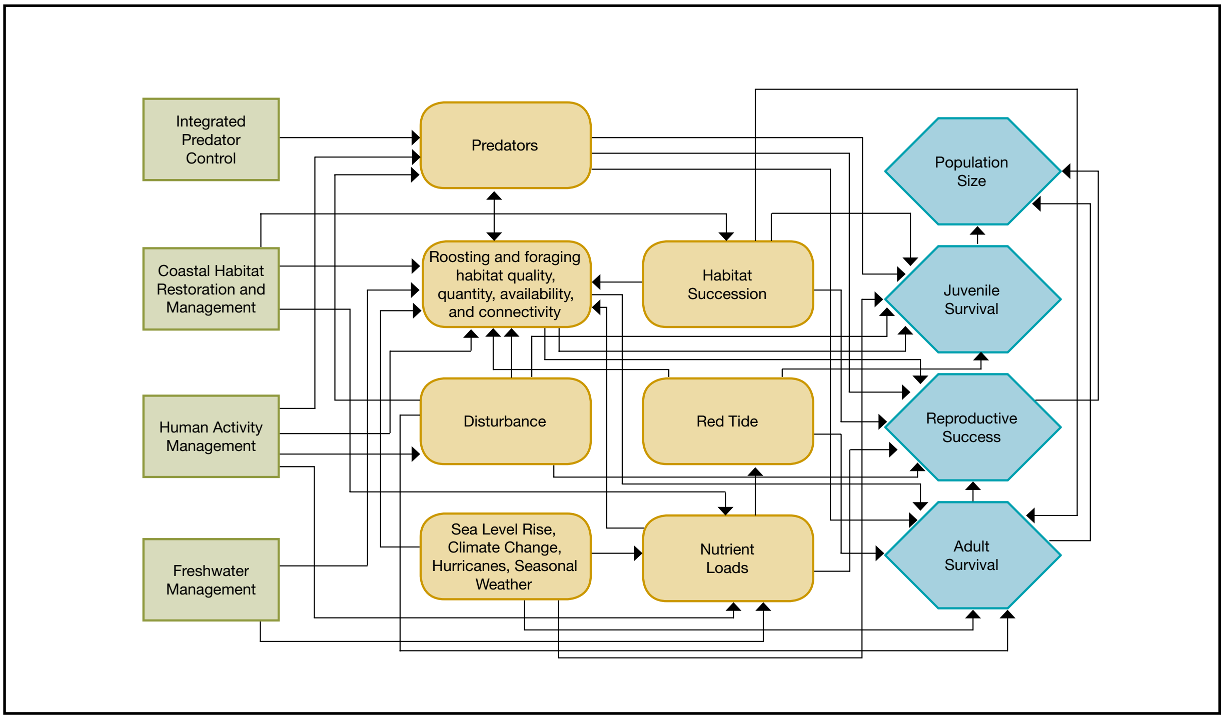
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of shorebirds.



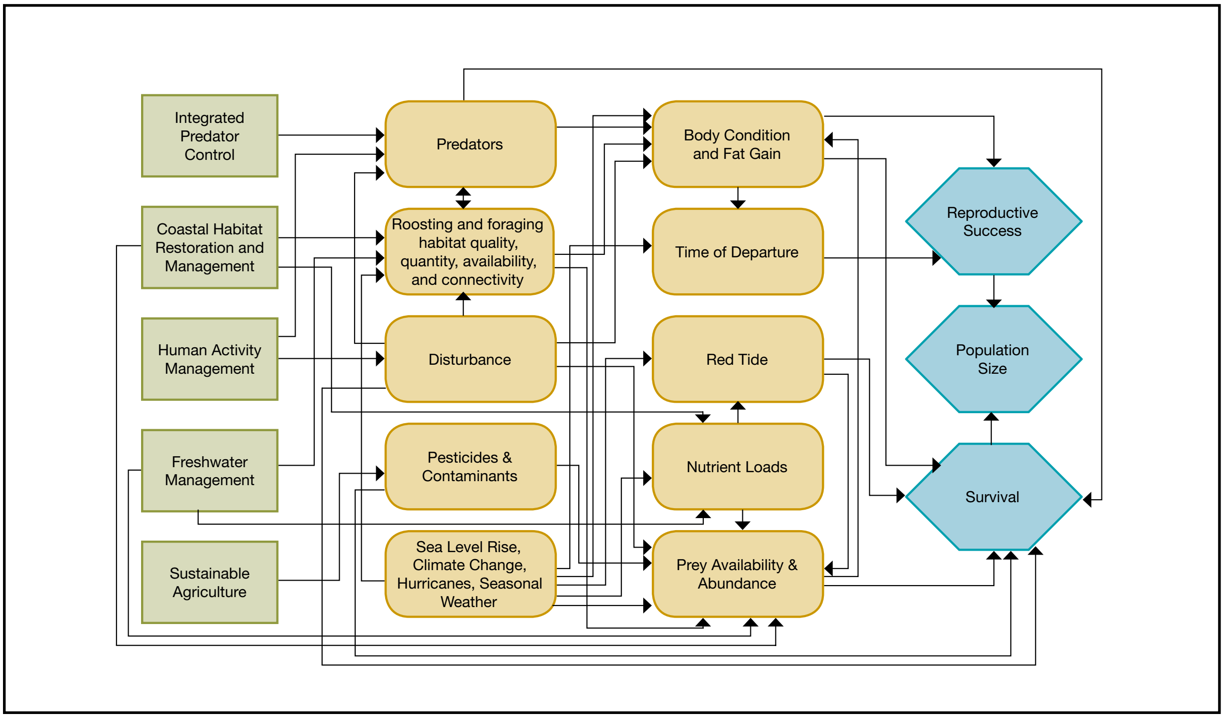
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Piping Plover*** *(Charadrius melodus) within the Gulf of Mexico Region.*



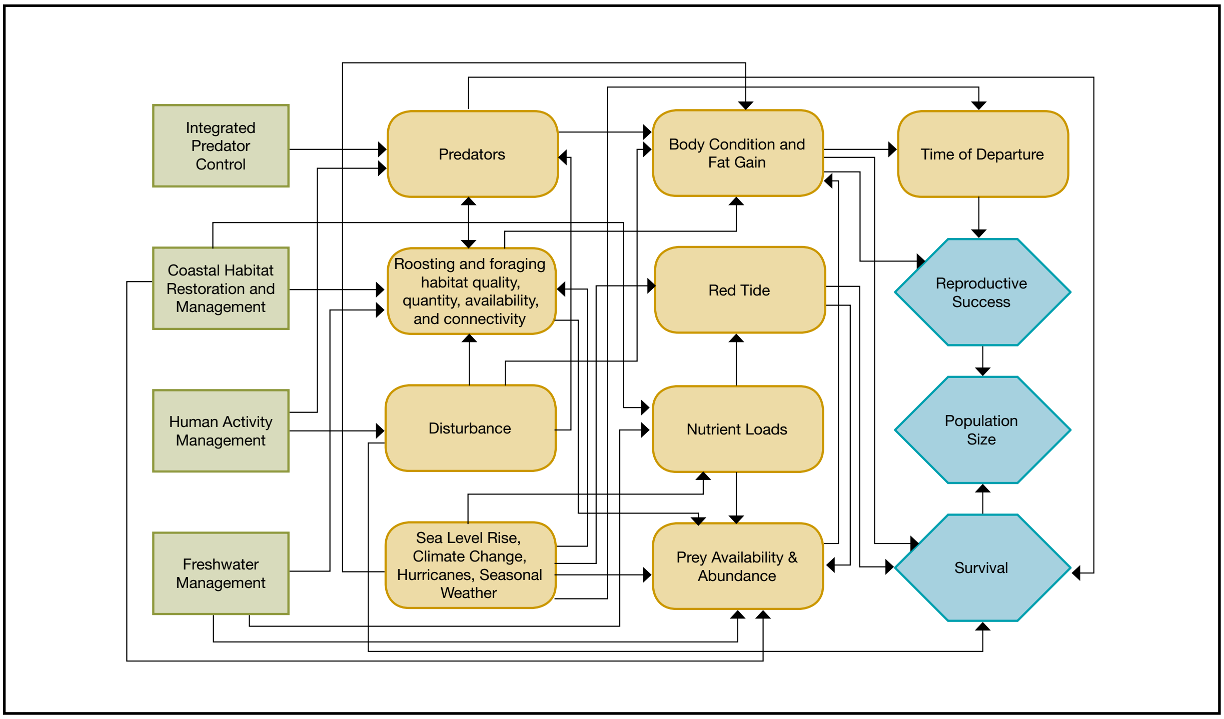
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Wilson's Plover*** *(Charadrius wilsonia) within the Gulf of Mexico Region.*



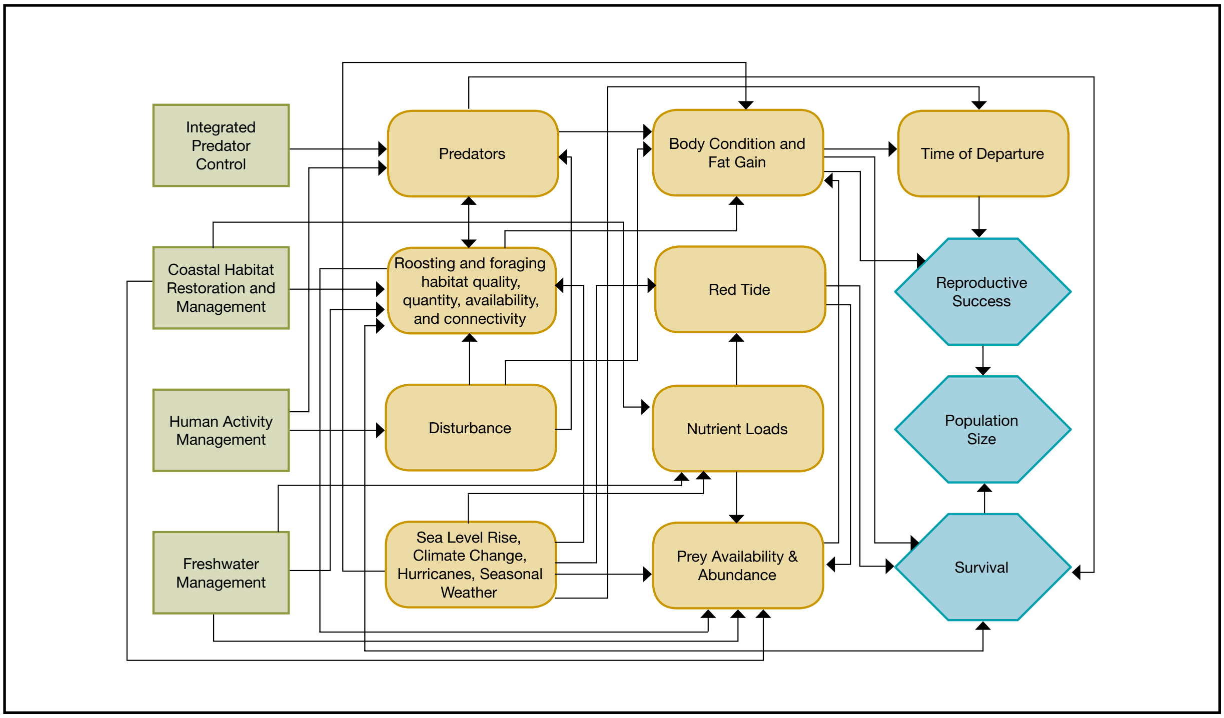
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Snowy Plover*** *(Charadrius nivosus) within the Gulf of Mexico Region.*



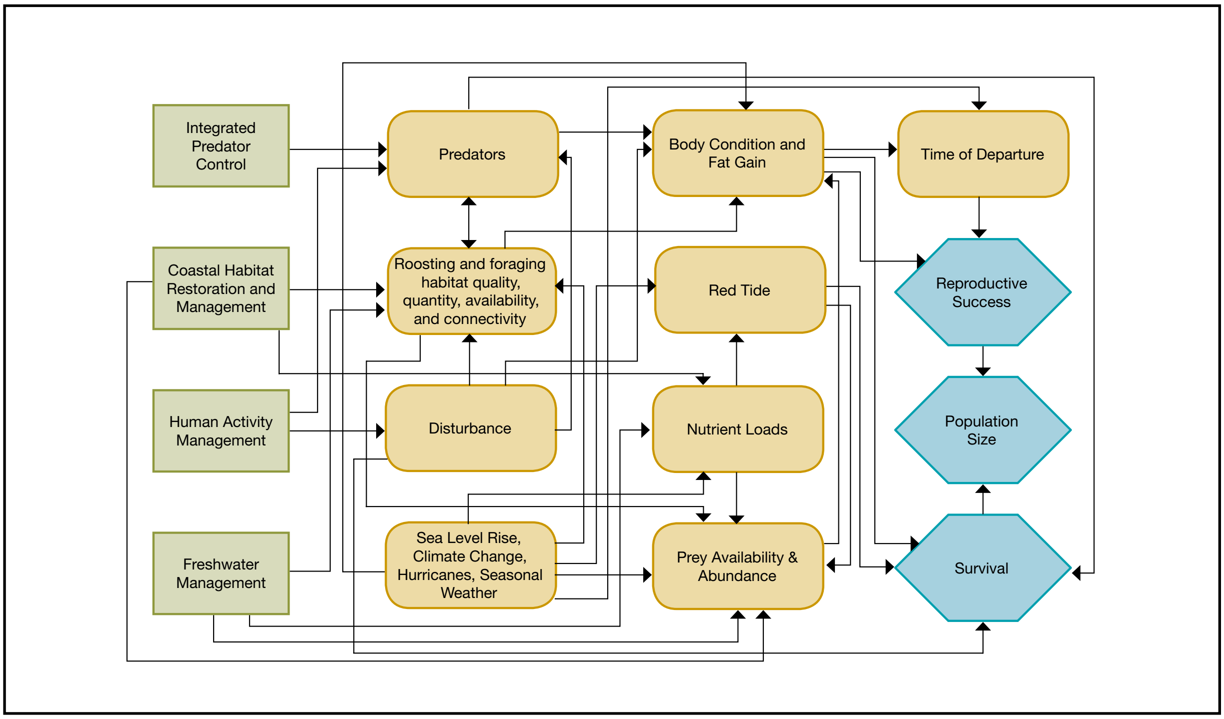
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Long-billed Curlew*** *(Numenius americanus) within the Gulf of Mexico Region.*



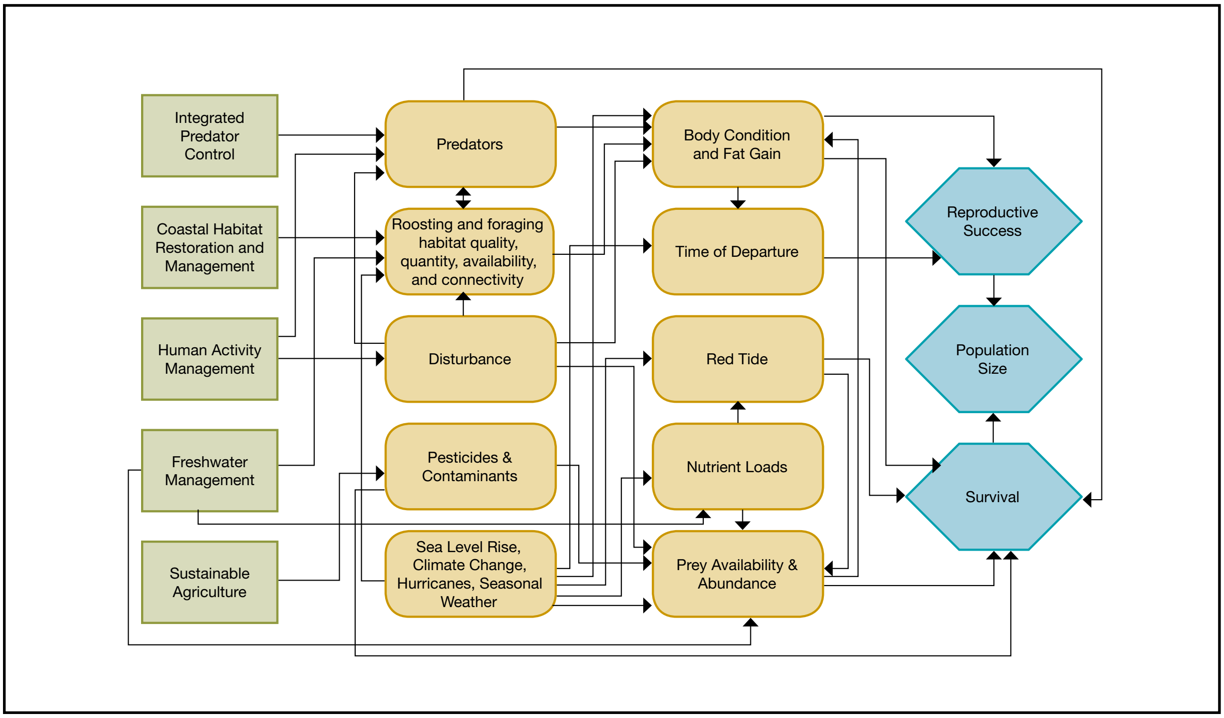
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the ***Marbled Godwit*** *(Limosa fedoa) within the Gulf of Mexico Region.*



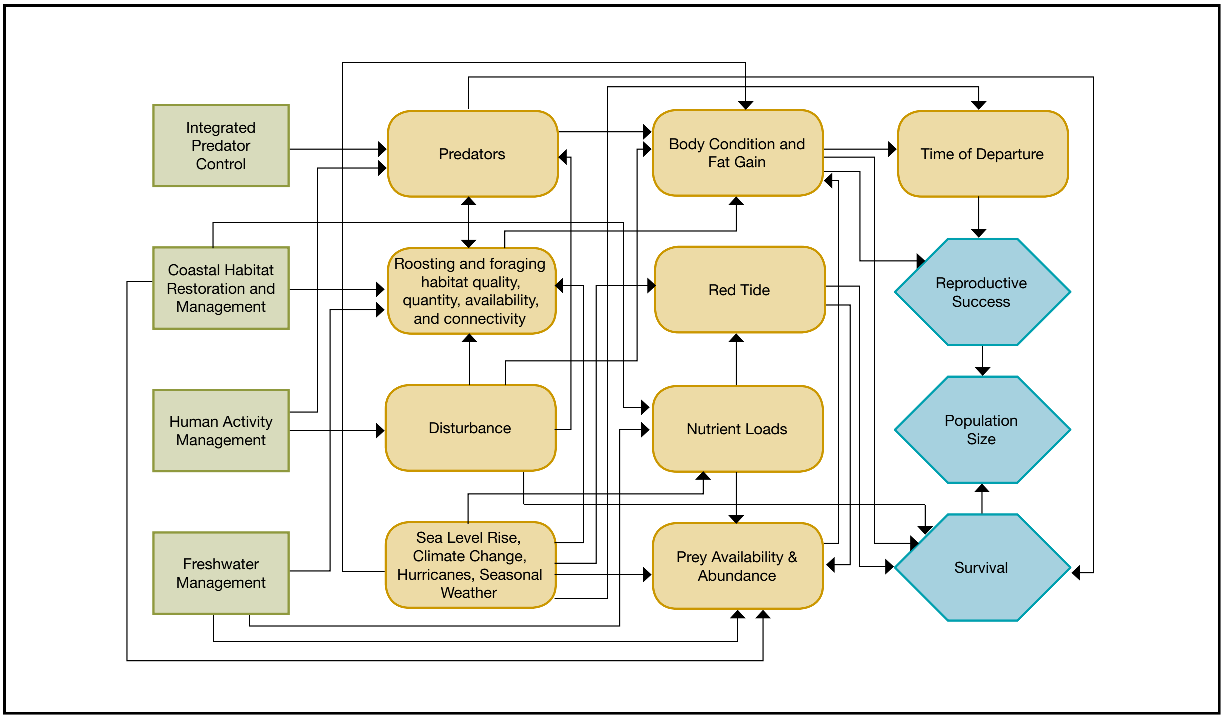
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the **Red Knot** (Calidris canutus) within the Gulf of Mexico Region.*



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



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



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

8

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: WADING BIRDS

Authors:
Peter Frederick (1*)
Clay Green (2)

1. Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL
2. Department of Biology, Texas State University, San Marcos, TX
(*) Corresponding Author: **pfred@ufl.edu**

Roseate Spoonbill (*Platalea ajaja*). Photo credit: Keenan Adams

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GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: WADING BIRDS

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

The Gulf of Mexico is home to 16 species within this group including egrets, herons, ibises, spoonbills, cranes, and storks. These species are most easily divided as cranes (Gruiformes) and the more traditionally classified long legged wading birds that includes herons, egrets, ibises and spoonbills (Pelecaniformes) and storks (Ciconiiformes). Across this group, these species use a variety of tidal, non-tidal, and freshwater wetlands, as well as some upland habitat (storks, ibises, cranes) along the Gulf of Mexico. In comparison to other species groups (e.g., marshbirds), the long-legged wading birds have been well studied as a group for a variety of reasons including conservation status (e.g., Whooping Crane, Mississippi Sandhill Crane, Reddish Egret, Roseate Spoonbill) and their role as indicators of ecosystem health and restoration (White Ibis, Wood Stork; Frederick et al. 2009). While the group as a whole has been well studied, certain species within the group have been less studied and a better understanding of their ecology and population status and trends is critical to the conservation of this group.

Long-legged wading bird ecology varies greatly across this group from common species that range across the Gulf of Mexico (e.g., Great Egret, Tricolored Heron) to more restricted, disjunct populations (e.g., Reddish Egret) to species with very limited distribution (e.g., Whooping Crane, Florida and Mississippi Sandhill Cranes). Most species within this group are permanent residents along the Gulf of Mexico with some having migratory and resident populations (e.g., Reddish Egret, Little Blue Heron, Great Egret, Tricolored Heron, Wood Stork, White Ibis) (refer to Appendix 1). The northern Gulf states (Louisiana, Mississippi, Alabama, and portions of Florida and Texas) often have migratory populations that winter south of the U.S., whereas Texas and Florida have more permanent (non-migratory) populations. However, what proportion of the population is resident versus migratory is not well understood for most species. Whooping Cranes *(Grus americana)* winter along the Gulf of Mexico and breed well north of the Gulf coast with the exception of the recently established experimental, non-essential population in Louisiana (Urbanek and Lewis 2015), whereas Mississippi and Florida Sandhill Cranes *(Antigone canadensis pratensis)* are strictly residents of the Gulf of Mexico (Gerber et al. 2014). Wood Storks *(Mycteria americana)* are both year-round and migratory in Florida, while Wood Storks in Texas only occur during post-breeding season (e.g., July–September) and are likely from the Mexican breeding population (Coulter et al. 1999).

Two of the three cranes (Whooping Crane, Mississippi Sandhill Crane), as well as Wood Storks are classified as threatened/endangered under the U.S. Endangered Species Act. While none of the other long-legged wading birds are federally-listed species, Reddish Egret *(Egretta rufescens)* is listed as a Bird of Conservation Concern at the federal level (USFWS 2008). Reddish Egret, Little Blue Heron *(Egretta caerulea)*, and Roseate Spoonbill *(Platalea ajaja)* are all listed as threatened in Florida (Kushlan et al. 2002, Wilson et al. 2014).

Breeding Season

All of the species in this group breed within the GoMAMN boundaries (Figure 1.2) including the recently established breeding population of Whooping Cranes in Louisiana. Tricolored Heron *(Egretta tricolor)*, Little Blue Heron, and Great Egret nest across the entire region from south Florida to south Texas, whereas the Reddish Egret, and Roseate Spoonbill are more disjunct, primarily breeding in coastal Texas, Louisiana, and coastal Florida (Dumas 2000, Koczur et al. 2019, McCrimmon et al. 2011, Rodgers et al. 2012, Frederick 2013). White Ibis *(Eudocimus albus)* breeding colonies are usually concentrated within a specific region of the GoMAMN boundaries, but have a wide range and shift their centroid of breeding in response to concentrations of food (Frederick et al. 1996). The Little Blue Heron breeds along much of the Gulf coastline, but a large portion of the population breeds at inland freshwater locations (Rodgers et al. 2012). Wood Stork occurrence in Texas is during the post-breeding season and the Wood Stork breeding population within the Gulf of Mexico is restricted to Florida (Coulter et al. 1999).

The long-legged wading birds are all colonial nesting birds, generally nesting in mixed-species colonies on islands

Table 8.1. *Wading bird species to be considered for monitoring programs at multiple geographic scales across the northern Gulf of Mexico. Table includes species residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).*

Common Name	Latin Name	Breeding	Wintering	Migratory	Landcover Association(s)[a]	Trend Score	Continental Concern Score
Florida Sandhill Crane	*Antigone canadensis pratensis*	x	x		Palustrine Emergent Wetland, Lacustrine/Riverine, Grassland, Upland Evergreen Forest (Wet Longleaf and Slash Pine Flatwoods & Savannas)	3	17
Mississippi Sandhill Crane	*Antigone canadensis pulla*	x	x		Palustrine Emergent Wetland, Lacustrine/Riverine, Grassland, Upland Evergreen Forest (Wet Longleaf and Slash Pine Flatwoods & Savannas)	1	15
Whooping Crane	*Grus americana*		x	x	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal (saltmarshes, shallow bays, and exposed tidal flats; also harvested cropfields & pasturelands)	1	16
Wood Stork	*Mycteria americana*	x	x		Palustrine Forested Wetland (bottomland hardwods), Palustrine Emergent Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland; utilizes aquaculture ponds (catfish, crawfish)	3	12
Great Egret	*Ardea alba*	x	x		Palustrine Forested Wetland (bottomland hardwods), Palustrine Emergent Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland; utilizes aquaculture ponds (catfish, crawfish) Estuarine Scrub/Shrub Wetland, Estuarine-Tidal Riverine Coastal	1	7
Little Blue Heron	*Egretta caerulea*	x	x		Palustrine Forested Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland, Estuarine Coastal, Estuarine Scrub Shrub	4	11
Tricolored Heron	*Egretta tricolor*	x	x		Estuarine Emergent Wetland, Estuarine Forested Wetland, Estuarine Scrub/Shrub Wetland, Estuarine-Tidal Riverine Coastal, Estuarine Coastal	2	11
Reddish Egret	*Egretta rufescens*	x	x		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Estuarine Scrub/ Shrub, Estuarine-Coastal	3	15
White Ibis	*Eudocimus albus*	x	x		Palustrine Forested Wetland (bottomland hardwods), Palustrine Emergent Wetland, Estuarine Forested Wetland, Estuarine Emergent Wetland; utilizes aquaculture ponds (catfish, crawfish) Estuarine Scrub/Shrub Wetland, Estuarine-Tidal Riverine Coastal	3	12

Table 8.1 (continued).

Common Name	Latin Name	Breeding	Wintering	Migratory	Landcover Association(s)[a]	Trend Score	Continental Concern Score
Roseate Spoonbill	*Platalea ajaja*	x	x		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Estuarine Scrub/ Shrub, Estuarine-Coastal	2	10

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

(e.g., barrier, spoil, or natural inland islands) or forested wetlands using a variety of tree, shrub, and other woody vegetation as nesting substrate. Colonies are typically over water (e.g., cypress-tupelo swamp, willow head, mangrove) or islands surrounded by water in a variety of marine, estuarine, and freshwater systems. Within these systems, Great Egrets, Wood Storks, and Roseate Spoonbill typically nest higher in trees (e.g., cypress, mangrove), whereas Little Blue Herons, White Ibises, and Tricolored Herons usually nest lower in trees or shrubs or other woody vegetation (Coulter et al. 1999, Dumas 2000, Heath et al. 2009, McCrimmon et al. 2011, Rodgers et al. 2012, Frederick 2013). Within barrier and spoil islands along Texas and Louisiana coasts, these species may nest in low woody vegetation, cacti or even on the ground. Reddish Egrets nest in mangroves (Florida) and low vegetation and cacti in Texas and Louisiana (Hill and Green 2011, Holderby et al. 2012). Wood Storks typically breed in freshwater and estuarine forests (e.g., bald cypress, black gum, willow), inundated by freshwater (e.g., tree islands) or tidally influenced waters (mangroves; Coulter et al. 1999, Tsai et al. 2016).

The Florida Sandhill Crane breeding range is restricted to peninsular Florida and the Mississippi Sandhill Crane *(Antigone canadensis pulla)* restricted to Harrison and Jackson County, Mississippi (Gerber et al. 2014). The Florida Sandhill Crane uses freshwater emergent palustrine marshes, often with higher herbaceous cover for nesting (Bennett 1989), whereas the Mississippi Sandhill Crane uses pine savannas, freshwater marsh, and pine plantations for nesting (Wilson 1987). During the breeding season, both cranes forage in a variety of freshwater, palustrine, and brackish marshes, as well as in some upland and agricultural habitats.

Spring And Autumn Migration Seasons

While the wading birds vary somewhat in migratory behavior across the Gulf of Mexico, all of the species are documented throughout the year across the Gulf states. Spring migration for migratory wading bird populations usually occurs in March/April with fall migration movements ranging between September and November. However, movements can occur at any time of year, and appear to be in response to local food and hydrological conditions (e.g., Bates et al. 2016, Frederick et al. 1996). Most of the wading bird species exhibit some post-breeding dispersal that typically occurs June into October. Coastal Texas and south Florida likely contain resident populations of Tricolored Heron, Little Blue Heron, Great Egret (*Ardea alba*), Roseate Spoonbill, White Ibis, and Reddish Egret, as individuals from each of these species are documented during both migration and wintering months. A decline in numbers of the Little Blue Heron, Tricolored Heron, and Reddish Egret in northern Gulf states (e.g., Louisiana) likely indicates at least some of the population is migrating southward during fall. Telemetry studies on Reddish Egrets reveal that ~40% of Texas/Louisiana birds migrate to Mexico and/or Central America, whereas the remainder are considered resident (Koczur 2017). Great Egrets are migratory throughout much of their range in North America, but along the Gulf of Mexico can be either residential or a mixture of resident and migratory birds from further north. Great Egrets are known to perform long-distance, trans-Gulf migrations in fall and spring (Fidorra et al. 2016). Roseate Spoonbills often exhibit inland movement during the post-breeding season and then may migrate to the Caribbean and/or Central and South America with resident populations remaining in south Texas and Florida. The White Ibis, perhaps the most nomadic of all of the wading birds, exhibit strong post-breeding dispersal, but can also be documented year-round in many Gulf states (Frederick et al. 1996). The Wood Stork occurs year-round in Florida and movements (e.g., post-breeding, winter) seem to be influenced by both season and regional environmental conditions.

Mississippi Sandhill and Florida Sandhill Cranes are considered strictly non-migratory populations and remain in Harrison and Jackson County, MS, and Florida/Georgia, respectively, year-round (Gerber et al. 2014). The Whooping Crane winter population at Aransas National Wildlife Refuge (Texas) usually begins spring migration in late March with the last bird migrating northward by the beginning of May (Urbanek and Lewis 2015). Autumn migration generally occurs in mid- to late-September and stretches to the end of October with the birds on their wintering territories by November.

Winter Season

The Gulf of Mexico provides important wintering habitat for all of the long-legged wading birds and cranes with some species (e.g., Great Egret) occurring throughout the Gulf states. While the Tricolored Heron, Reddish Egret, and Little Blue Heron can occur throughout the Gulf of Mexico during the winter season, there is some reduction in numbers of wintering individuals along the northern Gulf (e.g., north Florida, Mississippi, Alabama), but consistent occurrence of these species in coastal Texas and peninsular Florida. Roseate Spoonbills winter primarily in Texas and Florida with individuals in Louisiana being mostly restricted to southwest Louisiana (i.e., Cameron and Vermillion parishes, Dumas 2000). White Ibises occupy most of their breeding range during the winter season, but this can vary due to winter temperatures, and the regional nomadism and post-breeding dispersal exhibited by this species (Frederick et al. 1996). Wood Storks are also found primarily within their Florida breeding range during the winter, and during the winter the population in Florida is augmented with migrants from the Carolinas and Georgia.

Within the crane populations, the Mississippi and Florida Sandhill Cranes are non-migratory and occupy the same range for wintering and breeding. The Whooping Crane population in Texas winters primarily at Aransas National Wildlife Refuge and surrounding Texas coastal bend area, whereas the Florida and Louisiana populations are non-migratory and hence occupy the same general area year-round.

CONSERVATION CHALLENGES AND INFORMATION NEEDS

CRANES: All of the North American crane species (and subspecies) have been well studied. They share similar demographic profiles, having long adult life, low annual reproductive output, and low survival of offspring. Because of these characteristics, crane populations are sensitive to any influences on adult survival rates, such as traumatic mortality (hunting, powerline collisions), predation, and disease. Predation is the number one cause of mortality in adult and young Mississippi Sandhill Cranes (Seal and Hereford 1994, Gee and Hereford 1995, Olsen 2004) while collision with vehicles, powerlines, and fences are important secondary causes of mortality (S. Hereford, personal communication).

Since Whooping cranes are migratory, the risks of mortality during migration across large areas of unprotected habitat are of concern. Of particular concern is the suitability of wetland and riparian habitat along the migratory route.

Whooping Crane (*Grus americana*) family group. Photo credit: Michael Gray

Whooping Cranes and both subspecies of Sandhill Crane exist at low population sizes, and may be constrained by genetic problems though potential implications are currently not well understood. The Mississippi Sandhill cranes are highly inbred, contributing to low survival and nest success (Henkel 2010).

While Whooping Cranes breed well outside the GoM area, both Mississippi and Florida Sandhill Cranes are sedentary and breed well within the GoM area. Sandhill Crane nest success is strongly driven by predation on eggs and developing young (Seal and Hereford 1994, Dwyer and Tanner 1992). Predator protection relies largely on placing nests within ponds or extensive areas of inundated marsh, wet prairie, or savanna and heavy emergent wetland vegetative cover, and nest success may be augmented by trapping and removal of potential predators (Hereford, personal communication, Dwyer and Tanner 1992, Bennett and Bennett 1990). Similarly, predator avoidance of adults and young at night outside the nesting season is dependent on roosting areas that are inundated, allowing birds to detect the approach of nocturnal predators. Reduced areas of freshwater inundation and increased woody vegetation can increase predation rates and make otherwise suitable habitat functionally unsuitable, sometimes resulting in reduced survival probabilities and abandonment (Dellinger personal communication). In both Mississippi and Florida, crane populations are therefore increasingly vulnerable due to increased frequency and intensity of droughts, exacerbated by increased human use of freshwater resources in Florida. Vulnerability may come as a result of forced movement as habitat conditions degrade within a season (e.g., drought or disturbance). Sandhill Cranes will travel widely, often making them more vulnerable to mortality from collisions and predation (FWC 2013). Conversely, too large a rain event may flood nests and such flood events may be increasing in both frequency and intensity (S. Hereford personal communication). As Florida Sandhill Crane populations become surrounded by suburban and urban land uses, mortality may increase due to exposure to domestic pets and vehicular traffic, especially during periods of forced movements.

Cranes generally need open habitat to forage and to avoid predation, and habitat loss has been identified as an important threat to the Florida Sandhill Crane population (Nesbitt and Hatchitt 2008). Lack of fire in wetlands and in the wetland-upland interface has also been identified as a critical threat to habitat suitability for this species (FWC 2013). Open habitat can be achieved by a number of means including frequent inundation, fire, grazing, tree felling, mulching, and mowing. Decreased use of fire and shrinking pasturelands on the landscape are seen as important threats both generally, and for specific populations of Sandhill Cranes (FWC 2013). The Mississippi Sandhill Crane is especially dependent on frequent, low intensity fire to maintain the openness of the wet pine savanna habitat (Hereford 1995, Frost et al. 1996, Hereford and Billodeaux 2010)

The migratory population of Whooping Cranes is highly dependent during the winter on a small number of food types produced in estuarine habitats in and around the Aransas National Wildlife Refuge in Texas, though foraging is opportunistic. Juvenile and subadult Blue Crabs (*Callinectes sapidus*) are a primary food item (Westwood and Chavez-Ramirez 2005), and the production of crabs is strongly influenced by salinity regimes, which are driven by freshwater flows to the estuary (Pugesek et al. 2013). The fruits of Carolina wolfberry (*Lycium carolinium*) are another key food resource that is available for crane consumption through a portion of the winter season, and productivity of the wolfberry is dependent on moderate salinity conditions (Butzler and Davis 2006). The management of instream freshwater flows to coastal bays within the Guadalupe-San Antonio basin is therefore, of critical concern for this species, specifically in its wintering habitat within and around the Aransas National Wildlife Refuge (Wozniak et al. 2012). The net influence of drought or reduced freshwater flows during winter may not, however be the most important factor affecting this population (Butler et al. 2014). Habitat loss from development continues to be a serious concern on the wintering grounds. The recent establishment of black mangroves (*Avicennia germinans*) and continuing habitat conversion due to sea-level rise are natural phenomena from climate change that must be factored into habitat conservation for this species (Chavez-Ramirez and Wehtje 2012).

LONG-LEGGED WADING BIRDS: Of the priority long-legged wading birds, two are either coastal specialists (Reddish Egret) or are frequently associated with coastal habitats (Roseate Spoonbill). These species are dependent upon particular coastal habitats for foraging, like shallow seagrass beds and mudflats (Reddish Egret; Koczur et al. 2019), shallow coastal wetlands (Roseate Spoonbill; Koczur et al 2019), or Cypress-Tupelo swamps in Louisiana. Both species are also largely restricted to coastal island habitat for nesting. Because of this, critical habitats for these species are particularly vulnerable to effects of both sea-level rise (SLR) and coastal storm effects.

Generally, the long-legged waders show a strong connection between foraging and breeding, with poor nest success often associated with temporary declines in food supply (Frederick and Spalding 1994, Herring et al. 2010, Beerens et al. 2015), and breeding population size may fluctuate and be predicted from annual and antecedent hydrological conditions (Beerens et al. 2015). For this reason, any threats to the production or availability of food are of great importance to population responses.

All of the long-legged waders forage in shallow water (5–30 cm) and foraging success and choice of foraging site are sensitive to both depth and density of aquatic prey (Gawlik 2002). Prey populations and densities in shallowly inundated wetlands of many types are often strongly affected by hydroperiod (Reutz et al. 2005, Dorn and Trexler 2007), and there appears to be an important tradeoff between length of hydroperiod and community structure (Trexler et al. 2005, Dorn and Cook 2015). At very long hydroperiods, prey populations may be driven by piscine predators that are essentially in competition with birds. At the lower end of the hydroperiod scale, aquatic community structure and size of standing stocks of wading bird prey are more likely to be limited by time since drying.

In coastal zones, prey communities and standing stocks are also structured by salinity (Green et al. 2006, Lorenz and Serafy 2006), which is largely dependent upon upstream freshwater flow. In Florida Bay, for example, annual availability of prey of Roseate Spoonbills is dependent upon upstream flow from the Everglades, and success of nesting is predictable from hydrologic parameters (Lorenz et al. 2009). This follows the general finding that intermediate salinities typical of estuaries are at least partly responsible for greater productivity of fishes and invertebrates found there (Livingston et al. 1997), as well as structuring habitat in other ways (Flemer and Champ 2006). Reduced freshwater flows to estuaries are becoming more common in coastal areas generally (Alber 2002) and constitute a major threat to populations of long-legged waders. Similarly, flows are also becoming more highly managed, resulting in greater extremes of discharge, altered timing of releases, and increased variability in flooding regimes. These changes alter typical patterns of drying, directly affecting both production of prey (hydroperiod too short or long) and access to prey (drying patterns subdued or lost altogether).

Sea-level rise and altered freshwater flows may together also "squeeze" coastal foraging and nesting habitat for this group of birds. This results from a narrowing of the extent of appropriate salinities and hydroperiods as sea-level rises, and freshwater flows either decrease or become more highly variable.

Foraging success of long-legged waders is also sensitive to vegetative structure (Lantz et al. 2010, Adams et al. 2008), with some species strongly linked to particular habitats (seagrass beds, open flats), and a general avoidance of woody vegetation. As temperatures and sea-level both increase, there will be a tendency in the southern part of the monitoring area for increased coverage of woody coastal vegetation such as mangroves, with a concomitant reduction in coastal graminoid-dominated marshes. This may constitute a large reduction in foraging area. In other areas, it is not as clear that vegetation will shift towards woody species, and greater number and intensity of coastal storms in some cases may result in more open habitats such as mudflats and open water.

For these reasons, all of the long-legged waders appear to be strongly dependent on local hydrology and freshwater flow for suitability of foraging habitat. As such, all are vulnerable to changing rainfall patterns, upstream water management, sea-level rise and its effect on local hydrology, and the effects of hydrology on foraging habitat structure.

Long-legged waders are with rare exceptions colonial nesters, and while nest success is thought to be proximally driven by foraging success, nesting habitat preferences appear to be driven by predation, mostly by aquatic, arboreal mammals. Long-legged wading birds have no defensive behaviors that are effective against arboreal mammals like raccoons (*Procyon lotor*), and rely instead on inaccessibility of colony sites to exclude predators (Post and Seals 1993, Burtner and Frederick 2017). Breeding colonies are typically located on islands surrounded by water, or in large expanses of flooded forest. While presence of water may exclude some mammals by forcing them to swim, the presence of American Alligators (*Alligator mississippiensis*) below nests appears to exert a strong effect on exclusion of raccoons and other mammals (Burtner and Frederick 2017). There is also a clear benefit to alligators that reside under nests, because they have access to a large potential food resource through falling chicks (Nell and Frederick 2015). This process may have important demographic and habitat choice effects—the degree to which colonies of Wood Storks are surrounded by water is predictive of colony longevity (Tsai et al. 2016).

Islands and forested wetlands that are suitable for nesting

Reddish Egret (*Egretta rufescens*). Photo credit: Michael Gray

are therefore, crucial to the breeding distribution, nest-site selection, and nest success of long-legged wading birds. This is especially the case where raccoon populations are increasing in coastal areas (Erwin et al. 1995, 2001). Although the availability of islands has been shown to limit colonial waterbird nesting (Erwin et al. 2001, Tsai et al. 2016), it is unclear whether islands of this kind are limited in number or type in various parts of the Gulf coastal states, and whether this ultimately limits populations. Certainly, coastal islands are being eroded and lost as sea-level rises, but islands may also be created through very similar processes.

Many historically important colonies of long-legged wading birds were coastal, and rising sea levels already appear to be degrading vegetation and substrate on those islands. It is unclear if the processes by which islands are created will keep up with this loss as coastal areas are inundated, and perhaps experience greater severity and frequency of storms. In the absence of other information it seems prudent to typify island availability as a potential threat.

Lastly, the GoM system is an area that produces oil spills of various frequencies and volumes annually (primarily in Texas and Louisiana; NOSC 2011). Long-legged wading birds are quite vulnerable to oiling in the coastal zone because they forage directly in shallow waters that are likely to either accumulate fresh oil from a spill or accumulate oil in sediments. Further, the prey that wading birds eat are small crustaceans and fishes that are likely to either be exposed to oil because

Florida Sandhill Cranes (*Antigone canadensis pratensis*). Photo credit: Randy Wilson

of their shallow habitats, and/or serve as biomagnifiers of oil because of their position in the trophic web. Oiling may also strongly affect the survival of young birds. Breeding colonies are often located in intertidal zones in the GoM area [cf 40% (Florida) to 77% (Texas)], and young birds may be oiled through a variety of processes including direct contact with parents, ingestion of prey boluses brought by parents, and direct oiling as they learn to feed. Typically, long-legged wader young learn to forage in the immediate vicinity of the colony (Rodgers 1987) and may remain in that area for a period of weeks before dispersing post-fledging. This period is one in which naive juveniles with no experience of oil or ability to avoid it could become heavily exposed. Finally, oiling can strongly affect survival of vegetation in coastal colonies, and the loss of this structure could lead to immigration to other locations for breeding in future years. Oiling, therefore, must be seen as a major threat to populations of this group of birds.

Methylated mercury is known to be particularly available and widely distributed in southeastern wetlands and is known to have strong effects on birds generally (Wolfe et al. 1998, Evers et al. 2008). Mercury bioaccumulates rapidly in wetland fauna because of complex food webs, and long-legged wading birds are good candidates for exposure because of their trophic position. Effects include teratogenesis, decreased hatching success, reproductive impairment, and endocrine disruption. Some of these effects are influential enough to affect population trajectories (Frederick and Jayasena 2010). The degree to which other contaminants may pose a threat is largely unknown for this group of birds. Wood Storks, Roseate Spoonbills, and White Ibis are among the species commonly observed foraging in roadside ditches and other habitats that may serve as conduits for contaminant exposure.

IDENTIFICATION OF PRIORITIES

Priority Management Actions

Information and learning about the effects of management actions on bird populations and life history parameters is of primary interest to individuals attempting to manage bird populations directly, or estimate the non-target effects of other management activities on birds in the coastal zone. The GoMAMN value model (Figure 2.2) prioritizes reducing uncertainty about effects of management actions on bird populations as one of the three main categories of values that relate directly to birds. In the case of cranes, many of the species are of critical conservation concern because of small population size, and direct management is needed to boost life history parameters and affect population size. Although the long-legged wading bird section has fewer endangered species than the cranes, many long-legged wading bird species are declining, in some cases rapidly, and many of these species are seen as indicators of wetland health. One of the challenges for this group is that individuals may be nomadic, and coordinated management actions are therefore needed throughout the range of these species. Priority management actions and monitoring goals are outlined in Table 8.2.

As above, we have split the priority management actions for wading birds into cranes, and long-legged wading birds.

CRANES. For cranes, land use, land management, and land conversion are thought to be management actions (Figure 8.1 and Appendix 8) that most strongly affect nesting, foraging, and roosting habitat for the representative species (Table 8.1). Burning practices in particular, have been repeatedly identified as having a strong influence on suitability of habitat for Mississippi and Florida Sandhill Cranes (USFWS 1991, Hereford 1995, FWC 2013), and on the use of upland habitats by Whooping Cranes in winter (Chavez-Ramirez et al. 1996). When burning is not possible due to smoke management concerns or other constraints, forestry mulching or other mechanical treatment to reduce woody vegetation can restore or maintain openness. Ecological restoration activities may also strongly influence different types of habitat, particularly where they affect open habitats and areas of degraded stopover, roosting, or feeding habitat. Freshwater management is also of critical concern for this group because of the linkage between hydroperiod and food production, water depth and predation, and freshwater flows and estuarine habitat suitability.

For Whooping and Sandhill cranes, water levels are of prime concern for management for a number of reasons. Roosting sites are of particular importance since cranes are exposed to greatly increased predation pressure when roosting in dry or partially dry sites. However, it remains unclear how much predation at these sites affects population size and demographic processes relative to other stressors. Measuring this effect is therefore a priority management need. For Whooping Cranes, flooded areas are known to be a critical resource on the breeding sites in Canada, but thresholds and net effect of breeding ground hydrology on demography is poorly understood. Data on this relationship are therefore a priority need for breeding area management. The majority of the wild Whooping Crane population winters in coastal estuarine habitat in Texas, and estuarine crabs are an important food source. Freshwater mixing in the estuary is probably important for maintaining crab populations, and management of upstream freshwater flow has been contentious and a focus for this species. However, the specific relationship between freshwater flow and crab abundance in the Aransas area is not well understood, and a focus on that question is a priority need to direct water management strategies. For Mississippi Sandhill Cranes, fire is known to be a critical force for maintaining open, coastal savannas that are preferred habitat. Before burning can be fully developed as a tool, we need an understanding of how much habitat is ultimately created or needed under different burning regimes. For all cranes, mortality from powerline and vehicle collisions is known to be a frequent problem, and for species with small population sizes, can have a significant effect on populations (Stehn and Wassenich 2008, Martin and Shaw 2010). Before management can be enacted on this subject, we need to know more about the degree to which powerline collisions affect demography, and the conditions under which powerline collisions occur.

Similarly, Whooping Cranes and Mississippi Sandhill Cranes have a critically low population size, and losses of long-lived adults have a particularly strong effect on demography. In recent years several individuals have been shot—the degree to which these illegal activities can be curtailed is not known

LONG-LEGGED WADING BIRDS. Reddish Egrets are listed as threatened or of concern at federal and state levels, and their close association with particular kinds of estuarine and marine habitat that are dynamic, and often at risk, put them on the front lines of management action. Along with many other species, Reddish Egrets often nest on dredge

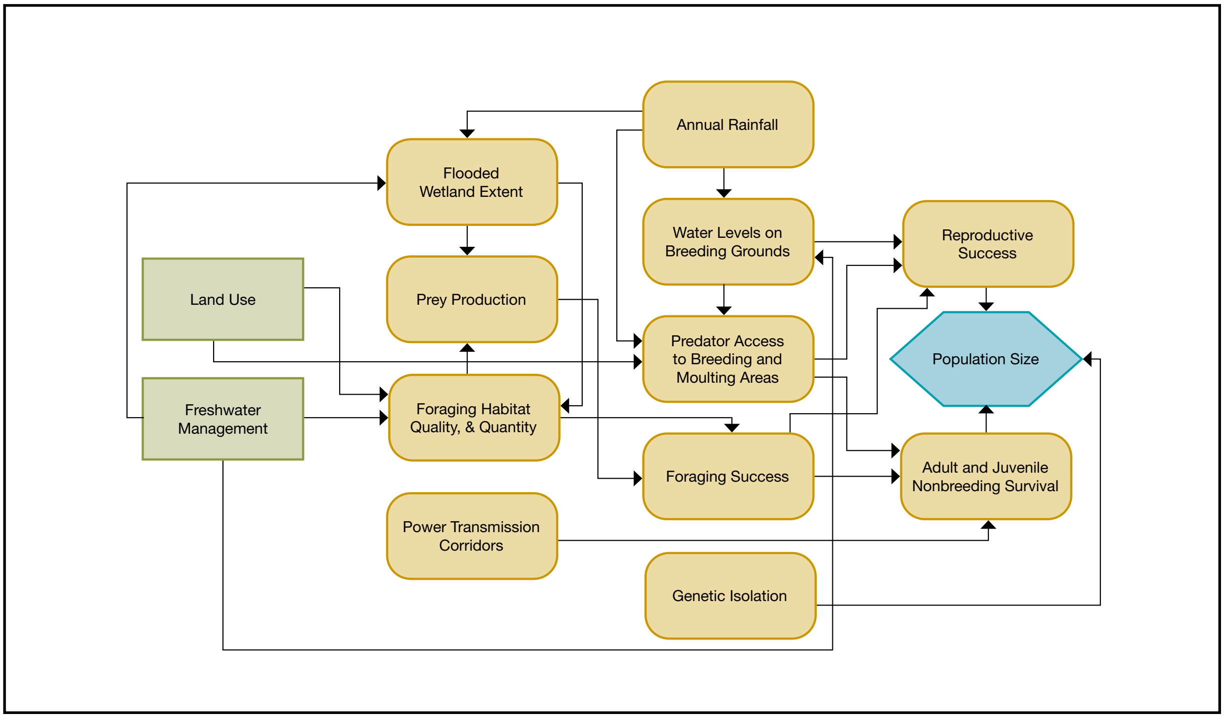

Figure 8.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Florida Sandhill Crane*** *(Antigone canadensis pratensis) within the Gulf of Mexico Region (see Appendix 8 for additional influence diagrams for other priority wading birds).*

spoil islands. Since dredging and deposition of material is a likely restoration response to various coastal issues, dredging activities could have a large impact on several wading bird species (Figure 8.1 and Appendix 8). It is unknown, however, whether nesting sites are limiting for these species, and if they are, under what conditions dredge spoil islands will be used if created (e.g., proximity to foraging habitat, disturbance or predators), resulting vegetative structure, island size, etc. This information could lead to a powerful management tool for several species and is thus, a high priority. Dredging activity is also of interest because in the case of Reddish Egret, it could be used to create the shallow, sparsely vegetated flats that are a preferred foraging habitat for this species. It is unclear, however, whether flats created from dredge material have or could have the same foraging value as natural flats. A comparison of foraging and nest success of birds foraging on natural and dredge material flats is therefore a priority for directing this potentially important management tool.

Similarly, nest success by most of the herons, ibises, and storks on the list are known to be strongly affected by quality of foraging habitat (Beerens et al. 2015; Figure 8.1 and Appendix 8). The role of hydroperiod is known to be critical to both abundance and composition of the fish community and nest success in the Everglades, and management of hydroperiod is therefore, effective as both a predictive and manipulative tool for managing these populations. While this information probably has some value for managing marshes outside of the Everglades, the relationships could be quite different, especially where riverine flow dominates, and where nutrient budgets are different than the oligotrophic Everglades. A robust understanding of those relationships (reproductive and foraging success in relation to hydroperiod) is therefore, needed to fully develop hydrological management in freshwater coastal marshes, and has risen to the level of being a priority need.

A second major driver of prey dynamics for coastal wading birds is salinity regime (Figure 8.1 and Appendix 8). Intermediate salinities of estuaries have been generally shown to be associated with enhanced secondary productivity, and the Everglades has served as a showcase of the effect of coastal salinization on avian foraging and reproductive success (Lorenz and Serafy 2006). As with freshwater hydroperiod (above) the transferability of this information to other coastal areas in the GoM is unknown. However this information could have considerable value both for managing foraging habitat through managing freshwater inflows from upstream, and for

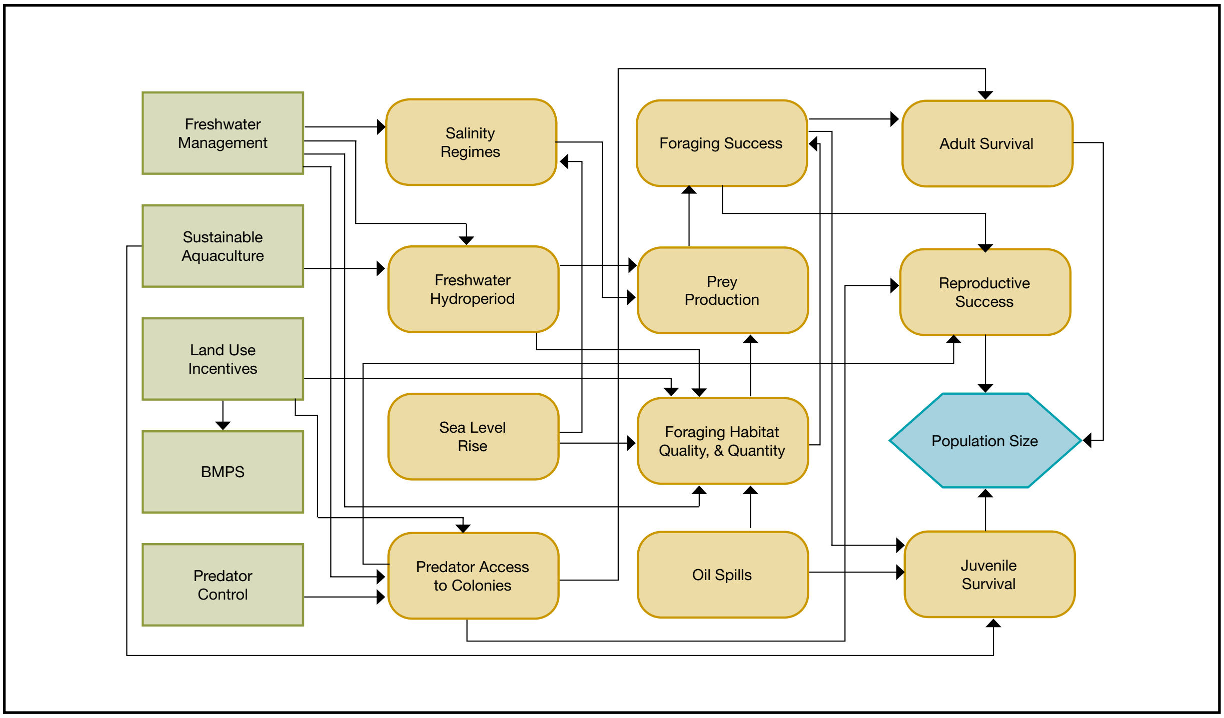

Figure 8.2. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the* ***Great Egret*** *(Ardea alba) within the Gulf of Mexico Region.*

Table 8.2. *Uncertainties underpinning the relationship between management decisions and populations of wading birds in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, D]	Effect Size[c, D]
Reddish Egret Breeding, Nonbreeding	Habitat and Natural Process Restoration (Dredging)	Dredging is one of the few ways new nesting habitat is created. Dredging may both create and destroy foraging habitat, and has strong potential to alter currents and flow in foraging habitat. What is the effect of dredging on REEG populations and how can it be used to increase REEG populations?	Comparison of foraging success in dredge spoil and natural habitats of varying ages. Occupancy analysis of colony locations on dredge spoil and natural islands	Both positive and negative effects are possible but neither have been measured. Interplay between open foraging and mangrove and/or SAV density may be key. This may be a powerful tool but the effects are unknown.	High	High
Whooping Crane Nonbreeding	Habitat and Natural Process Restoration (Freshwater Management)	Lack of surface water results in higher predation of adults and juveniles at molting sites. How important is this effect?	Predation rates in relation to water levels at molting sites	Degree to which this occurs is unknown but adults and juveniles are known to be very vulnerable to predation at this stage.	High	Unknown
Florida Sandhill Crane Breeding, Nonbreeding	Habitat and Natural Process Restoration (Freshwater Management)	Foraging habitat is critical to productivity of young. This is strongly affected by local hydropattern, but how strong is this effect on breeding initiation or success?	Nesting success and fledging success in relation to hydroperiod	Difficult to predict variability in rains and therefore difficult to predict population trajectory—this is extremely sensitive to future climate scenarios.	High	High
Roseate Spoonbill, Tricolored Heron, Wood Stork, White Ibis, Great Egret, Little Blue Heron Breeding, Nonbreeding	Habitat and Natural Process Restoration (Freshwater Management)	In freshwater areas, intermediate hydroperiods result in maximal production of small fishes and invertebrates, affecting foraging and nesting success. What is the magnitude of this effect in relation to other influences on reproduction and foraging?	Reproductive success and foraging success in relation to hydroperiod	This mechanism has been clearly demonstrated in the Everglades but has not been investigated in other parts of the range. Other parts of the range may have different relationships. Ability to manage surface water correctly depends on understanding this relationship.	High	High
Tricolored Heron, Roseate Spoonbill, Great Egret, White Ibis, Wood Stork, Whooping Crane Breeding, Nonbreeding	Habitat and Natural Process Restoration (Freshwater Management)	Production of prey may be positively affected by intermediate salinities in coastal areas, dependent upon freshwater flows. Prey productivity affects foraging and nesting success. How important is this effect on reproduction and foraging by wading birds in the coastal GOM?	Forage fish population fluctuation in relation to salinity regimes. Wading bird nest occupancy and success in relation to salinity regimes.	This mechanism has been clearly demonstrated in the Everglades but has not been investigated in other parts of the range. Uncertainty in a) relationship of salinity to forage fish populations, and b) how powerful this effect is in determining nest occupancy and success.	High	High

Table 8.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b]	Effect Size[c]
Whooping Crane Breeding	Habitat and Natural Process Restoration (Freshwater Management)	Flooded areas are a critical resource for initiation of breeding, breeding success and postbreeding survival of chicks. What are the thresholds for this effect on population size?	Need clarification from crane people	Thresholds for demographic effects through timing and level of water are poorly known. Ultimate effect on population trajectory unknown.	High	Unknown
Reddish Egret, Roseate Spoonbill, Tricolored Heron, Wood Stork, White Ibis, Great Egret, Little Blue Heron, Mississippi Sandhill Crane, Whooping Crane Breeding	Invasive/ Problematic Species Control (Predator Management)	Access of colonies or nests to nest predators results in large differences in nest success, driving recruitment and ultimately population size. What affects predator access to colonies or nests?	Predator access in relation to colony characteristics and colony management; inventory of suitable nesting colonies is needed.	Predator presence seems to be driven by distance from land, predator population density, and presence of alligators – but there may be other parameters affecting access, and the factors affecting mammalian predator populations are too poorly understood to be able to manage colonies directly.	High	High
Mississippi Sandhill Crane Breeding, Nonbreeding	Habitat and Natural Process Restoration (Habitat Management - Prescribed Fire)	Changes in fire frequency results in closing in of coastal savannahs and prairies resulting in suboptimal habitat – food and susceptibility to predation are both affected. How much habitat is needed under different burning scenarios?	Habitat quality in relation to burning regime.	How much habitat is needed and how does that affect demography?	High	High
Roseate Spoonbill, Little Blue Heron, Great Egret, White Ibis, Wood Stork, Mississippi Sandhill Crane, Whooping Crane Breeding, Nonbreeding	Habitat and Natural Processes Restoration (Habitat Management - Agriculture)	Productivity/availability of prey in some parts of the range is strongly affected by presence of shallow water aquaculture and rice culture. Prey productivity affects foraging and nesting success. What production practices are most compatible with long legged wading bird foraging/ reproduction in rice/ aquaculture fields, and how strongly can these practices affect reproduction?	Foraging success and nesting success in relation to specific rice aquacultural practices.	Prey productivity and availability are likely to be strongly driven by particular mixes of culture practices, and these effects are poorly understood for wading birds. Risk of mortality through depredation permits is unknown.	High	High
Whooping Crane Breeding, Nonbreeding, Migration	Species Management (Species Stewardship)	Direct mortality through shooting affects survival rates to the point that this may be limiting this very small population. The reasons for shooting are critical to understand.	Mortality due to shooting	Unclear why birds are being shot, and what can be done to reduce this part of mortality.	High	Low

Table 8.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b]	Effect Size[c]
Whooping Crane, Mississippi Sandhill Crane, Florida Sandhill Crane Breeding, Nonbreeding	Site/Area Management (Energy Development)	What features of powerlines are most likely to affect crane mortality rates?	Mortalities due to powerline collisions, in relation to powerline management actions.	Degree of effect is unknown and possibly changing; interventions are available but their effect is poorly understood.	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.

predicting net effects on long-legged wading bird populations in relation to sea-level rise. Sea-level rise may also be pushing oligohaline zones upriver and into coastal freshwater marsh systems, effectively reducing habitat availability and possibly reducing productivity of wading bird foraging habitats. Monitoring nest success and occupancy of long-legged wading birds in relation to local salinity regimes in foraging habitat is therefore a priority.

Because long-legged wading birds depend on high prey availability in shallow water for foraging (Gawlik 2003), shallow water aquaculture of various types is often an attractant, and in some parts of the range (Louisiana) may be a dominant part of the wetland landscape. Rice and crawfish aquaculture, in particular, produce large quantities of invertebrate and vertebrate prey in depths preferred by wading birds (Fidorra et al. 2015), but culture of aquarium, bait- and food fish may be equally important in some regions. The relationship may, in many cases, be beneficial to wading birds, but dependence of bird populations on aquaculture may make them susceptible to frequent and sometimes widespread interruptions in food supply due to conversion to other crops dictated by market forces, and changes in culture practices. Further, the majority of rice/crayfish aquaculture is centered in southwest Louisiana, which is vulnerable to salinization as sea-level rise continues and coastal marshes erode. This could have a large effect on wading bird populations, but little is known about the risks of this problem. It is also unclear to what extent the relationship of birds and aquaculture causes mortality due to animal damage control efforts. Both beneficial and detrimental aspects of the relationship with aquaculture are potentially strong, but there is not enough specific knowledge about nesting success or nesting propensity in relationship to specific aquaculture practices, certainly not enough to predict whether a population-level effect is likely. Enlightened management of this relationship requires more information about nesting and survival of birds in relation to rice and crawfish aquaculture. This priority should include annual information about the extent and type of aquaculture throughout the southeast.

Most of the long-legged wading birds nest colonially in locations isolated from high ground by water as part of a strategy to avoid nest predation (Post and Seals 1993). This mechanism depends in part on the action of alligators, that are attracted to colonies by dropping food, but also serve to deter nest predation by aquatic mammals (Burtner and Frederick 2017, Nell and Frederick 2015). Since wading birds have no other form of group or individual nest defense, these mechanisms have direct effects on nest success, nesting location, and ultimately population size (Tsai et al 2016, Nell and Frederick 2015). As medium-sized mammals like raccoons and opossums become more abundant in response to agriculture practices and urbanization patterns, this effect is likely to become magnified. Several management actions are possible (Table 8.2, Figure 8.1 and Appendix 8), including predator control, management of surface water, alligator management, management of encroaching floating mats around colonies, and creation of colony islands. However, use of these practices is hampered by specific knowledge about the effect size of specific management actions. It is also unknown whether safe colony sites are actually limiting the populations of birds. It is therefore, a high priority to understand: 1) the effect of specific actions on nest predation rates, 2) the conditions that limit access by predators to colonies, and 3) the inventory of suitable islands and forested wetlands throughout the range of the birds. A related problem is overwash and erosion of coastal islands as sea-level rises (Erwin et al. 1995), which can lead to outright loss of nesting habitat. A common reaction is to use dredge spoil to build up nesting islands—but this often increases elevation to the point that mammalian predators can live or at least temporarily shelter on the islands. A better understanding of inundation in relation to predation risk could strongly influence efficacy of constructed nesting islands, and is a high priority.

Priority Status and Trend Assessments

All of the priority species in this group are chosen either because they: 1) are listed species at federal or state levels, 2) had Partners in Flight (2017) Species Assessment scores >3, indicating high uncertainty as to population status, 3) are species that were particularly at risk during the Deepwater Horizon oiling event, or 4) are common species that are able to serve as surrogates for less widespread or less abundant species. For subspecies (i.e., Mississippi and Florida Sandhill Crane) that have not been ranked by the Partners in Flight (PIF 2017) Species Assessment, we have based our prioritization on USFWS and Florida Wildlife Commission (FWC) recent reports on status and trends of these subspecies. Priority monitoring actions for Status and Trends Assessments are provided in Table 8.2.

For long-legged wading bird and crane species, besides the population estimates from PIF, we have limited information for Little Blue Heron, Tricolored Heron, Great Egret, Roseate Spoonbill, and White Ibis (Appendix 1) status and trends at the population level within the Gulf of Mexico. Great Egret, Roseate Spoonbill, and Tricolored Heron populations are stable to increasing, whereas population estimates for White Ibis are uncertain and Little Blue Herons show a slight to moderate decrease (PIF 2017). For these species, we have no long-term monitoring programs across multiple states, but do have some information within regions (e.g., South Florida Wading Bird Report, Texas Colonial Waterbird database). For Reddish Egret, the Reddish Egret Working Group (REWG) maintains a colony database across the Gulf of Mexico (and throughout the species range) with most recent estimates at ~1,100 breeding pairs across the GoM (Wilson et al. 2014), although population trends per se have not been estimated. The breeding population of Wood Storks fluctuates annually, but recent estimates are ~10,000 nesting pairs and stable to slightly increasing trend (USFWS North Florida Ecological Services Field Office).

For the crane species, Whooping Cranes are increasing, both in the wintering population in Texas and the recently established non-migratory population in Louisiana. However, the global population is still critically low and trend estimates should be viewed cautiously. The Mississippi Sandhill Crane remains in critically low numbers (less than 130 individuals) with an estimated 25 breeding pairs (Hereford and Degrickson 2018). The Florida Sandhill Crane population is larger (~4,000–5,000 individuals), and has remained stable to slightly decreasing over the past decade (Nesbitt and Hatchitt 2008).

The species are ranked below as priorities by Partners in Flight (2017) and regional/working group reports.

- **Priority 1** – Mississippi Sandhill Crane, Whooping Crane, Reddish Egret
- **Priority 2** – Little Blue Heron, Wood Stork
- **Priority 3** – White Ibis, Tricolored Heron, Florida Sandhill Crane
- **Priority 4** – Roseate Spoonbill
- **Priority 5** – Great Egret

White Ibis and Great Egret are both numerous and common. In discussions about their value, the Long-Legged Wading Bird Working Group repeatedly cited these two species as widely distributed species that would be valuable for answering management (Table 8.2) and ecological process (Table 8.3) questions across the Gulf (Figure 1.2). These two species serve as bookends of the spectrum related to philopatry (White Ibis = nomadic, Great Egrest = high breeding philopatry), food habits (White Ibis = invertebrate, Great Egret = strictly piscivorous), foraging behavior (White Ibis = tactile forager, Great Egret = visual, stalking, spearing), and water depth requirements (White Ibis = 5–15 cm, Great Egret = 10–30 cm). Quite aside from the PIF scores, monitoring populations of ibises and Great Egrets has high value for understanding the effect of widespread management actions or ecological processes that occur at large geographic scales. They also may be indicative of the range of conditions associated with habitat suitability for many species (see Influence Diagrams). Tricolored Herons were chosen, in part, because of their tendency to breed and feed in coastal estuarine areas, and their foraging habit suggests they may be indicators of small fish populations in shallow waters of estuaries.

Response metrics for status and trends of Mississippi Sandhill Cranes, Whooping Cranes, Reddish Egrets, Little Blue Herons, Wood Storks, Tricolored Herons, Florida Sandhill Cranes, and Roseate Spoonbills are the global

Table 8.3. *Uncertainties related to how ecological processes impact populations of wading birds in the northern Gulf of Mexico.*

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Reddish Egret, Roseate Spoonbill Breeding, Non-breeding	Interactions Between Organisms	Is reproductive success driven primarily by foraging success, and is foraging success driven primarily by prey standing stock or density?	Reproductive rates in relation to food availability, habitat suitability, and predation.	Unclear whether other events like disease and predation may also affect demography. Factors affecting prey production are unknown and assumed to be 1) related to quality of mangrove/ submerged aquatic vegetation patches close to foraging areas and/or 2) water quality (e.g. salinity, freshwater flows, turbidity).	High	Unknown
Mississippi Sandhill Crane, Florida Sandhill Crane Breeding	Climatic Processes	By what mecanisms are nesting propensity and nesting success affected by local hydrology and local weather processes?	Nest success in relation to local hydrology.	Difficult to predict variability in rains and therefore difficult to predict population trajectory—this is extremely sensitive to future climate scenarios	High	High
Reddish Egret Breeding, Non-breeding	Climatic Processes	How do hurricanes affect foraging habitat and prey base, and can this mechanism affect demography?	Foraging habitat in response to local hurricane effects.	Mechanisms have not been demonstrated, and degree of effect of both habitat creation and prey production are unknown. Interplay between open foraging habitat and mangrove and/or submerged aquatic vegetation density may be key for this species.	High	Unknown
Reddish Egret, Roseate Spoonbill, Tricolored Heron, Great Egret, Little Blue Heron, White Ibis, Wood Stork Breeding, Non-breeding	Climatic Processes	Will sea level rise affect foraging habitat by altering hydrological and depth characterisstics of existing foraging habitat, and altering salinity characteristics?	Foraging habitat suitability through modeling and measurements in response to sea-level rise.	This process is well known in Florida Bay but not demonstrated elsewhere. Relative contributions of hydraulic effects and salinity effects are unknown. Possibility of creation of novel habitat through sea-level rise and storm action exists but has not been demonstrated.	High	High
Reddish Egret, Roseate Spoonbill, Tricolored Heron, Great Egret, Little Blue Heron, White Ibis, Wood Stork Breeding, Non-breeding	Climatic Processes	To what degree will sea-level rise physically create or destroy foraging habitat through erosion and salinization, leading to altered patterns of vegetative communities and depths of foraging areas.	Rates of foraging habitat flux in relation to sea-level rise.	Rates and mechanisms by which destruction and creation of foraging habitat are unknown but could both be widespread. Predictive abilities are very poor at the moment. Interactions with storms suggests these effects are going to be episodic.	High	High

Table 8.3 (continued).

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Whooping Crane Non-breeding	Climatic Processes	How will coastal development and sea-level rise affect wintering habitat for Whooping Cranes?	Wintering habitat acreage and suitability in relation to sea-level rise.	Uncertain how coastal development and mangrove invasion will affect inland movement of habitat; rates and whether habitat can keep up with it. Displacement or loss?	High	High
Mississippi Sandhill Crane Breeding, Non-breeding	Movements of Organisms	To what extent does inbreeding depression affect population trajectories?	Rates of genetic drift and inbreeding depression in relation to chick viability.	Degree to which this process affects survival and recruitment.	High	Unknown

[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.

and local population sizes, and trends based on those sizes. For White Ibises and Great Egrets, total population size is of less interest, but specific responses to priority ecological drivers and management actions is of direct interest.

Priority Ecological Processes

The GoMAMN value model also prioritizes reduction of uncertainty about ecological processes that typically drive avian populations. These are valued because they help us to understand large swings in populations that arise from natural fluctuation in physical or meterological cycles that eventually will allow prediction of population fluctuations in the absence of management actions. All of the species in this group travel widely during their annual life-cycle within the GoMAMN area, and considerable evidence suggests movements are often because of attraction to or repulsion from particular ecological conditions. Understanding such relationships and how they affect demography is of high priority to the GoMAMN value model. Priority Ecological Processes for monitoring are shown in Table 8.3. The ecological processes driving wading bird populations are often related to management actions (e.g., hydrologic patterns and water management) and many are already treated within the Priority Management Actions section. The examples highlighted below are largely independent of specific management actions.

CRANES: Nesting by all three of the cranes is affected by surface water, either as a deterrent to predation, or as a predictor of future water and prey abundance. While this relationship is often quantitatively described, it is extremely difficult to predict future population trajectories because climatic patterns remain too variable to work with effectively. The ability to understand and predict the effects of this relationship depends on 1) more specific relationships between rainfall, local hydrology, and reproductive success, and 2) better downscaled models of future rainfall.

The majority of the Whooping Crane population winters in estuarine marshes of coastal Texas, where the low elevation gradients make coastal marshes susceptible to sea-level rise. Further, with increasing temperatures predicted from climate change, much of the area may transition from saltmarsh to mangrove forest. These are obvious concerns for the future of the primary winter foraging habitat for this critically endangered species. The uncertainties are primarily ones of degree—how fast the habitat will be lost, and ultimately, how much will be lost. A better understanding of this process is a priority because it will lead to a reduction in uncertainty about the future of the population.

The effects of inbreeding depression and genetic drift can become problematic in the current population sizes of all of the crane species or populations of concern to GoMAMN. These effects may be manifested through reduced survival, fecundity, and nest success. Genetic effects are currently unknown, in part, because they may be cryptically embedded or masked in a mix of other, non-genetic effects. It is a priority to understand rates of chick production in relation to genetic measures of drift and introgression.

LONG-LEGGED WADING BIRDS: Foraging success and reproductive rates of long-legged wading birds are strongly influenced by quality of foraging habitat. In the coastal zone, foraging habitat is very likely to be affected by global change processes including SLR, increasing temperatures, and increasing storm frequency and intensity. Some of the mechanisms may be complex—higher sea level may, for example, result in lower annual differences in water level, which birds may depend on seasonally for prey availability. It is unclear whether these processes will create new habitat as old habitat is destroyed, and predicting the net effect and location of the new habitat is of keen interest to imagining future demography and occupancy by wading birds. Monitoring habitat flux and suitability in relation to SLR and storm events in targeted areas and species around the Gulf is therefore of high priority.

Reddish Egrets and Roseate Spoonbills both rely heavily on marine flats and shallows for foraging. Unlike in freshwater wetlands, the factors controlling standing stocks of prey in these habitats are poorly understood, but may be important for predicting habitat quality, occupancy, and nest success. Understanding factors affecting food availability in these habitats is therefore of high priority for these two species. Reddish Egrets rely almost exclusively on very shallow, sparsely vegetated marine flats for foraging. The conditions that create or maintain an inventory of these somewhat ephemeral habitats are not well understood, but severe storms like hurricanes may be cyclically important. Measuring foraging habitat in relation to local storm activity is therefore a targeted priority for this species.

Roseate Spoonbill populations have grown quite slowly from lows in the last century, and there appears to be a considerable lag in occupancy of new, apparently favorable habitat. This lag may be a characteristic of a general tendency towards philopatry or it could be driven by density dependence (i.e., birds begin to move into unoccupied habitat as their population approaches carrying capacity). Understanding which these two processess is dominant could be important to predicting demographic responses, and forming expectations about the timing of responses to the creation or enhancement of habitat. Monitoring long-distance movements of individuals, and their responses to newly created habitat is therefore of high priority for this species.

Great Egret (*Ardea alba*). Photo credit: Robert H. Burton

Large oil spills are clearly anthropogenic in origin in modern epochs, but are not considered a management action in the context of the GoMAMN. Two main classes of effects could strongly affect wading bird populations—direct effects from oiling of eggs, adults, or juveniles would result in expected declines in survival, and/or indirect effects through long-term damage to nesting and foraging habitat and the associated prey base. While the effects are well known in a qualitative sense, the degree, amount, and time to recovery are poorly understood. There are two classes of priority information needed to reduce uncertainty about effects on populations. First, there is a need for information on the dose-response relationship of oil on various species of long-legged wading birds in relation to both survival and future reproduction. Second, there is a need for information on the long-term effect and response time of foraging habitat and prey populations to oiling events.

SUMMARY AND MONITORING RECOMMENDATIONS

★ Establish baseline monitoring of multi-species nesting colonies of all long-legged wading birds to facilitate status and trend assessments. This information can also be used to assess geographical movements, impacts of hurricanes, changes in foraging habitat, and the relationship between foraging habitat variables (salinity and hydropattern) and nesting success. Further, the focus on colonies can also be used to understand the importance of predation, and the effect size of management options that can be used to affect predators and their access to colonies.

★ Evaluate the effects of salinity dynamics on foraging and nesting success of wading birds nesting in estuaries. Salinization and unnaturally pulsed freshwater flows are becoming common in Gulf estuaries, and appear to have strong effects on both foraging habitat, and prey abundance and composition. This knowledge could have strong implications for watershed management throughout the Gulf coast.

★ Evaluate the impacts of sea-level rise and changing temperatures on foraging habitat and potential nesting locations for wading birds. Sea-level rise physically creates and destroys foraging habitat through erosion and salinization leading to altered patterns of vegetative communities (e.g. mangrove intrusion) and depths of foraging areas. Monitoring quality and extent of habitat are both important, and these parameters should be compared to evolving knowledge of habitat needs of each species.

★ Increase knowledge of the relationship between particular aquaculture/rice practices and rotations, and their value to foraging and nesting wading birds. The extent (acreage) of each practice needs to be tracked through time, and the relationship of different practices evaluated for each species.

★ Continue population monitoring of each of the crane species/subspecies. Where possible, relate population dynamics and vital rates (fecundity, survival, longevity) to hydrological variables like hydroperiod, wetted area, and rainfall to further the understanding of the role of hydropattern in propensity and success of nesting and survival of offspring.

★ Perform specific adaptive studies of the effects of prescribed fire and mechanical woody vegetation management on Mississippi Sandhill Crane habitat value in order to establish an effective burn program.

★ Establish a monitoring program that allows rapid assessment of the effect of episodic coastal oiling on long legged wading bird survival and health. This may extend to tracking of survival of individual birds oiled.

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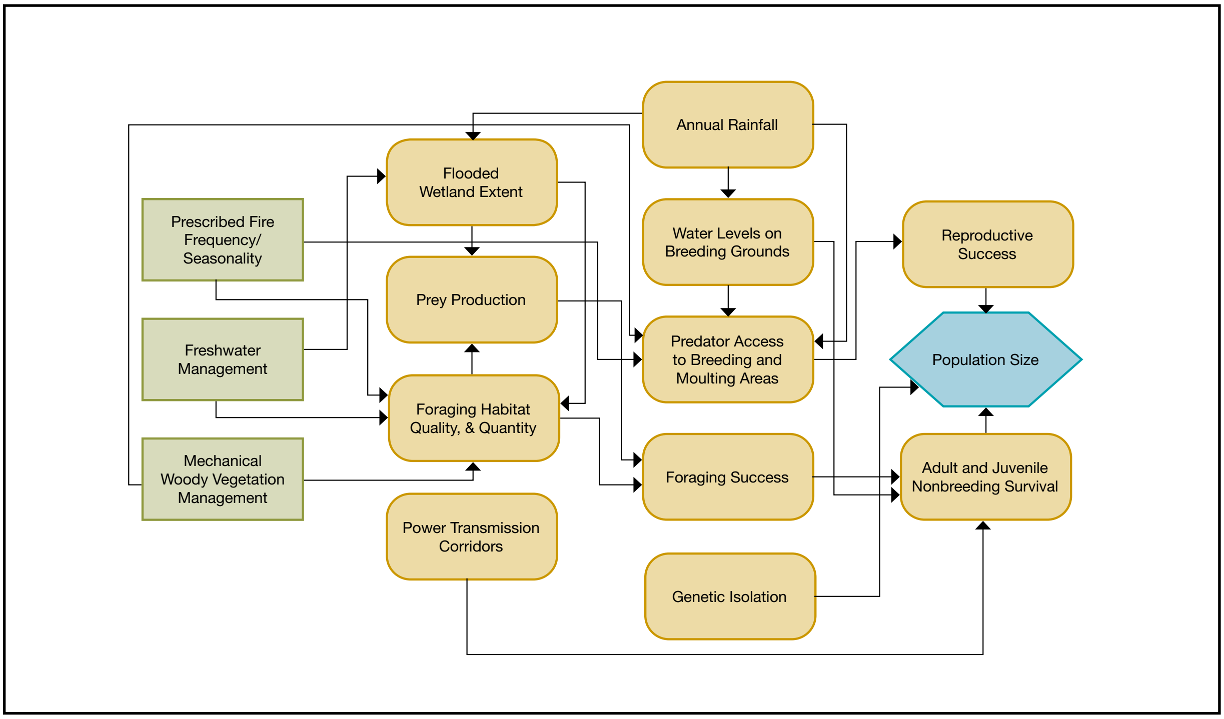
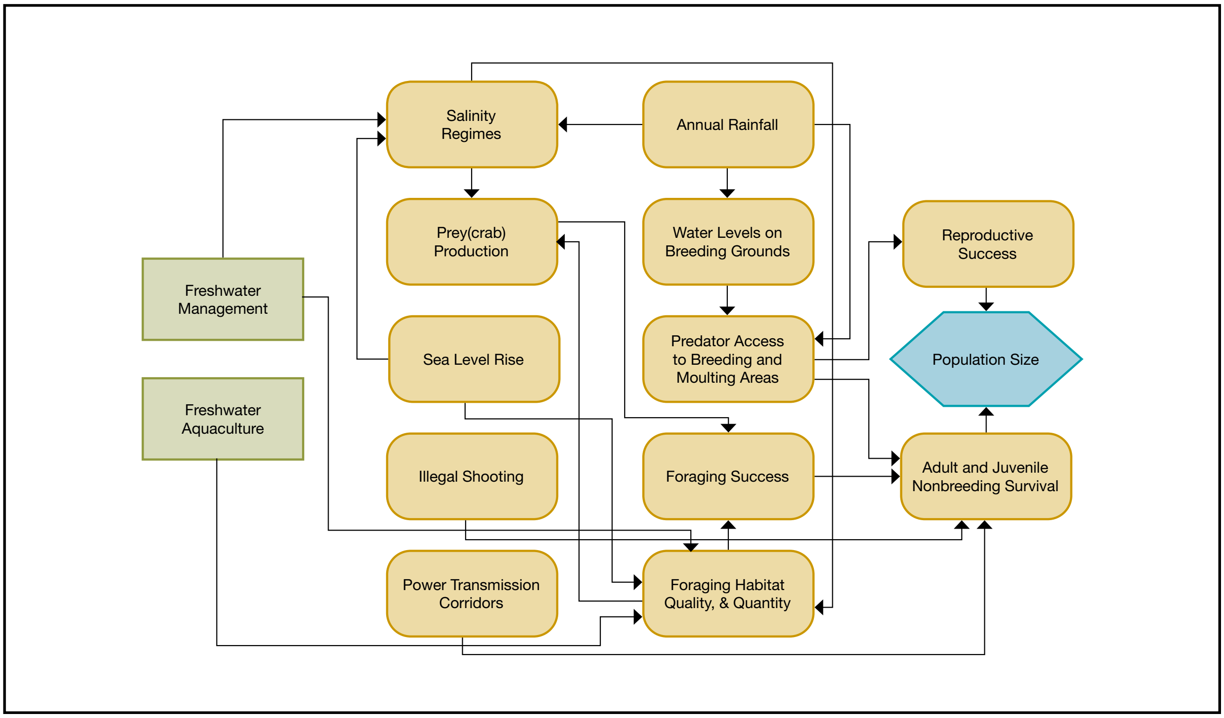
APPENDIX 8

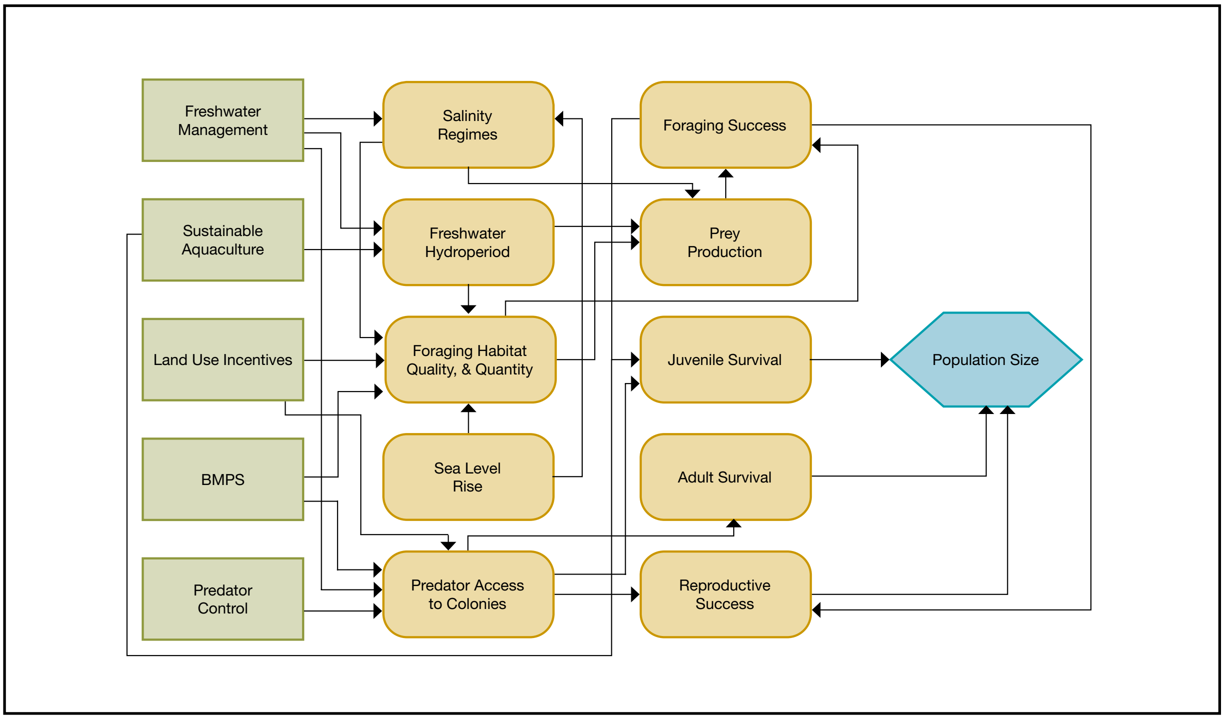
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of wading birds.



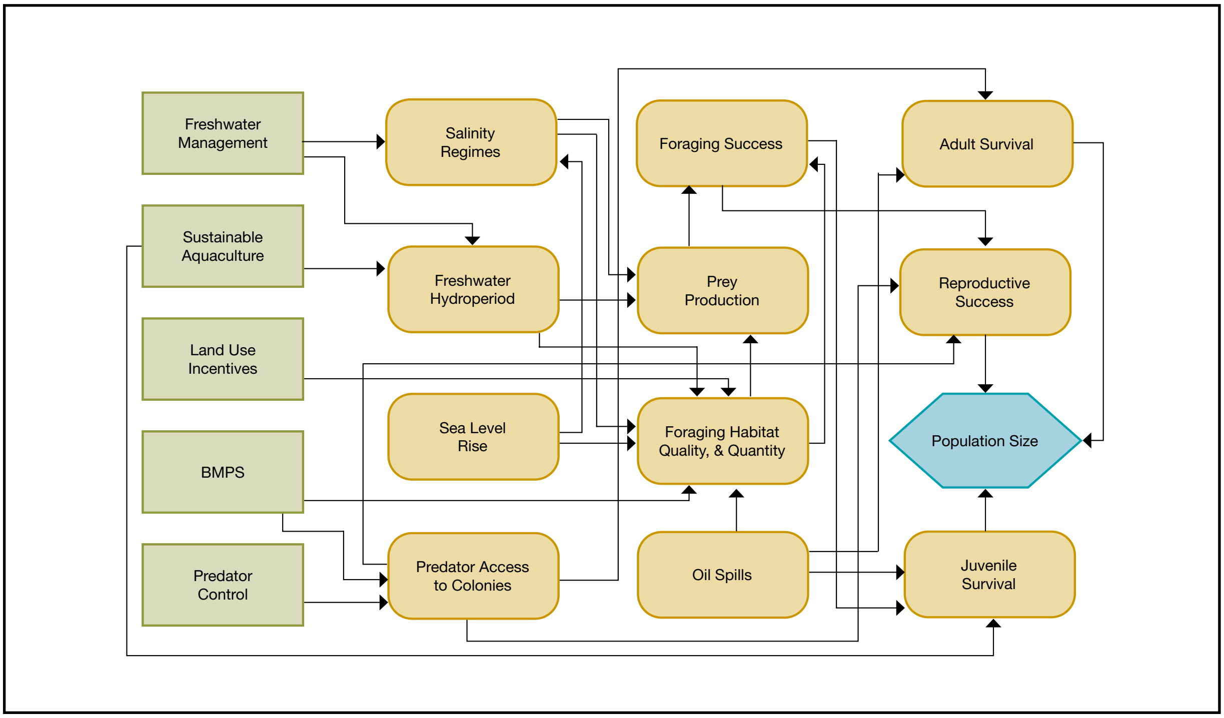
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Mississippi Sandhill Crane*** *(Antigone canadensis pulla) within the Gulf of Mexico Region.*



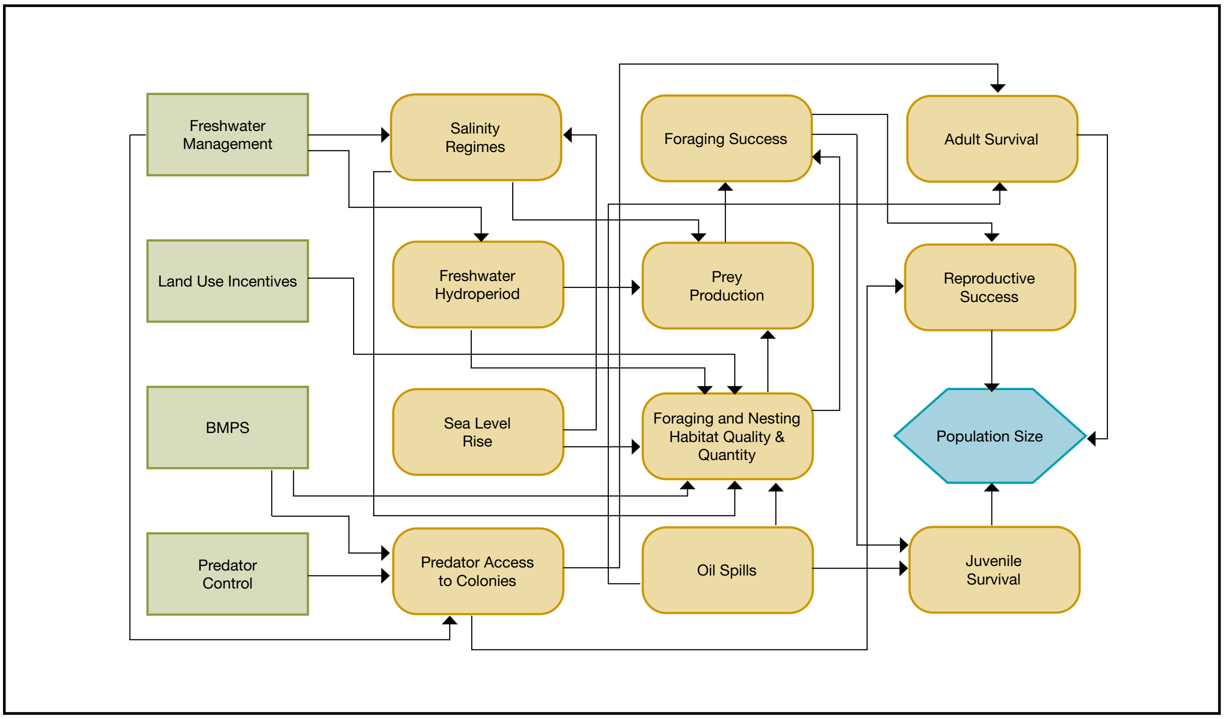
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Whooping Crane*** *(Grus americana) within the Gulf of Mexico Region.*



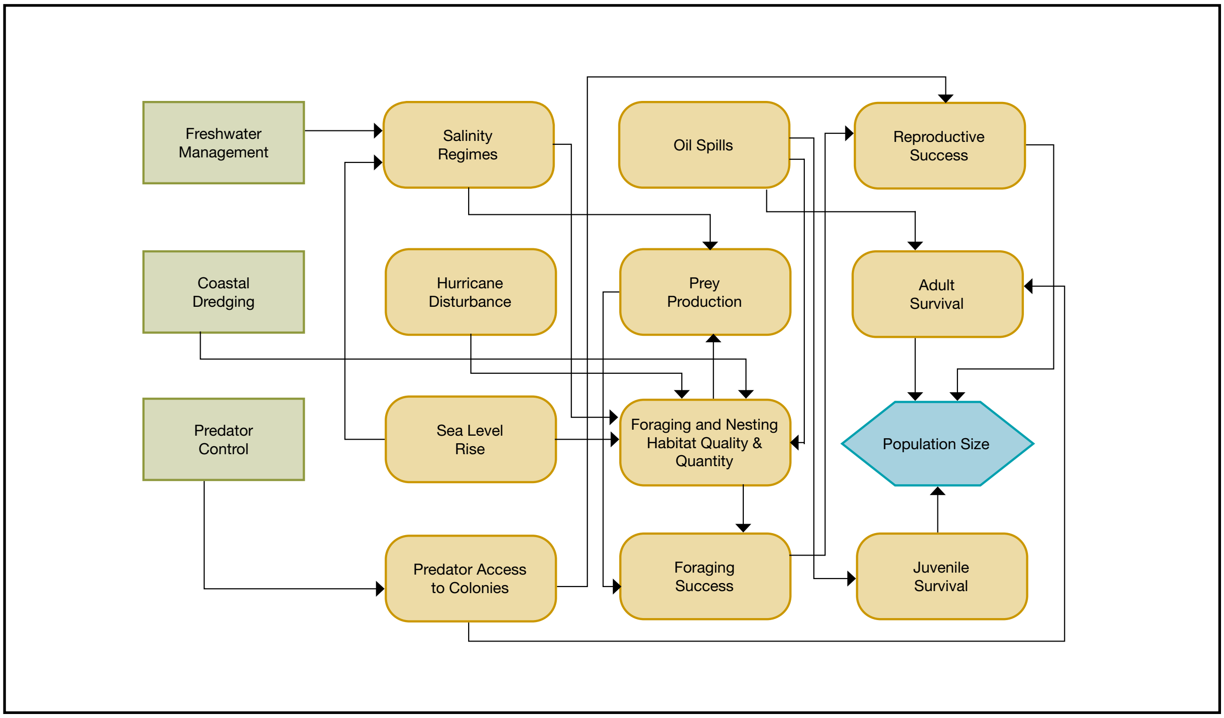
Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the ***Wood Stork*** *(Mycteria americana) within the Gulf of Mexico Region.*



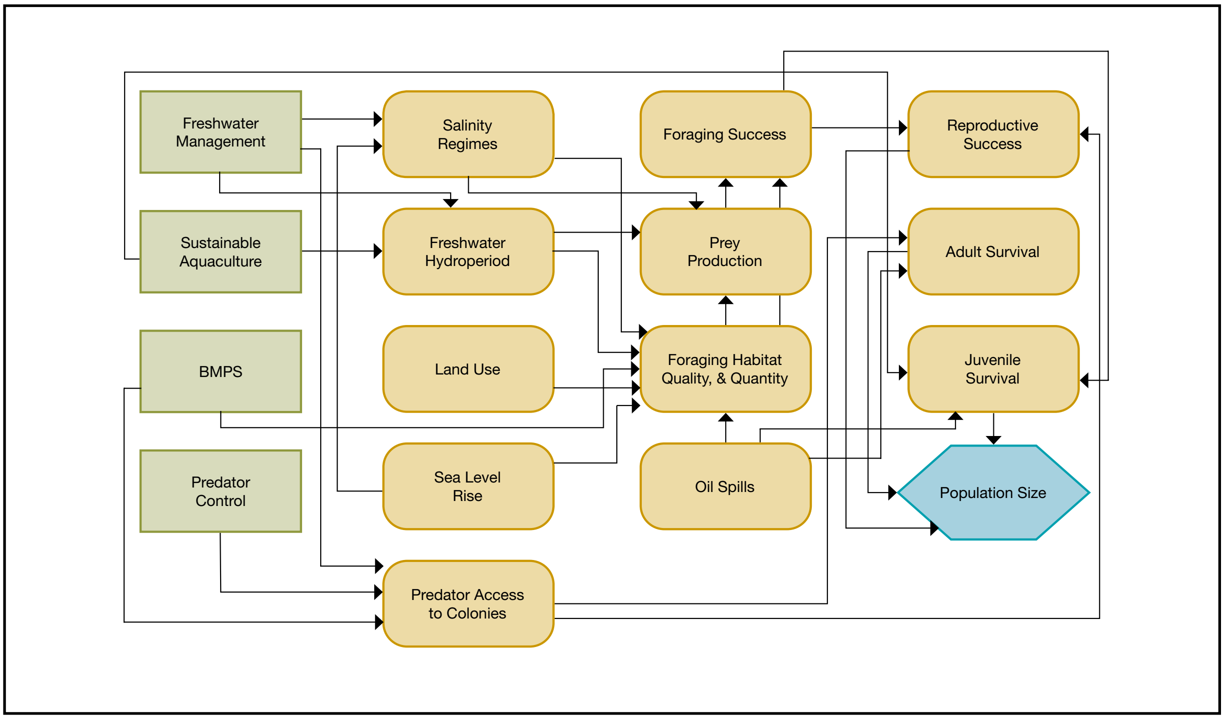
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Little Blue Heron** (Egretta caerulea) within the Gulf of Mexico Region.*



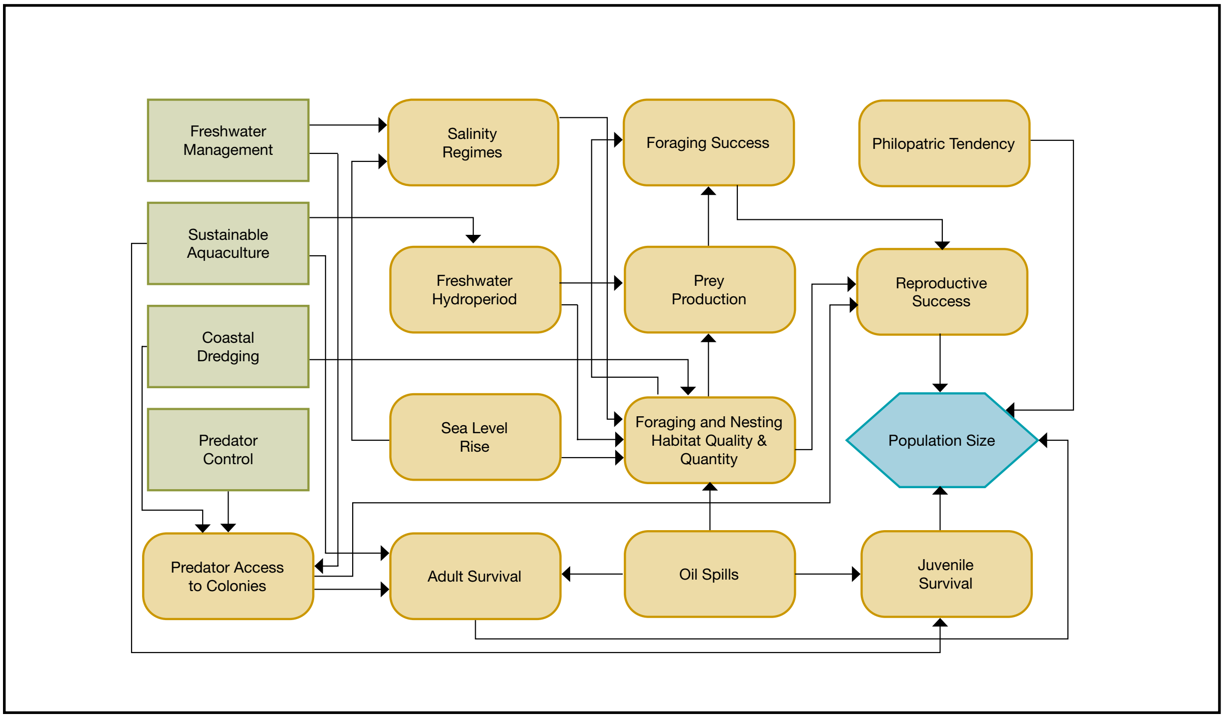
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold-boxes) and population size (blue hexagon) for the **Tricolored Heron** (Egretta tricolor) within the Gulf of Mexico Region.*



*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population size (blue hexagon) for the **Reddish Egret** (Egretta rufescens) 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 **White Ibis** (Eudocimus albus) 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 ***Roseate Spoonbill*** *(Platalea ajaja) within the Gulf of Mexico Region.*

9

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: WATERFOWL

Authors:
Stephen J. DeMaso (1)
Michael G. Brasher (2,3)
Jeffrey S. Gleason (4*)

1. U.S. Fish and Wildlife Service, Gulf Coast Joint Venture, Lafayette, LA
2. Ducks Unlimited, Inc., Gulf Coast Joint Venture, Lafayette, LA
3. Current Address: Ducks Unlimited, Inc., Memphis, TN
4. U.S. Fish and Wildlife Service, Gulf Restoration Office, Chiefland, FL

(*) Corresponding Author: **jeffrey_gleason@fws.gov**

Pair of Mottled Ducks (*Anas fulvigula*). Photo credit: Ron Bielefeld

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GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: WATERFOWL

Conditions on the breeding grounds and the demographic parameters associated with the breeding season tend to influence waterfowl populations more significantly than any other part of their lifecycle (Koons et al. 2014). However, without adequate migration and winter habitat, waterfowl may experience lower seasonal survival and return to the breeding grounds in poorer body condition (Ankney and Macinnes 1978, Krapu 1981, Kaminski and Gluesing 1987, Johnson et al. 1992, Dubovsky and Kaminski 1994, Heitmeyer 1995, Newton 2006, Moon et al. 2007, DeVries et al. 2008, Guillemain et al. 2008, Anteau and Afton 2009, Sedinger and Alisauskas 2014). Poor body condition can result in reduced reproductive success, thus, lowering recruitment into the following year's breeding population. Therefore, wintering habitat quantity and quality along the Gulf Coast is critical to many waterfowl species (NAWMP 1986, DU 1997). For example, Blue-winged Teal (*Spatula discors*)spend ≤5 months on the breeding grounds, spending the remainder of the year in migration and on the wintering grounds (Rohwer et al. 2002). Given the downward trajectory of quantity and quality of most migration and wintering habitats for waterfowl, it is also important to ensure that additional significant population bottlenecks do not occur within the northern Gulf of Mexico geography (Figure 1.2).

Waterfowl hunters have an important economic impact on local, state, and national economies (USFWS 2015). Waterfowl hunters spend money on a variety of goods and services for trip-related and equipment-related purchases. Trip-related expenditures include food, lodging, transportation, and other incidentals. Equipment expenditures consist of guns, decoys, calls, hunting dogs and food, camping equipment, specialized hunting clothing (e.g., camouflage chest waders), boat-motor-trailer, and other input costs. These impacts send ripple effects throughout the economy with these direct expenditures only part of the economic impact of waterfowl hunting. Trip-related and equipment-related expenditures associated with waterfowl hunting generated over $3.0 billion in total economic output in 2011. This impact was dispersed across local, state, and national economies (USFWS 2015). Waterfowl hunters also directly pay for conservation efforts at the national and state levels through the Pittman-Robertson Act, and through the purchase of both federal and state duck stamps.

The Gulf of Mexico coastal region is an important area for many wintering waterfowl species (NAWMP 1986, DU 1997, Bellrose 1980, Baldassarre 2014). Three species of waterfowl [Mottled Duck (*Anas fulvigula*), Northern Pintail (*Anas acuta*), and Lesser Scaup (*Aythya affinis*)] met the criteria to be considered species of conservation concern by GoMAMN (Appendix 1). Moreover, the GoMAMN Waterfowl Working Group strongly believes that Redhead (*Aythya americana*), Blue-winged Teal, and Gadwall (*Mareca strepera*) also warranted inclusion herein as additional targets for monitoring (Table 9.1).

Mottled Ducks spend their entire life cycle in coastal marshes and inland landscapes along the Gulf of Mexico (Stutzenbaker 1988). The remaining waterfowl species migrate through and/or overwinter in coastal habitats of the Gulf of Mexico in continentally-significant numbers (Bellrose 1980, NAWMP 1986, Baldassarre 2014).

DESCRIPTION OF WATERFOWL SPECIES AND THEIR HABITATS IN THE GULF OF MEXICO REGION

MOTTLED DUCK (*Anas fulvigula*). Mottled Ducks are non-migratory, and must satisfy all of their annual resource needs from habitats existing within a relatively small geographic area (Stutzenbaker 1988, Wilson 2007, Bielefeld et al. 2010, Haukos 2012). There are two distinct populations of Mottled Ducks—a Florida population and a Western Gulf Coast population, which are separated both genetically and geographically (McCracken et al. 2001, Bielefeld et al. 2010). The native Mottled Duck range includes peninsular Florida and coastal marshes along the Gulf of Mexico from Alabama west and south to Tampico, Mexico. This is a dabbling duck species that prefers fresh to brackish wetlands including marshes, natural and human-made ponds, ditches, and impoundments in both rural and suburban areas in Florida, and coastal marshes and inland freshwater wetlands along the western Gulf Coast. Although often the least gregarious of North American dabbling ducks, large concentrations may be found in fallow-flooded agricultural

Table 9.1. *Waterfowl species to be considered for monitoring programs at multiple geographic scales across the northern Gulf of Mexico. Table includes residency status, landcover association, and the North American continental trend and conservation concern scores (Partners in Flight 2017).*

Common Name	Latin Name	Breeding	Wintering	Migratory	Landcover Association(s)[a]	Trend Score	Continental Concern Score
Blue-winged Teal[b]	*Spatula discors*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	1	7
Gadwall[b]	*Mareca strepera*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland	1	8
Mottled Duck	*Anas fulvigula*	X	X		Palustrine Emergent Wetland, Estuarine Emergent Wetland (brackish to saltwater marshes), Cultivated Crops, Grassland	5	17
Northern Pintail	*Anas acuta*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Cultivated Crops	4	12
Redhead[b]	*Aythya americana*		X	X	Estuarine Emergent Wetland, Estuarine-Coastal, Estuarine-Open Water, Marine-Nearshore	1	8
Lesser Scaup	*Aythya affinis*		X	X	Palustrine Emergent Wetland, Estuarine Emergent Wetland, Estuarine-Coastal, Estuarine-Tidal Riverine Open Water, Estuarine-Open Water, Marine-Nearshore	4	11

[a]See Chapter 1 and Appendix 2 for full description of landcover associations.
[b]This species is not included in the GoMAMN Birds of Conservation Concern list (Appendix 1), but is considered an important monitoring target by the Waterfowl Working Group, as well as its socio-political importance (hunted species) and its ecological importance and/or potential for use as an indicator species (Caro 2010).

fields and storm- and wastewater treatment impoundments during the wing molt in Florida and in harvested rice (*Oryza sativa*) fields after breeding along the western Gulf Coast (Bielefeld et al. 2010).

Mottled Ducks are seasonally monogamous. Compared to other species of ducks, pair formation occurs early, with nearly 80% of all individuals paired by November. Breeding starts in January, continuing into July and usually peaking in March–May. Females build nests on the ground or suspended immediately above it in dense stands of grass or other vegetation. Most pair bonds probably terminate during incubation, but some may persist through brood-rearing; only females incubate eggs (Bielefeld et al. 2010).

Wetland drainage in Florida, degradation of coastal marshes by saltwater intrusion and erosion in Louisiana and Texas, and urban development throughout the range pose serious conservation challenges for managers of this species (Figure 9.1). It should be made clear here, that though there are range-wide conservation issues for this species like habitat loss, the primary threats and thus, management actions in response to those threats for the Florida and Western Gulf Coast populations may be vastly different. For example, in Florida, introgressive hybridization with feral Mallards (*Anas platyrhynchos*; domesticated strains released into the wild) is possibly the single greatest threat to the future of the Mottled Duck as a unique species (Williams et al. 2005, Bielefeld et al. 2010). Certainly, hybridization with Mallards is a concern for the Western Gulf Coast population, but probably lesser so than for the Florida population (Ford et al. 2017). For the Western Gulf Coast population, the highest priority conservation actions revolve around increasing both nest success and brood survival (Wilson 2007, see also Rigby and Haukos 2014), and better targeting limited conservation dollars on the landscape to the highest priority habitats (Krainyk and Ballard 2014).

Though we consider both populations in this document, much of the information specific to Mottled Ducks is based largely, but not solely on the Western Gulf Coast population. Partly this is a function of the relatively larger portion of the GoMAMN geography (Figure 1.2) covered by this population. Additionally, it is related to the composition of the GoMAMN Community of Practice (CoP) and the Waterfowl Working Group, as well as the conservation impetus for this population in the Gulf Coast Joint Venture. Finally, it is a simple function of the large volume of scientific literature for this particular population of Mottled Duck.

LESSER SCAUP (*Aythya affinis*). This medium-sized black and white diving duck is one of the most abundant and widespread of North American diving ducks. This late fall migrant is one of the last waterfowl to leave an area at freeze-up. Throughout fall and winter, Lesser Scaup form large flocks on rivers, lakes, and large wetlands. Individuals also winter in estuaries and marine habitats of the Gulf of Mexico with areas like Lakes Borgne, Maurepas, and Ponchartrain in Louisiana holding fairly large numbers of scaup in some years (Kinney 2004, Louisiana Department of Wildlife and Fisheries unpublished data). Large rafts of this species have been observed wintering offshore in the Gulf of Mexico during some winters (Anteau et al. 2014, GoMMAPPS unpublished data).

Lesser Scaup are among the latest of migrant waterfowl to move north in spring; small migrant flocks often are still moving through southern portions of the Prairie Pothole Region in mid-May (Naugle et al. 2000). Ducklings hatch synchronously, spending less than one day in the nest before they follow the female to water, and they fledge by late August or September. Adults and ducklings are mainly carnivorous, consuming aquatic invertebrates (mainly crustaceans, insects, and mollusks) during the breeding season and throughout the annual cycle (Anteau et al. 2014).

Our knowledge of population size and trends is confounded by 1) unknown biases in the waterfowl breeding population survey because timing of the survey does not always match that of Lesser Scaup migration and breeding (Naugle et al. 2000, Schummer et al. 2018), and 2) the inability to separate Greater (*Aythya marila*) and Lesser Scaup in survey data (Afton and Anderson 2001), although Lesser Scaup are estimated to make up 80% of the "scaup" counted during the May waterfowl breeding population surveys (USFWS 2017). Though the potential reasons for long-term population

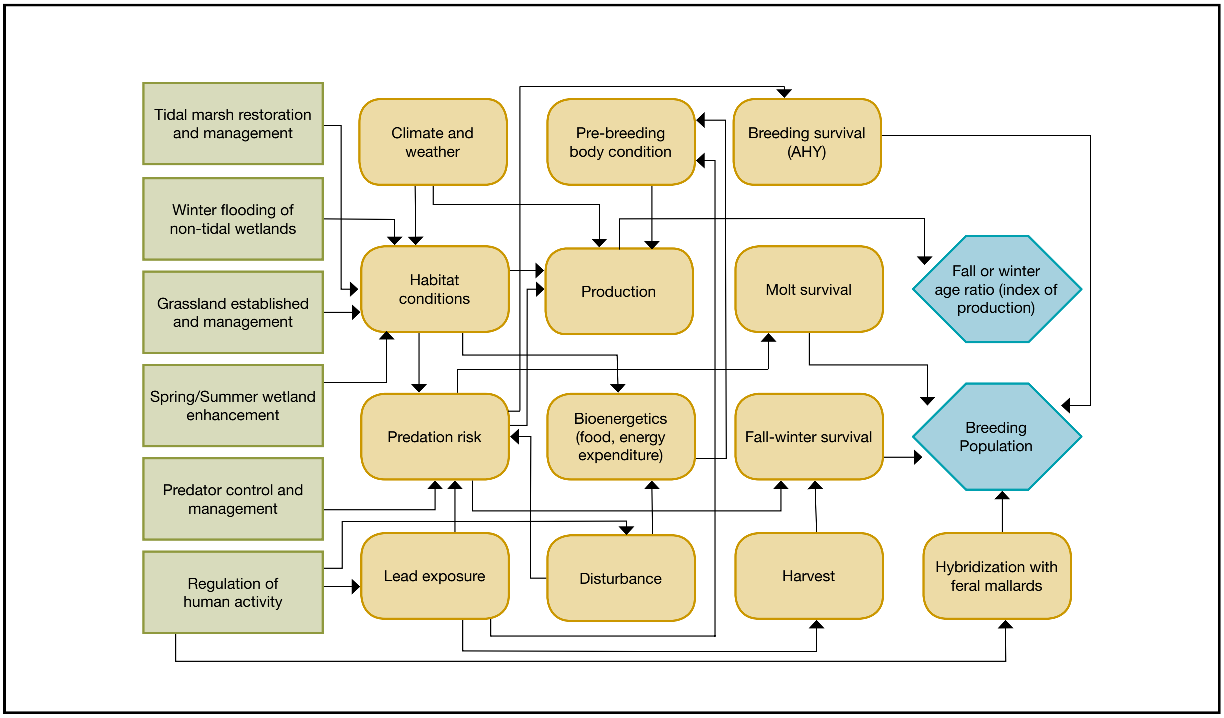

Figure 9.1. *Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the* ***Mottled Duck*** *(Anas fulvigula) within the Gulf of Mexico Region.*

Lesser Scaup (*Aythya affinis*). Photo credit: Ron Bielefeld

declines of Lesser Scaup are varied and uncertain (Austin et al. 2000), scaup numbers have declined significantly (but see Afton and Anderson 2001, Schummer et al. 2018) from 6–8 million in the early 1970s and has been around 3–5 million beginning in the mid-1980s and continuing today (USFWS 2017). It appears the scaup population has stabilized, but remains below the long-term average of 5 million in most years. Like for the Northern Pintail, the USFWS implemented an Adaptive Harvest Management (AHM) framework to inform scaup harvest regulations (Boomer and Johnson 2007, USFWS 2018). Ongoing conservation measures coupled with prudent harvest management (USFWS 2018, see also Koons et al. 2006), suggest that Lesser Scaup and scaup, in general, should have a secure future in North America (Anteau et al. 2014).

NORTHERN PINTAIL (*Anas acuta*). This medium-sized dabbling duck is circumpolar in distribution and abundant in North America, with core nesting habitat in Alaska and the Prairie Pothole Region of southern Canada and the northern Great Plains. An early fall migrant, the species arrives on Gulf Coast wintering areas beginning in October, after wing molt, often forming large roosting and feeding flocks on open, shallow wetlands and flooded agricultural fields (Clark et al. 2014).

Northern Pintails are among the earliest nesting ducks in North America, beginning shortly after ice-out in many northern areas. Annual nest success and productivity vary with water conditions, predation, weather, and geography. Ducklings hatch together in one day, follow the female to water after a day in the nest, and fledge by July or August (Clark et al. 2014).

On both breeding and non-breeding portions of its range, Northern Pintails typically select habitats with large expanses of low emergent cover. Winter habitats are threatened by hydrologic and water quality changes impacting seagrasses, water scarcity (directly impacting rice culture and the ability to flood fields post-harvest), and loss of habitat quantity and quality (through increased salinization) of coastal marsh. Other threats include: water shortages, conversion of rice into other agricultural commodities, drainage of wetlands and grassland for agriculture, commercial and residential development, and urbanization. Periods of extended drought in prairie nesting regions have caused dramatic population declines, usually followed by periods of recovery. Over the long term, however, the continental population of Northern Pintails has declined significantly from 6 million in the early 1970s to less than 3 million in the late 1980s and early 1990s (USFWS 2017). Since then, the population appears to have stabilized. Ongoing conservation measures, such as habitat restoration and enhancement of agricultural lands, as well as prudent harvest management (USFWS 2010), suggest that Northern Pintails should have a secure future in North America (Clark et al. 2014).

REDHEAD (*Aythya americana*). This diving duck, restricted to North America, breeds widely throughout the Prairie Pothole Region of the United States and Canada. This wide-ranging species exhibits a high degree of flexibility in habitat and food use and reproductive behavior. In contrast to its extensive breeding distribution, the Redhead in winter is concentrated mostly in coastal areas along the Gulf of Mexico, with hundreds of thousands of birds (about 80% of the continental population) traditionally found in the hypersaline lagoons of the Laguna Madre of Texas and the Laguna Madre of Tamaulipas, Mexico (Bellrose 1980, Woodin and Michot 2002, Baldassarre 2014).

The Redhead begins arriving from its northern breeding grounds to its winter range in October. The species depends heavily on rhizomes of shoal grass (*Halodule wrightii*), a seagrass species, for winter nutrition (Cornelius 1977, Michot and Nault 1993, Mitchell et al. 1994, Adair et al. 1996, Michot et al. 2008). Pairs begin to form on the winter range, and by the time the last birds have left on their northward migration in March, pair formation is well underway (Woodin and Michot 2002).

The Redhead demonstrates facultative brood parasitism to a greater extent than any other North American duck. Inter- and intraspecific egg parasitism is very common with

Flock of Redhead (*Aythya americana*) ducks.
Photo credit: Ron Bielefeld

this species; parasitic egg-laying has been known to increase nest abandonment and depress clutch size, nest success, and egg success for some host species (Sayler 1992, Woodin and Michot 2002). This species is considered primarily an over-water nester (though some upland nesting does occur) with nests commonly comprised of dominant emergent vegetation (e.g., *Typha* spp., *Scirpus* spp.) within semi-permanent and seasonal wetlands (Woodin and Michot 2002).

This species breeds primarily in the Prairie Pothole Region of the northern Great Plains and Canada, across the Intermountain West into northern California, with scattered smaller numbers breeding into Alaska (Woodin and Michot 2002, Baldassarre 2014). Like other northern breeding species of ducks herein, Redhead populations are influenced by wet-dry cycles in their northern breeding range, as well as conversion of both wetland and grassland habitats to rowcrop agriculture (Drever et al. 2007, Doherty et al. 2013, Wright and Wimberly 2013). Threats on the wintering grounds are varied and include natural and anthropogenic changes to their habitats and the seagrass beds in and around Laguna Madre and into Mexico. Wind energy development in coastal Texas is a relatively recent potential population impacting factor that is poorly understood (but see Lange 2014, Lange et al. 2018). The continental Redhead population hovered around an estimated half-million birds from 1955–early 1990s and has since increased fairly dramatically, likely partially owing to a 10-year wet-cycle on the prairies. The population has been at or exceeding the long-term average (700,000) since about 2005 (USFWS 2017). Unlike Northern Pintails and Scaup, there is no AHM harvest management process designed specifically for this species (USFWS 2018). Redhead populations appear generally resilient to past and current harvest pressures (Péron et al. 2012) and as such, this species should be secure across North America well into the future.

GADWALL (*Mareca strepera*). A medium-sized dabbling duck that breeds throughout the north-central United States and Prairie Provinces of Canada, the Gadwall winters in the southern United States and coastal Mexico, the largest concentrations occurring along the Gulf Coasts of Louisiana and Texas. During winter, individuals spend most of the day feeding on leaves and stems of aquatic vegetation in mixed flocks with other waterfowl (Paulus 1982). Gadwall will extensively use brackish marsh, where submerged aquatic vegetation is available (LeSchack et al. 1997). Gray (2010) found that female Gadwall in Southwestern Louisiana used freshwater and intermediate marsh types substantially more so than other marsh types found within the coastal marsh zone. Also, Gadwall use of freshwater marsh increased after Hurricane Ike altered the natural salinity gradient within most of the coastal marsh zone. This characteristic is rather unique among the species selected by the waterfowl working group.

Habitat degradation and drought conditions on breeding areas during the 1960s, 1970s, and early 1980s led to declines in many populations of waterfowl in the United States (Reynolds et al. 2007, Doherty et al. 2013, 2015). More recently, commodity prices and changing technology has allowed for the spread of corn (*Zea mays*) and soybeans (*Glycine max*) much further north and west, into what was considered to be traditionally wheat-country (Higgins et al. 2002). As a result, both wetland drainage and grassland conversion dramatically increased across the Prairie Pothole Region (Rashford et al. 2011, Doherty et al. 2013, Walker et al. 2013, Wright and Wimberly 2013, Johnston 2014). Gadwall population response to wet-dry cycles on the prairies was much like that of the Blue-winged Teal, in that the population began a strong increase in the early- to mid-1990s as a function of a lengthy wet-cycle. The population estimate has been well above the long-term average (2.0 million birds) since 1995 (USFWS 2017) owing to improved wetland conditions (LeSchack et al. 1997).

BLUE-WINGED TEAL (*Spatula discors*). One of the most common breeding ducks in the north-central United States and prairie Canada, Blue-winged Teal are early migrants for wintering habitats largely south of the United States. Adult males begin southern migration well in advance of migrating females and juveniles, and are often abundant in Gulf Coast marshes by mid-August (Bellrose 1980, Rohwer et al. 2002, Baldassarre 2014).

Blue-winged Teal limit foraging to aquatic areas where the majority of their diet is plant matter, particularly seeds. On migration and wintering areas, they use a variety of shallow open water wetland habitats, such as flooded agricultural lands, palustrine wetlands, and fresh to intermediate coastal marsh. During the period just before and during egg-laying, adult females consume large amounts of aquatic invertebrates, mainly insect larva and snails, to meet the heightened protein requirements for egg production (Alisauskas and Ankney 1992). Like many other waterfowl, females store fat prior to nesting and then use this energy to form eggs and help meet the demands of incubation (Alisauskas and Ankney 1992, Rohwer et al. 2002).

The population status of the Blue-winged Teal mirrors wetland conditions on the prairie breeding grounds. Populations dropped to a 40-year low in 1990 after several dry years, but in the decade following numbers more than doubled (USFWS 2017). Blue-winged Teal population estimates was at or below the long-term average of 5.1 million birds from 1955–mid-1990s, and since then, the populations has responded to a lengthy wet period on the prairies with recent population estimates of 6.4–6.7 million birds (USFWS 2017). This positive response suggests that long-term wetland degradation on the prairies had not irreversibly damaged teal breeding habitat. However, the combination of wetland drainage and conversion of grasslands for row crop agriculture remain the biggest threat to waterfowl breeding habitat (Reynolds et al. 2007, Stephens et al. 2008, Wright and Wimberly 2013, Johnston 2017). Like other prairie-nesting ducks, the local productivity of a population is strongly influenced by nest success and brood survival (Rohwer et al. 2002).

Breeding Season

Mottled Ducks are the only dabbling duck to breed in significant numbers across the Gulf of Mexico (Baker 1983, Stutzenbaker 1988). Breeding and nesting season begins in January and generally peaks in March and April, when females are typically well into incubation (Rigby 2008, Bielefeld et al. 2010). Mottled ducks typically nest in coastal marsh and adjacent grasslands (Grand 1988, Stutzenbaker 1988, Rigby 2008, Haukos et al. 2010), where nests are built in large grass expanses that are adjacent to permanently flooded marsh, impoundments, or other areas with wetland habitat is available during spring/summer (Stutzenbaker 1988). Nests are built on the ground within mixture(s) of live and dehiscent portions of species such as marsh-hay cordgrass (*Spartina patens*), Gulf cordgrass (*S. spartinae*), and saltgrass (*Distichlis spicata*) (Baker 1983, Rorabaugh and Zwank 1983, Grand 1988, Stutzenbaker 1988, Rigby 2008). Nest success of dabbling ducks is usually higher (i.e., lower predator efficiency) in large, unfragmented blocks of grassland habitat (e.g., Stephens et al. 2004, 2005). Moorman et al. (1991) found that Mottled Duck ducklings had higher survival and growth rates when salinity levels were <9 parts per thousand (ppt).

Spring and Autumn Migration Seasons

Among the waterfowl that utilize habitats along the Gulf Coast during the non-breeding period, Blue-winged Teal are among the most transient, as they mostly winter south of this region in Mexico, Central and South America, and the Caribbean islands. For the rest of the non-breeding waterfowl species of conservation concern (Table 9.1) the Gulf of Mexico region is generally viewed as a winter terminus (Bellrose 1980, Baldassarre 2014). The primary habitats for Blue-winged Teal during the migratory seasons are marsh (Palustrine and Estuarine Emergent Wetlands) and agricultural lands, i.e., flooded rice. Some segment of the Blue-winged Teal population embarks on a Trans-Gulf migratory route (Russell 2005, GoMMAPPS unpublished data) from staging areas along the northern Gulf Coast to their wintering destinations further south (Bellrose 1980, Baldassarre 2014); also cross the Gulf on their way back north in the spring.

Winter Season

Coastal marshes, ricelands, seagrass meadows, and non-tidal palustrine wetlands provide the most important habitat for waterfowl in the Gulf Coast region during the non-breeding period (Chabreck et al. 1989, Hobaugh et al. 1989, Stutzenbaker and Weller 1989). Other habitat types used by waterfowl in lesser numbers within this region include nearshore marine waters and coastal embayments, some of which support large concentrations of wintering scaup and smaller numbers of other diving ducks (Kinney 2004).

Among these habitat types, coastal marshes are the most expansive, totaling over 1,324,700 ha throughout the region (Enwright et al. 2015). The vast majority (82%) of coastal marsh within this region occurs in Louisiana and southeastern Texas (Enwright et al. 2015). Management of coastal marshes for wintering waterfowl revolves around hydrologic restoration and management to encourage growth of vegetation communities that provide abundant foraging resources, which typically includes actions to produce low salinity, low turbidity waters at appropriate foraging depths (Chabreck et al. 1989, Nyman and Chabreck 2012).

Ricelands are the dominant and most important waterfowl habitat type within inland regions of the western Gulf Coast (i.e., Louisiana and Texas). While essentially all waterfowl within this region exploit food resources within ricelands, this habitat type is particularly valuable for Northern Pintails and Arctic-breeding geese. Several characteristics of ricelands within the Gulf Coast region make these habitats uniquely valuable to waterfowl, most notably the frequent practice of producing two rice crops annually. The first crop is typically harvested during July–August, and harvest of a ratoon crop often follows in October–November (Hobaugh et al. 1989, Petrie et al. 2014). This results in two pulses of waste rice and natural seeds whose timing generally coincides with the arrival of early and late migrating waterfowl (Wilson and Esslinger 2002). Additionally, when not in active production, ricelands in this region may be left idle during which time they will support communities of annual grasses and sedges (Hobaugh et al. 1989). When flooded during winter, idled ricelands provide abundant seed resources that are readily used by waterfowl (Marty 2013).

Seagrass meadows occur in saline and hypersaline shallow waters along the Gulf Coast, being most prevalent in the Big Bend area of Florida, Mobile Bay in Alabama, Mississippi Sound in Alabama and Mississippi, Chandeleur Islands in Louisiana, Texas Coastal Bend and the Laguna Madre in Texas (Handley et al. 2007). Shoal grass and wigeon grass (*Ruppia maritima*) are among the most valuable seagrasses in the Gulf Coast region, being an especially important component of the diet of Redhead, Northern Pintail, and American Wigeon (*Mareca americana*) (Ballard et al. 2004, Michot et al. 2008). Lesser and Greater Scaup are also common within the Laguna Madre, although their diet in coastal waters is dominated by Atlantic surf clams (*Spisula solidissima*) (Harmon 1962). Weller (1964) recognized the importance of the Laguna Madre area for wintering Redheads, likely due primarily to the abundant shoal grass meadows and availability of other essential habitat resources.

Non-tidal, non-agricultural palustrine wetlands provide additional foraging habitat for waterfowl in this region, although their importance varies geographically. Across most of this region, these wetlands are valued for their food resources (Anderson 2008); yet in south Texas, they provide both food resources (Mitchell et al. 2014) and dietary fresh water for waterfowl that have been foraging in hypersaline waters of the Laguna Madre (Adair et al. 1996, Ballard et al. 2010). Landscape positioning of palustrine wetlands in south Texas is an important determinant of waterfowl use for dietary fresh water, as waterfowl use is higher on wetlands closer to seagrass bed foraging sites in the Laguna Madre (Adair et al. 1996).

CONSERVATION CHALLENGES AND INFORMATION NEEDS

Primary Threats and Conservation Challenges

The widespread, persistent loss of Gulf Coast wetlands is the most significant threat to priority waterfowl habitats in this region. Since 1932, more than 487,650 hectares of coastal marshes and forested wetlands have been converted to open water in Louisiana alone (Couvillion et al. 2011). Additionally, from 2004–2009, intertidal wetlands along the entire U.S. Gulf of Mexico decreased by 38,445 hectares (Dahl and Stedman 2013). The primary causes of coastal wetland loss are numerous and include relative sea-level rise, reduced riverine sediment loads, leveeing of major rivers, excavation of canals and waterways for oil and gas extraction and navigation, saltwater intrusion caused by hydrologic alteration, industrial and residential development, and increased frequency and/or intensity of hurricanes and tropical storms (Craig et al. 1979, Moulton et al. 1997, Gosselink et al. 1998, Glick et al. 2013, Handley et al. 2015). While projections of future marsh loss are not available for the entire Gulf Coast region, another 453,250 hectares of vegetated marsh in Louisiana is expected to be converted to open water by 2060 (CPRA 2012).

Rice has existed as a dominant agricultural crop in coastal Louisiana and Texas since the late 1800s (Phillips 1951, Craigmiles 1975). In the early 1980s, Gulf Coast rice production began a significant long-term decline as a result of various programmatic and economic factors. Some of the more important drivers of declines in rice acreage include the Federal Acreage Reduction Programs (Brewer 1984), rising land prices, higher land opportunity costs, and increased competition for limited water (Alston et al. 2000). Moving forward, the factor likely to have the greatest impact on future rice trends is the availability and affordability of reliable water supplies (Alston et al. 2000, Baldwin et al. 2011). Flooded rice fields (i.e., ricelands or rice prairies) are a critically important habitat type, as well as an important food resource for waterfowl wintering within the GoMAMN geography (Hobaugh et al. 1989, Krapu and Reinecke 1992, Baldassarre and Bolen 1994).

Seagrass coverage and distribution have varied across the region since the mid-20th century with most sites experiencing declines (Handley et al. 2007). Natural processes along with human activities have contributed to these changes through impacts on water clarity, salinity, sediment deposition, and physical disturbance (Onuf 1996, Handley et al. 2007). Primary causes of seagrass change are maintenance dredging, which buries seagrasses and elevates turbidity, nutrient and contaminant burdens from agricultural and industrial land uses, stormwater run-off, altered hydrology, as well as physical damage from propeller scarring (Handley et al. 2007, Martin et al. 2008).

Shifts in seagrass species composition in the northern Gulf of Mexico are also a concern, chiefly because of their implications to these plants as important waterfowl food resources. Notable shifts [i.e., replacement of shoal grass by manatee grass (*Syringodium filiforme*) and turtle grass (*Thalassia testudinum*)] have been documented in the Laguna Madre of Texas, caused primarily by salinity moderation following construction of the Gulf Intracoastal Waterway and ship passes through Padre Island (Quammen and Onuf 1993). Because shoal grass is the dominant food source for wintering

Redheads and Northern Pintails in south Texas (Ballard et al. 2004), continued declines in shoal grass availability are likely to reduce the capacity of the region to support wintering waterfowl populations.

Wind energy development is another emerging concern for wintering waterfowl populations and their habitats in south Texas (Kuvlesky et al. 2007). Beginning in 2008, several large wind farms were constructed adjacent to the Laguna Madre, encompassing lands that contain >10% of the non-tidal freshwater ponds upon which Redheads depend for dietary fresh water (Lange 2014). A recent study revealed evidence for strong negative impacts of these developments on Redhead behaviors and habitat use (Lange et al. 2018). Redhead use of freshwater ponds within the wind farms decreased 78% between pre- and post-construction periods, despite the total number of wintering Redheads in the region increasing by 228% between these same time periods (Lange et al. 2018). Effects of wind energy development apparently extended to Redhead habitats as well, as fewer wetlands contained water during the post-construction period, after correcting for differences in environmental conditions (Lange et al. 2018). Due to the potential for expansion of wind energy development proximal to critical Redhead habitats in south Texas, wind energy development is expected to grow in south Texas, which may intensify threats to wintering Redhead populations (Lange et al. 2018). Wind energy development is not constrained to just land-based siting, as there is interest (Bureau of Ocean Energy Management and National Renewable Energy Laboratory) in developing offshore windfarms as well. The combination of both land-based and offshore windfarms in key waterfowl wintering areas of the northern Gulf of Mexico has the potential to make key foraging, roosting, loafing, and freshwater habitats functionally unavailable (e.g., Larsen and Guillemette 2007, Loesch et al. 2013).

In general, all the waterfowl species considered herein (Table 9.1) tend to occupy specific habitat types (Block and Brennan 1993) within their geographic range, principally palustrine and estuarine emergent wetlands for Lesser Scaup, Mottled Duck, Northern Pintail, Blue-winged Teal, and Gadwall, or estuarine-coastal for Lesser Scaup, Northern Pintail, and Redhead. In addition, Mottled Duck and Northern Pintail are found in shallow-flooded cultivated croplands and Lesser Scaup can be found in deep-flooded agricultural fields (i.e., crawfish ponds). Management actions which impact more habitats or a greater proportion of the Gulf of Mexico Region (Figure 1.2) and a greater number of the GoMAMN Birds of Conservation Concern (Appendix 1) are a higher priority (refer to Priority Management Actions below).

Influence diagrams represent an hypothesized cause-effect web of key factors affecting species or ecological (or management) outcomes (Marcot et al. 2006), or more simply, how we think the system behaves. Here, the Waterfowl Working Group used a series of WebEx's, Conference Calls, and emails to create draft versions of species-specific influence diagrams, and through an iterative process and series of reviews arrived at final versions of the influence diagrams (Figure 9.1, Appendix 9). The influence diagrams should be read from left to right with management activities and/or restoration projects on the left, ecological processes and/or potential population impacting factors in the center, and avian response parameters of interest on the right. Each of the waterfowl species' influence diagrams (Figure 9.1, Appendix 9) should be considered unique given species differences in migration chronology, habitat use and preferences (Kaminski et al. 1988, Baldassarre and Bolen 1994), foraging behavior and diets, morphology, etc. (Nudds 1992). However, when comparing all of the influence diagrams, that of the Mottled Duck (Figure 9.1) and Blue-winged Teal (Appendix 9) are probably the most distinctive, but for vastly different reasons. In the case of the Mottled Duck, it is the only species that carries-out its entire annual life-cycle within the GoMAMN geography (Bielefeld et al. 2010). In contrast, the Blue-winged Teal which breeds in the Prairie Pothole Region is the earliest arriving migrant in the fall (July–Sept), overwinters in areas to the south across the Gulf of Mexico, and is one of the latest waterfowl species to move through the geography during the spring migration back north to the breeding grounds (Rohwer et al. 2002). Given inherent differences across these influence diagrams, there are also clear similarities especially with regards to management actions and/or restoration projects and the avian response parameters of interest (Table 9.2). This is particularly true for the traditional migrant waterfowl species; Lesser Scaup, Northern Pintail, Redhead, and Gadwall (see Appendix 9).

Here forward within the context of priorities, we are limiting discussions to only those three waterfowl species identified as GoMAMN Birds of Conservation Concern (see Appendix 1): Mottled Duck, Lesser Scaup, and Northern Pintail. However, the other three waterfowl species (Redhead, Gadwall, and Blue-winged Teal) remain relevant to the broader discussions of monitoring and avian response metrics or parameters of interest, particularly given that status and trends (abundance or population estimates) type monitoring often includes all waterfowl species, e.g., Mid-winter Waterfowl Surveys (Dubovsky 2017, Fronczak 2017).

Additional threats and conservation challenges to birds of the Gulf of Mexico can be found in Burger (2017, 2018). Though not strictly limited to just breeding and wintering waterfowl in the Gulf of Mexico, Burger (2017, 2018) does a good job of describing the importance of this

Northern Pintail (*Anas acuta*). Photo credit: Donna Dewhurst

area to Gulf of Mexico breeding birds and North American migrant birds, discussing potential population impacting factors, providing monitoring and research needs, and describing the respective habitats in both the northern (i.e., GoMAMN geography Figure 1.2) and southern Gulf of Mexico.

IDENTIFICATION OF PRIORITIES

Monitoring

Here we briefly describe the Waterfowl Working Group's perspectives related to monitoring. Additional, more specific information will be provided later as it relates to priority management actions, status and trends assessments, and ecological processes (Tables 9.2-9.3). We recommend the reader review and consider the three roles of monitoring related to a given management action(s) within an adaptive management framework as described by Lyons et al. (2008); see also Hutto and Belote (2013) and Reynolds et al. (2016).

Generally speaking, the most rigorous and expansive waterfowl monitoring and population estimation efforts traditionally and currently occur on the breeding grounds (Cowardin and Blohm 1992, Smith 1995). Nonetheless, numerous surveys are conducted by both state (e.g., Mississippi and Louisiana; e.g., Pearse et al. 2008a) and federal agencies during the non-breeding period to index regional distribution and abundance of waterfowl (Sharp et al. 2002, Soulliere et al. 2013, Andersson et al. 2015). Despite the availability of data from these surveys, in some cases, we still lack basic information regarding the potential impacts of landscape change and habitat conditions on migrating and wintering waterfowl demography. We similarly lack a thorough understanding of how environmental and habitat conditions influence Mottled Duck vital rates throughout their annual cycle.

These data deficits directly relate to our three sub-objectives:

1. A need for status and trends data for both waterfowl populations and their habitats within the GoMAMN boundary (Figure 1.2),
2. An improved understanding of the areas required by waterfowl and specific actions to better and/or more efficiently manage those areas, and
3. A better understanding of the ecological processes affecting waterfowl within the GoMAMN boundary (Figure 1.2) and beyond (e.g., cross-seasonal effects; Sedinger and Alisauskas 2014).

The GoMAMN Waterfowl Working Group values monitoring that 1) have explicit objectives that are clearly linked to management objectives/decisions and conservation actions, 2) estimate metrics (Sauer and Knutson 2008) with a sampling design and methodology that permits unbiased and statistically rigorous results while minimizing costs (Field et al. 2005, MacKenzie and Royle 2005) and logistical issues, 3) ensures continuity despite changes in objectives, personnel, and technologies, and 4) makes monitoring results readily available and easily interpretable (and implementable) for a variety of partners and stakeholders, including decision- and policy-makers (Figure 2.2).

For example, the development and implementation of a Gulf of Mexico-wide waterfowl monitoring "program" would generate species-specific baseline population abundance estimates, which will allow for the effective evaluation of future anthropogenic (e.g., oil spills) and natural events (e.g., hurricanes). Also, understanding changes in daily lipid-reserves in migrating wild birds can be used as an indicator when evaluating habitats and species management and conservation (Anteau and Afton 2008, Anteau and Afton 2009, Anteau and Afton 2011). As such, we consider that some index [BCI = body mass (g)/wing chord (mm); Dzubin and Cooch 1992] of body condition (Ringelman and Szymczak 1985, Dooley et al. 2010; but see also Schamber et al. 2009) for wintering waterfowl may be just as or more important than estimating abundance for the target species (Table 9.1). In addition, we believe a better understanding of both seasonal (Moon and Haukos 2006, Moon et al. 2017) and/or annual (Haukos 2015) survival (apparent) estimates for all relevant sex-age classes is a particularly salient avian response metric (Lebreton et al. 1992, Sæther and Bakke 2000, Koons et al. 2014) for evaluating both management actions and ecological processes. Furthermore, we believe if these waterfowl data streams were collected repeatedly over a long period of time across multiple sites (i.e., Gulf-wide) it would allow us to not only evaluate population (and habitat) trends, but also to evaluate species-level responses to management actions and/or restoration efforts, i.e., monitoring roles 2 and 3 in Lyons et al. (2008). That is to say, we will have collected data on important individual-level demographic parameters at a temporal and spatial scale that matters (Robinson et al. 2014), thus, increasing our strength of interference. Together, these data would allow us to develop and further refine diurnal and nocturnal waterfowl-habitat associations for species across the region, which should result in greater management efficacy at specific areas (and specific times) (Davis et al. 2018). As an example, it has been well documented that Northern Pintails have different diurnal and nocturnal habitat associations in southwestern Louisiana (Cox 1996, Cox and Afton 1997, Link et al. 2011), but such information is generally lacking for the other GoMAMN waterfowl species targets (Table 9.1). Estimating population size/abundance and associated trends, collecting body condition data, in particular, pre-departure body condition, spring departure dates by species, and deriving seasonal and/or annual survival estimates for adult females are all high priority avian metrics across species and sub-objectives (Figure 9.1, Appendix 9). Additionally for Mottled Ducks, data on the breeding population size (USFWS 2016) and fall/winter age ratios from birds harvested by waterfowl hunters (Dubovsky 2017, Fronczak 2017), as an index to annual productivity (Nichols 1991), is also relevant.

Priority Management Actions

In general, the Waterfowl Working Group has traditionally relied upon national (NAWMP 1986 and revisions), regional (Wilson 2007), and state-level (TPWD 2011) waterfowl planning efforts to inform waterfowl habitat management and conservation decisions, as well as to prioritize research and monitoring efforts (Brasher et al. 2012). In addition, here we also utilized and applied the standard lexicon of conservation actions classification developed by Salafsky et al. (2008:Table 2) to define and inform priority management actions. More broadly, the bird conservation community (i.e., GoMAMN) has outlined its values through the objectives hierarchy (Figure 2.2). Part of the objectives hierarchy refers specifically to management actions, which indicates that the broader GoMAMN Community of Practice values monitoring efforts that: 1) affect multiple GoMAMN Birds of Conservation Concern, in this case, several waterfowl species (Appendix 1), has a large footprint or large spatial scope, 2) identify the various types of uncertainty while simultaneously reducing uncertainty associated with given management action(s) (Williams 2011), 3) address management actions which are commonly/frequently used as part of Gulf of Mexico restoration activities, and 4) address explicit objectives and/or questions about management action(s) all within an adaptive management framework (Williams et al. 2009).

The Waterfowl Working Group, used Lyons et al. (2008), Salafsky et al. (2008), and Williams (2011) as anchoring points for prioritizing management actions. We evaluated and selected from a suite of potential management actions that were believed to have the highest probability of affecting a large number of priority waterfowl species. The management actions that were selected included: habitat and natural process restoration (e.g., Deepwater Horizon Project Tracker, http://dwhprojecttracker.org), and site/area management efforts to reduce and/or mitigate disturbance to waterfowl (maximizing energy intake while minimizing energy expenditure) (Table 9.2). Of these, the most consistent and potentially influential management action appeared to be habitat and natural process restoration in estuarine and palustrine emergent wetland systems, aquatic bed, grasslands, and open water (Appendix 9). Habitat and natural process restoration appears in all influence diagrams and is related to the greatest number of ecosystem processes in those diagrams of any management activity. Some management actions are not likely to have a major influence on waterfowl. For example, though harvest management is broadly applied across a variety of habitats and has potential to influence myriad waterfowl species across North America, harvest-related effects are generally thought to be relatively minor at the population-level, at least for most duck species (Sedinger and Herzog 2012, Cooch et al. 2014). Alternatively, wastewater management is not practiced widely across the GoMAMN geography, i.e., relatively small spatial scale, but could potentially affect (positively or negatively) wintering waterfowl if the management action happened to overlap spatially and temporally with a high concentration of wintering waterfowl area. Both the frequency of management actions and the amount of habitat affected by these individual categories of management actions vary widely across the Gulf of Mexico (see Deepwater Horizon Project Tracker). When we further evaluated the various management actions using a matrix of the Effect Size (ES) x Uncertainty Score (US) whereby only species and management actions that had values <3 were considered important, only management actions associated with the Mottled Duck are considered high priority. Sustainable energy development for wintering Redheads had an ES x US = 2, due to the potential for direct (i.e., reduced overwinter survival) and indirect effects (i.e., reduced body condition) of wind energy development, primarily in the Laguna Madre area of Texas. However, the Redhead is not identified on the GoMAMN Birds of Conservation Concern (Appendix 1) and is therefore, not discussed further. The Mottled Duck is discussed further here, because as previously indicated, it is unique in that its full-annual-cycle occurs in the GoMAMN geography (Figure 1.2). Interestingly, none of the ES x US values were <3 during the winter period, whereas all but one of the ES x US values were <3 during the breeding period (Table 9.2). The Waterfowl Working Group clearly believed that potential population bottlenecks for this species were limited to the breeding season (Figure 9.1). As such, both wetland and grassland habitat needs for this species require on-the-ground management actions within the GoMAMN geography (e.g., Wilson 2007). Mottled ducks typically nest in coastal marsh and adjacent prairie habitats (Grand 1988, Stutzenbaker 1988, Rigby 2008, Haukos et al. 2010), where nests are built in large grass expanses that are adjacent to permanently flooded marsh or impoundments (Stutzenbaker 1988). Therefore, management of grass for nesting habitat and palustrine emergent marsh and sustainable agriculture (i.e., rice) provide brood-rearing habitat and foraging areas throughout the year (Krainyk and Ballard 2015). This requires a diversity of management actions depending on the habitat and other limiting factors related to the management action like cost constraints and/or funding availability, timing, and ability to actually implement a given management action. Freshwater emergent wetland systems that include rice fields and wetlands devoted to crawfish aquaculture and activities related to sustainable agriculture are also important for this species.

Because little research has been conducted to directly evaluate efficacy of management actions for waterfowl in the Gulf of Mexico Region, significant reduction in uncertainty of the effects of management on priority species would likely occur for any management action(s) if properly monitored. Further, these activities could be assessed in an adaptive management framework (Williams et al. 2009), although for many actions the recurring decision would be made at different locations (e.g., marsh restoration sites), rather than in the same location at different times (e.g., flooding of agricultural fields). All waterfowl monitoring projects addressing management actions and their effects on waterfowl also need to consider the timing of those actions (Table 9.2), since region-specific timing of migration for most waterfowl species is pretty poorly documented, and migration chronology is changing rapidly (Notaro et al. 2016). Management actions may have differential effects on target waterfowl species and their respective populations within and across seasons (Sedinger and Alisauskas 2014). Also, the same management action may also have different effects on a target waterfowl species or waterfowl community depending on what season the specific management action(s) is performed (e.g., burning grasslands for Mottled Duck nesting). Finally, we should expect or anticipate potential for delayed response in a given waterfowl species to a given management action, but the response will likely depend on a myriad of factors including, but not limited to the type of management action, and the scope and scale of the action (NASEM 2017).

Although, some waterfowl data needs and specific avian metrics were mentioned previously, here we provide several specific examples for Mottled Ducks during the breeding season related to a given management action, all of which had ES x US values <3 (Table 9.2). For brevity, not all Mottled Duck management action examples with values <3 are included here.

The first management action example relates to the loss of grassland nesting habitat (through various causes) which reduces the availability (i.e., quantity) of suitable nest sites in proximity to low salinity wetlands leading to poor productivity via both reduced breeding propensity and lower nest success (Table 9.2, Figure 9.1). Per Salafsky et al. (2008:Table 2) the two management actions that most directly relate to this: land/water protection and land/water management. This management priority could potentially be addressed through policy changes and/or additional targeted funding for conservation programs like wetland and grassland easements (i.e., perpetual or term-limited; protect remaining grassland parcels) and wetland and grassland restorations, as well as conservation delivery via working with private landowners to provide technical assistance (i.e., to better manage existing lands). One could use the Mottled Duck Decision Support Tool (DST) to target specific management actions to specific tracts of land identified as "highest priority" (Krainyk and Ballard 2015). Avian metrics of interest related to this priority management action would be estimating breeding propensity, deriving daily survival rates of marked nests, and estimating hen breeding season survival (Table 9.2). Initially, these data would most likely address monitoring role number 1, as identified by Lyons et al. (2008). However, if this were done within a broader experimental design at a relatively large spatial scale (at a minimum with multiple experimental and control sites across Louisiana and Texas) with recurring decision-points, it could potentially address all three roles of monitoring.

The second management action example is only slightly different from the first (Table 9.2). It relates to the fragmentation of nesting habitat (through various causes) which enables greater search efficiency by predators thereby reducing nest success and breeding season survival of hens, not only leading to lower productivity in year t, but also lost reproductive potential in years $t + 1$, $t + 2$, etc., due to the mortality of some proportion of breeding-age hens (see Sargeant and Raveling 1992). The management action(s) most directly related to this is: species management and land/water management. Building off the first example, one could potentially use the

Mottled Duck DST (Krainyk and Ballard 2015) to identify the "highest priority" grassland tracts and conduct mammalian predator removal at some sites (i.e., experimental) in combination with non-removal sites (i.e., controls) with predator surveys at all sites (see Sargeant et al. 1993); within a well thought-out experimental design at a relatively large spatial scale; sites across the Mottled Duck breeding range from Alabama to Texas. Avian metrics that would be priorities are estimating daily survival rates of marked nests, estimating duckling and/or brood survival, and estimating hen breeding season survival. At the patch-scale, important parameters to describe sites would determine the quantity and configuration (e.g., patch size, perimeter:area ratio, distance to brood wetland) of grassland tracts. At the nest-scale, measurements like visual obstruction readings (Robel et al. 1970), i.e., height/density of vegetation, would be collected at all marked nests (see Durham and Afton 2003). These data would most likely address monitoring role number 1 as identified by Lyons et al. (2008). Ultimately, the data collected would address monitoring role number 2 (Lyons et al. 2008) with the appropriate design, scale, and replication (Eberhardt and Thomas 1991, Johnson 2002a, 2002b).

The third management action example for the Mottled Duck during the breeding season is much different than the previous two (Table 9.2). Low water availability for wetland management reduces the availability of preferred low salinity wetlands at various times during the annual lifecycle of the Mottled Duck which may negatively affect: 1) breeding propensity, re-nesting effort, and brood survival, 2) breeding season hen survival, and 3) survival of flightless adults and immatures during the molt period (e.g., Moon et al. 2017); through reduced food availability and/or food quality, increased physiological stress due to higher salinities (Moorman et al. 1991), and potentially increased predation risk. The two management actions that most directly relate to this: land/water protection and land/water management. This management priority could potentially be addressed through policy changes and/or additional targeted funding for conservation programs like wetland easements (i.e., perpetual or term-limited; protect remaining land parcels that are known brood and molting marshes) along with wetland restorations (and associated habitat management), as well as partnering with Ducks Unlimited to deliver beneficial conservation outcomes on private lands (i.e., technical assistance with water management and manipulation). Much like the previous examples, the where on the landscape question could be informed using the Mottled Duck DST (Krainyk and Ballard 2015). Clearly, it is not only about getting the where on the landscape right, but also about putting water on the landscape at the right time and in the right volume/amount. Priority avian metrics to evaluate management effectiveness for this example have been identified above. Monitoring roles number one and two (Lyons et al. 2008) would be addressed given the appropriate study design (experimental and reference sites), spatial and temporal resolution, and replication (Anderson 2001).

Though hybridization with Mallards is a concern for the Western Gulf Coast population of Mottled Ducks (Figure 9.1) and it received an ES x US score of 3 (Table 9.2) and is not considered further here. Hybridization is almost certainly a serious threat for the Florida population of Mottled Ducks (Bielefeld et al. 2010), but does not appear to require management intervention, at least not at this time, for the Western Gulf Coast population (see Ford et al. 2017).

Priority Status and Trends Assessments

GoMAMN and the Waterfowl Working Group both value monitoring efforts that address the question of how are avian populations and their respective habitats faring given current (and future) conditions within the GoMAMN geography (Figure 2.1). To better understand future, desired conditions and response to either or both management actions and restoration activities within the geography, we must first establish current population (i.e., how many of a given species within a defined time and space) and habitat (i.e., how many acres of a given habitat class/type within a defined time and space) baselines (NASEM 2017, Brasher et al. 2018). Point estimates for both population(s) and habitat(s) should provide a reasonable measure of their respective status or condition (e.g., May Waterfowl Breeding Population and Habitat Survey, also referred to as Waterfowl Population Status Report; USFWS 2017). Given a sufficient period of time over which the estimates are collected and assuming a given level of precision or confidence in the point estimates, one can then start to evaluate species (and habitat) trends through time (e.g., Breeding Bird Survey; Sauer et al. 2013).

The bird conservation community (i.e., GoMAMN) has outlined its values through the objectives hierarchy (Figure 2.2) and part of the objectives hierarchy refers specifically to status and trends assessment (Lindenmayer and Likens 2010a, 2010b; but see Nichols and Williams 2006) for both populations (Sauer and Droege 1990) and habitats. Not unlike monitoring associated with evaluating efficacy of management actions, the GoMAMN CoP values monitoring that: 1) include multiple GoMAMN Birds of Conservation Concern, in this case, several waterfowl species (Appendix 1), 2) has a large footprint or large spatial scope, 3) identify the various types of uncertainty while simultaneously reducing uncertainty associated with a given management action(s) (Williams 2011), 4) address management actions which are commonly/frequently used as part of Gulf of Mexico

Table 9.2. *Uncertainties underpinning the relationship between management decisions and waterfowl populations in the northern Gulf of Mexico.*

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck, Lesser Scaup, Northern Pintail, Gadwall, Blue-winged Teal Winter, Migration, Breeding (MODU only)	Habitat and Natural Process Restoration (Freshwater Management)	What are the consequences of low water conditions, limited wetland availability, & drought-like conditions on breeding Mottled Ducks? Cross-seasonal effects? Annual variation?	Pre-departure body condition, peak departure date(s), overwinter survival, and food resource availability (covariate)- e.g., obtain survival estimates for sample of marked birds across the geography from birds in DRY v WET years	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength & consistency of the relationship is uncertain.	High	Low
Mottled Duck, Lesser Scaup, Northern Pintail, Gadwall, Blue-winged Teal Winter, Migration, Breeding (MODU only)	Habitat and Natural Process Restoration (Freshwater Management)	What are the consequences of low water conditions, limited wetland availability, & drought-like conditions on wintering waterfowl? Cross-seasonal effects? Species-specific variation?	Pre-departure body condition, peak departure date(s), overwinter survival and food resource availability (covariate)- e.g., obtain survival estimates for sample of marked birds (LESC, NOPI, GADW, BWTE) across the geography in DRY v WET years	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength & consistency of the relationship is uncertain particularly for these spp. wintering in this geography.	High	Low
Mottled Duck, Northern Pintail, Blue-winged Teal Winter, Migration, Breeding (MODU only)	Habitat and Natural Process Restoration (Habitat Management - Agriculture)	What are the effects of declines in rice acres & production on breeding Mottled Ducks & wintering waterfowl? Do reductions in availability of this habitat result in subsequent declines in pre-departure body condition (e.g., fat reserves)?	Pre-departure body condition & peak departure date(s)- e.g., obtain body condition measurements (+ food habits/diets) for a sample of birds (MODU, NOPI, BWTE) in areas of primarily rice agr & more coastal ref sites	Reductions in acres of high energy food resources (e.g., rice) on the wintering grounds may lead to decreased body condition & later departure dates resulting in cross-seasonal effects to reproductive effort & output.	Low	High
Mottled Duck, Lesser Scaup, Northern Pintail, Gadwall, Blue-winged Teal Winter, Migration, Breeding (MODU only)	Site/Area Management (Disturbance)	Does human disturbance (hunting, ag operations, etc.) negatively affect wintering waterfowl body condition & delay spring departure date(s) due to increased movements (freq, duration, & total distance) & greater cumulative energy expenditure? Cross-seasonal effects?	Pre-departure body condition & departure dates- e.g., obtain body condition measurements throughout the Fall-Winter period (+ food habits/diet from sample collected by hunters) for sample of birds primarily using coastal estuarine habitats	Fairly certain that disturbance negatively affects energy expenditure, but uncertain about relationship between energy expenditure & body condition (i.e., how easily birds can compensate for greater energy expenditure).	High	Low

Table 9.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck, Lesser Scaup, Northern Pintail, Gadwall, Blue-winged Teal Winter, Migration, Breeding (MODU only)	Site/Area Management (Disturbance)	Does human disturbance (hunting, ag operations, etc.) negatively affect wintering waterfowl body condition & delay spring departure date(s) due to increased movements (freq, duration, & total distance) & greater cumulative energy expenditure? Cross-seasonal effects?	Pre-departure body condition & departure dates- e.g., obtain body condition measurements throughout the Fall-Winter period (+ food habits/diets from sample collected by hunters) for sample of birds using primarily inland palustrine habitats	Fairly certain that disturbance negatively affects energy expenditure, but uncertain about relationship between energy expenditure & body condition (i.e., how easily birds can compensate for greater energy expenditure).	High	Low
Lesser Scaup, Redhead Winter, Migration	Site/Area Management (Contaminants)	Does high anthropogenic nutrient inputs negatively affect wintering waterfowl food resources, i.e., seagrasses and mollusks? Are there then impacts to waterfowl via constraints on Fall-Winter energetics, pre-departure body condition, & delays in spring departure date(s)? Cross-seasonal effects?	Pre-departure body condition, departure date(s), overwinter survival & food resource availability (covariate)- e.g., obtain survival estimates from sample of marked birds (LESC, REDH) at known affluent sites & nearby ref sites. Also, tox. 'panel' of potential contaminants (e.g., Mg, Pb, Se, PCB, HCB, PAHs, etc.) from sample of collected birds	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength & consistency of the relationship is uncertain; particularly for these spp. wintering in this geography.	High	Low
Lesser Scaup, Redhead Winter, Migration	Site/Area Management (Disturbance)	Does human disturbance (hunting, comm & rec fishing, O&G operations, etc.) in marine environment negatively affect wintering waterfowl body condition & delay spring departure date(s) due to increased movements (freq, duration, & total distance) & greater cumulative energy expenditure? Cross-seasonal effects?	Pre-departure body condition, departure date(s), overwinter survival & food resource availability (covariate)- e.g., obtain overwinter survival estimates & body condition throughout the Fall-Winter period (+ food habits/diets for sample collected by hunters); primarily marine/estuarine habitats in "high" v. "low" disturbance sites	Fairly certain that disturbance negatively affects energy expenditure, but uncertain about relationship between energy expenditure & body condition (i.e., how easily can birds compensate for greater energy expenditure).	High	Low
Lesser Scaup Winter, Migration	Habitat and Natural Process Restoration (Freshwater Management)	Does altered hydrology increasing salinity thus, negatively affecting wintering waterfowl food availability & distribution, in particular bivalve/ mollusks? Do these changes influence pre-departure body condition & delayed spring departure date(s)? Cross-seasonal effects?	Pre-departure body condition, departure date(s), overwinter survival & food resource availability (covariate)- e.g., obtain overwinter survival estimates & body condition throughout the Fall-Winter period (+ food habits/diets for sample collected by hunters); primarily marine/estuarine habitat in "high" v "low" altered sites	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength and consistency of the relationship is uncertain; particularly for this species wintering in this geography.	High	Low

Table 9.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Lesser Scaup, Northern Pintail, Redhead Winter, Migration	Habitat and Natural Process Restoration (Freshwater Management)	Does altered hydrology result in increasing salinity thus, negatively affecting waterfowl food availability and/or quality, in particular bivalve/mollusk (LESC), SAV (NOPI), & seagrass (REDH)? Do these changes influence pre-departure body condition & delay spring departure date(s)? Cross-seasonal effects?	Pre-departure body condition, departure date(s), overwinter survival & food resource availability (covariate)- e.g., obtain overwinter survival estimates and body condition throughout the Fall-Winter period (+ food habits/diets for sample collected by hunters); primarily estuarine habitat in "high" v "low" altered sites	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength and consistency of the relationship is uncertain; particularly for these spp. wintering in this geography.	High	Low
Redhead Winter, Migration	Habitat and Natural Process Restoration (Freshwater Management)	Does altered hydrology result in increasing salinity thus, negatively affecting preferred seagrass species distribution & abundance? Do these changes influence pre-departure body condition & delay spring departure date(s)? Cross-seasonal effects?	Pre-departure body condition, departure date(s), overwinter survival & food resource availability (covariate)- e.g., obtain overwinter survival estimates & body condition throughout the Fall-Winter period (+ food habits/diets for sample collected by hunters); primarily marine habitat in "high" v "low" altered sites	Research shows a link between indices of food abundance & body condition & cross-seasonal reproductive success at large spatial scales, but strength & consistency of the relationship is uncertain; particularly for this species wintering in this geography.	High	Low
Redhead Winter, Migration	Site/Area Management (Energy Development)	Does the presence of wind energy development in proximity to freshwater wetlands negatively affect overwinter survival of wintering REDH? Direct mortality or indirect effects related to the presence of wind energy development?	Over-winter survival- e.g., obtain survival estimates on sample of marked birds using sites w/ wind energy development & nearby reference sites w/out wind energy development	Though recent research (Lange et al. 2018) has identified reduced use (based on counts) of wetlands in an area of wind energy development, overwinter survival in relation to the presence of wind towers is poorly understood in this geography.	High	Unknown
Redhead Winter, Migration	Site/Area Management (Energy Development)	Is body condition of wintering REDH negatively affected by wind energy development through reduced access to inshore freshwater wetlands? What is/are the mechanisms that influence body condition of REDH in the presence of wind energy development?	Pre-migration body condition- e.g., obtain body condition measurements on sample of birds using sites w/ wind energy development & nearby reference sites w/out wind energy development	Though recent research (Lange et al. 2018) has identified reduced use (based on counts) of wetlands in an area of wind energy development, overwinter & pre-migration body condition related to wind energy development is poorly understood.	High	Unknown
Mottled Duck Breeding only	Habitat and Natural Process Restoration (Freshwater Management)	Does altered hydrology result in increasing salinity thus, negatively affecting preferred food production, distribution, & availability? Do these changes negatively affect body condition & ultimately, breeding propensity, re-nesting effort, nest success, & brood survival?	Breeding propensity, re-nesting effort, estimating nest success & brood survival- 3 of the 4 require marked adult females (and ducklings); estimating nest success would also benefit from a marked sample, but is not a requirement per se	Several previous studies suggested link between habitat conditions (precip) & breeding propensity, but data are generally sparse, & no data linking weather/habitat condition impacts on re-nesting or brood survival.	High	High

Table 9.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck Breeding only	Habitat and Natural Process Restoration (Freshwater Management)	Does coastal marsh loss reduce wetland availability thus, increasing salinity levels in remaining wetlands? Does this negatively affect breeding propensity, re-nesting effort, nest success, & brood survival?	Breeding propensity, re-nesting effort, estimating nest success & brood survival- 3 of the 4 require marked adult females (and ducklings); estimating nest success would also benefit from a marked sample, but is not a requirement per se	Uncertain about effects of marsh loss & increasing salinity levels (marsh migration) on availability of nest sites, breeding propensity, nest success, & brood survival.	High	High
Mottled Duck Breeding only	Habitat and Natural Process Restoration (Freshwater Management)	Does reduced water availability constrain or limit wetland management capabilities to produce low salinity wetlands during breeding/nesting period & into brood-rearing? Does this ultimately affect breeding propensity, re-nesting effort, nest success, & brood survival?	Breeding propensity, re-nesting effort, estimating nest success & brood survival- 3 of the 4 require marked adult females (and ducklings); estimating nest success would also benefit from a marked sample, but is not a requirement per se	Several previous studies suggested link between habitat conditions (precip) & breeding propensity, but data are generally sparse, & no data linking weather/ habitat condition impacts on re-nesting or brood survival.	High	High
Mottled Duck Breeding only	Habitat and Natural Process Restoration (Freshwater Management)	Does altered hydrology result in increasing salinity thus, negatively affecting waterfowl food availability and/or quality (SAVs) for pre-breeding, breeding, brood-rearing, & molting MODU? Do these changes negatively affect breeding season survival of adult female MODU?	Survival estimation of adult female MODU during the various annual life-history periods, including molt	At least 1 study suggests breeding season survival decreases during "drought", but this contrasts with what we know about MALL in which dry or drought conditions results in reduced nesting propensity & thus, higher adult female survival.	High	Unknown
Mottled Duck Breeding ONLY	Habitat and Natural Process Restoration (Freshwater Management)	Does coastal marsh loss reduce wetland availability thus, increasing salinity levels in remaining wetlands? Does this negatively affect breeding season survival (MODU) of adult females (& their broods)?	Survival estimation for adult females during the breeding season- evaluate across the breeding range & compare period-specific survival estimates among years considered as WET v DRY w/ varying salinity levels of individual wetlands used by marked MODU	At least 1 study suggests breeding season survival decreases during "drought", but this contrasts with what we know about MALL in which dry or drought conditions results in reduced nesting propensity & thus, higher adult female survival.	High	Unknown
Mottled Duck Breeding ONLY	Habitat and Natural Process Restoration (Freshwater Management)	Does reduced water availability constrain or limit wetland management capabilities to produce low salinity wetlands during breeding/nesting period & into brood-rearing? Does this ultimately affect breeding season survival of adult females (MODU)?	Survival estimation for adult females during the breeding season- evaluate across the breeding range & compare period-specific survival estimates among years considered as WET v DRY w/ varying salinity levels of individual wetlands used by marked MODU	At least 1 study suggests breeding season survival decreases during "drought", but this contrasts with what we know about MALL in which dry or drought conditions results in reduced nesting propensity & thus, higher adult female survival.	High	Unknown

Table 9.2 (continued).

Species Season(s)	Management Category[a]	Question(s)	End-point to measure mgmt. performance	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck Breeding ONLY	Habitat and Natural Process Restoration (Habitat Management)	Does the loss of nesting habitat (via various causes) affect the availability of suitable nest sites in proximity to low salinity wetlands? Does this situation result in lower productivity due to reduced breeding propensity, lower re-nesting probability, & lower nest success?	Breeding propensity, re-nesting effort, & nest success- e.g., study design should account for spatial configuration at the landscape scale & site-scale variables; compare "high" quality wetland density (Experimental) & "low" quality wetland density (Control) sites (Krainyk and Ballard 2015)	Loss of nesting habitat is believed to have significant negative impact on productivity, but aspects of nesting habitat & particular effect sizes on productivity parameters is highly uncertain.	Low/High	High
Mottled Duck Breeding ONLY	Habitat and Natural Process Restoration (Habitat Management)	Does loss & fragmentation of grassland nesting habitat quality (e.g., overgrazing, encroachment of woody vegetation) negatively affect breeding propensity, re-nesting effort, & nest success (MODU)?	Estimate nest success in conjunction w/ breeding season survival of adult females & brood survival from marked sample- e.g., study design should account for spatial configuration at the landscape scale & site-scale variables; compare "high" v "low" quality sites (Krainyk and Ballard 2015)	Fragmentation of nesting habitat is believed to have significant impact on productivity, but aspects of nesting habitat & particular effect sizes on productivity parameters is highly uncertain.	High	Low/High
Mottled Duck Breeding ONLY	Habitat and Natural Process Restoration (Habitat Management)	Does loss & fragmentation of grassland nesting habitat quality (e.g., overgrazing, encroachment of woody vegetation) negatively affect breeding propensity, re-nesting effort, & nest success (MODU)?	Breeding propensity, re-nesting effort, & estimating nest success; consider breeding season survival of adult females & brood survival from a marked sample- e.g., study design should account for spatial configuration at the landscape & site-scale; predator v no predator removal sites	Degradation of nesting habitat believed to impact productivity through response by predators, but how particular aspects of fragmentation affect predator species composition & abundance not clear, & effect sizes are poorly understood for this species in this landscape.	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.

Abbreviations Used: MODU (Mottled Duck), LESC (Lesser Scaup), NOPI (Northern Pintail), REDH (Redhead), GADW (Gadwall), BWTE (Blue-winged Teal), MALL (Mallard) restoration activities, and 5) address explicit objectives and/or questions about management action(s) all within an adaptive management framework (Williams et al. 2009).

GoMAMN has established the following status and trends priorities for waterfowl in the Gulf of Mexico. Here, are included three waterfowl species considered as GoMAMN Birds of Conservation Concern (Appendix 1) as the highest priority, as well as three other waterfowl species considered as monitoring targets by the Waterfowl Working Group (Table 9.1). The details associated with this process are described previously in Chapter 1. We further used population trend data from the Partners in Flight (2017) Species Assessment. Waterfowl species for which the population trend is highly uncertain or highly variable received a score of 3, whereas species with a trend score <3 are of less concern, and those species with a score >3 are of higher concern (Table 9.1).

- **Priority 1** - Mottled Duck
- **Priority 2** - Lesser Scaup and Northern Pintail
- **Priority 3** - Redhead
- **Priority 4** - Gadwall and Blue-winged Teal

GoMAMN prioritized the species-habitats in the same relative "ranks" as the priority species. We believe any status and trends assessment represents a two-pronged approach where both the status and trends of priority species are monitored in conjunction with their associated habitats (see Osnas et al. 2014, Sedinger and Alisauskas 2014). Broadly speaking, when GoMAMN and the Waterfowl Working Group considered appropriate avian metrics for status and trends assessment, the typical avian parameters revolve around addressing monitoring role number one as identified by Lyons et al. (2008); system-state variables. In the case of priority waterfowl species this would include some estimate of abundance, population size, or density within a specified time and space, given some set of methodological and statistical assumptions associated with a given sampling frame. Concurrent, to the above waterfowl population estimates, ideally one would also collect habitat-related data (Osnas et al. 2014, Williams et al. 2014).

There are a number of existing avian (e.g., eBird-Walker and Taylor 2017; CBC-Dunn et al. 2005, Niven and Butcher 2011; BBS-Sauer et al. 2003, Sauer and Link 2011) and waterfowl (e.g., Midwinter Waterfowl Survey-Soulliere et al. 2013, Andersson et al. 2018; state-based winter waterfowl surveys-Pearse et al. 2008a, 2008b; IWMM-Loges et al. 2014; Mottled Duck Breeding Survey-USFWS 2016) monitoring programs that may (or may not) be appropriate within the broader GoMAMN monitoring framework to provide data on status and trends assessment for waterfowl. Each of the existing monitoring efforts has its own set of fundamental and means objectives (Lyons et al. 2008), as well as a respective set of assumptions, data limitations, biases, and caveats (e.g., Midwinter Waterfowl Survey; Andersson et al. 2015). Of the existing monitoring efforts identified above, those most likely to be of value include some version of a wintering waterfowl survey and the Mottled Duck breeding population survey. As has been documented by previous research (Eggeman and Johnson 1989, Heusmann 1999), we are not advocating here for the use of the Midwinter Waterfowl Survey per se, as the "best" existing survey platform given its obvious short-comings (Soulliere et al. 2013; but see also Johnson 2008). Though the Midwinter Waterfowl Survey is still conducted in at least some of the southern wintering waterfowl states in the GoMAMN geography (e.g., Texas), a number of states have either dropped this survey entirely (e.g., Florida), no longer conduct coastal waterfowl survey transects/segments (e.g., Alabama, Mississippi), or have created a state-based winter waterfowl survey sampling design (Pearse et al. 2008a, 2008b; e.g., Louisiana and Mississippi). Clearly there is a need for a survey platform and sampling design that provide statistically rigorous point estimates of abundance with some level of precision, a means of dealing with visibility (Pollock and Kendall 1987), observer, and detection bias while accounting for variation in effort (Pollock et al. 2002, 2006; Pearse et al. 2008b, Soulliere et al. 2013, Andersson et al. 2015, 2018), at a spatial and temporal resolution that provides data that simultaneously address GoMAMN objectives and allow assessment of waterfowl status and trends. What is less certain is that in the absence of an existing winter waterfowl survey that addresses GoMAMN objectives (Figure 2.2), is there funding available and the geo-political will to create and implement a "new" winter waterfowl survey? Any such waterfowl survey would require collaboration, cooperation, funding, and buy-in from diverse stakeholders; federal and state agencies, as well as the Flyways and Joint Ventures.

For waterfowl species that do not breed in the Gulf of Mexico and for which the proportion of the population wintering in the Gulf of Mexico is variable and unknown (e.g., Lesser Scaup, Northern Pintail, Blue-winged Teal, Gadwall, and Redhead), population-level status and trends assessment of ducks wintering in the Gulf of Mexico are simply not appropriate. However, the status and trends of just the Gulf of Mexico "wintering populations" of priority waterfowl species within the GoMAMN geography (Figure 1.2) may be appropriate and is a clear data need. Alternatively, population-level status and trends assessment for a species that carries-out its entire annual life-cycle in the Gulf of Mexico, like the Mottled Duck, seems appropriate (USFWS 2016, see also Ballard et al. 2001). The Mottled Duck Breeding Population Survey was initiated in 2010, in partnership with the Gulf Coast Joint

Venture, Louisiana Department of Wildlife and Fisheries, and the Texas Parks and Wildlife Department, appears to be a viable survey for estimating breeding population for the Western Gulf Coast population of Mottled Ducks. Currently, there are two breeding population surveys for Mottled Ducks, one for the Florida population (Bielefeld 2006) and one for the Western Gulf Coast population.

In addition to population and habitat surveys described above, the Waterfowl Working Group believes that evaluating body condition and/or lipid-reserve dynamics over the wintering period (Reinecke et al. 1988, Krapu and Reinecke 1992, Anteau and Afton 2008, Anteau and Afton 2009, Anteau and Afton 2011) for priority wintering waterfowl species is also a means of evaluating status and trends; as or more important than abundance status and trend assessments. In particular, the Waterfowl Working Group believes that data related to pre-departure body condition would be most relevant, if there were constraints on when data could be collected. This would be particularly so, if an appropriate sampling design is in place through a coordinated, integrated monitoring effort such that implementation was relatively simple, data were collected over an appropriate temporal and spatial scale, and a database provided readily available information for end-users. Body condition index data could be collected using existing waterfowl hunter check stations on National Wildlife Refuges and state Wildlife Management Areas in conjunction with site-scale research projects (e.g., Moon et al. 2007, Moon and Haukos 2009). In addition, these data could be used to evaluate a number of potential competing hypotheses, including the influence of climate-related variability on body mass, lipid reserves, and body condition (e.g., Guillemain et al. 2010).

Current waterfowl projects are collecting important data in important places and the Waterfowl Working Group recommends such site-scale, short-term research projects continue into the future. Nevertheless, GoMAMN values (Chapters 1 and 2) and desires waterfowl data collected at a larger contiguous spatial scale and a longer temporal scale to truly understand the status and trends of our priority waterfowl species (Table 9.2). In addition to limitations previously identified regarding population abundance data, additional constraints include the confounding effects of the continental population size, weather-induced migration intensity (Schummer et al. 2010, Notaro et al. 2016), and variability and changing habitat conditions (Davis et al. 2014) elsewhere within and across the relevant Flyways. New and existing monitoring efforts should also include consideration of major marsh types (Appendix 2), which in many cases may best be accomplished with stratification, e.g., for marsh birds (Johnson et al. 2009).

Priority Ecological Processes

GoMAMN and the Waterfowl Working Group both value monitoring efforts that address the question of how are the broader ecological processes affecting avian populations and their respective habitats within the GoMAMN geography (Figure 1.2)? The seasonality of ecological processes should also be considered, since a process impacting a system or species during the breeding season versus wintering season (e.g., an early vs late season hurricane) could have dramatically different effects on the system or species of interest. Uncertainty about how a process impacts a species or the waterfowl guild may also vary by season, e.g., we may have a good understanding of the impacts of sea-level rise on nesting waterfowl, but at the same time, a very poor understanding of how it might affect wintering waterfowl. To address these questions, GoMAMN and the Ecological Process Working Group therein initially utilized and applied the standard lexicon of threats classification developed by Salafsky et al. (2008:Table 1) to define and inform priority ecological processes (EPA 1999). Clearly, this was a fairly biased perspective of the realities and complexities of the Gulf of Mexico ecosystem (Chapters 1 and 2; see also Burger 2017, 2018); this approach really only considers anthropogenic impacting factors (see Johnson and St.-Laurent 2011). In addition, such an approach would have further underestimated the ecological relationships and myriad of complex interactions between management actions and/or restoration projects within the context of broader environmental variability (Benedetti-Cecchi 2003, NASEM 2017). Finally, such an explicit focus on anthropogenic threats would not allow us to learn (i.e., monitoring role 3 in Lyons et al. 2008), given uncertainty from unanticipated results (Wintle et al. 2010) that could lead us to additional testable hypotheses, provide context to avian response(s) to a given management action, or further clarify avian response(s) within the Gulf of Mexico ecosystem (Bjorndal et al. 2011). The Ecological Process Working Group used a series of WebEx's, Conference Calls, and emails through an iterative process to create draft version(s) of species-specific Taxa-based Working Groups ecological process spreadsheets. Additional details from Bennett et al. (2009:Table 1) were later incorporated into the process and final versions of spreadsheets were created by each of the seven Taxa-based Working Groups. In this case, the Waterfowl Working Group then populated columns and rows within the ecological process spreadsheet (Table 9.3), which was then used to inform final versions of the influence diagrams (Figure 9.1, Appendix 9).

More broadly, the bird conservation community (i.e., GoMAMN) has outlined its values through the objectives hierarchy (Figure 2.2). Part of the objectives hierarchy refers specifically to ecological processes and the GoMAMN CoP values monitoring that have a number of previously defined characteristics (Wilson et al. 2019). The Waterfowl Working Group, used Bennett et al. (2008), Lyons et al. (2008), and Williams (2011) as anchoring points for prioritizing relevant ecological processes. We evaluated and selected from a suite of potential processes that were believed to have the highest probability of affecting a large number of priority waterfowl species (Table 9.3). Finally, we further evaluated the various management actions using a matrix of the Effect Size (ES) x Uncertainty Score (US) whereby only species and ecological processes that had values <3 were considered important (Table 9.3). From Bennett et al. (2009), there were two ecological processes that were most relevant and broadly applicable: hydrological processes and climatic processes, but also interactions between organisms (i.e., predation) were important (Figures 9.1, Appendix 9). Similar to the Effect Size (ES) x Uncertainty Score (US) for management actions, none of the scores for species other than Mottled Ducks had values <3. Also similar to the ES x US values for management actions (Table 9.2), all high priority ecological processes (Table 9.3) for Mottled Ducks in which values <3 were almost exclusively during the breeding season.

Although, some waterfowl data needs and specific avian metrics were mentioned previously, here we provide several examples specific to Mottled Ducks during the breeding season related to a given ecological process, all of which had ES x US values <3 (Table 9.3). For a given ecological process, there may be multiple, potentially competing hypotheses (Lebreton et al. 1992), as well as different avian response metrics or parameters associated with each individual hypothesis. Therefore, for brevity, we did not include all Mottled Duck ecological processes examples with values <3 here.

The first ecological process example relates to hydrological processes and how altered hydrology may reduce wetland availability and abundance on the landscape (Table 9.3), which in turn, can lead to elevated salinity levels in remaining wetlands (Sklar and Browder 1998). This is particularly the case following tropical storms or hurricanes, whereby higher salinity offshore waters are pushed further inland from the associated winds and storm surge. Such an event could result in both direct (e.g., mortality of nesting hens, abandonment of nests due to flooding) and indirect (e.g., negative effects to food quantity or quality thereby increasing physiological stresses associated with molt) effects to breeding Mottled Ducks (see Ross et al. 2018). Moon et al. (2017) documented salinity ranges at some sites of 36ppt to >50ppt during their study of adult female survival of Mottled Ducks in Texas, partly owing to drought, as well as Hurricane Ike. In addition, sea-level rise may lead to movement of higher salinity waters further inland (Glick et al. 2013, Watson et al. 2015). For breeding Mottled Ducks elevated wetland (marsh) salinity may lead to reduced breeding season survival of adult females (Moon et al. 2017) and lower duckling and/or brood survival (Moorman et al. 1991). In addition, there may be sub-lethal effects (i.e., increased physiological stresses, reduced body condition) for both breeding females and ducklings using wetlands above what is thought to be the salinity threshold value of 9ppt (Moorman et al. 1991, see also Leberg 2017); compromised physiological condition could also result in increased vulnerability to predation. The issues associated with hydrological processes in the Gulf of Mexico are myriad and complex (Sklar and Browder 1998) as are potential solutions. In Louisiana at least, policy-makers and decision-makers have come together to attempt to address some of these very issues via the Louisiana Coastal Master Plan; some of the proposed projects are revolutionary with respect to design, scope, and scale (CPRA 2017). At a finer-spatial scale, some of the hydrological processes impacts could be addressed through policy changes in conjunction with targeted funding for on-the-ground conservation delivery via wetland easements (i.e., perpetual or term-limited), wetland restorations, and working with conservation partners and private landowners to provide resources such as funding, technical assistance, and equipment (e.g., water control structures, pumps, etc.) necessary to ameliorate high (>9ppt; Moorman et al. 1991) salinity levels (at critical times of the years) on priority wetlands on the landscape.

There are a multiple competing hypotheses nested within this single ecological process (Table 9.3, Figure 9.1). Hydrological processes are complicated even further in the face of climate change (Conroy et al. 2011) and related effects like sea-level rise (Watson et al. 2015). Avian metrics of interest related to this priority ecological process (Table 9.3) would be estimating breeding season survival of adult females and estimating duckling and/or brood survival (Figure 9.1) over a range of salinities in coastal marshes across the GoMAMN geography (Figure 1.2). In addition, data from marked females would provide information on potential habitat switching, whereby, brood-rearing and molting areas were selected primarily as function of salinity levels. Ultimately, we are interested in reducing the uncertainty associated with this ecological process and associated hypotheses (Williams 2011). The over-arching source of uncertainty, at least initially, would be environmental variation, but with an appropriate experimental design at a relatively large spatial and temporal scale with recurring decision-points, such an effort could potentially lead to reductions in structural or process uncertainty and partial controllability as well (Williams 2011). Such a monitoring effort here would really be focused on monitoring role number three, as identified by Lyons et al. (2008).

The second ecological process example relates to climatic processes (i.e., precipitation), though droughts are defined as natural disturbance regime. Here, we are considering precipitation and natural variability in wet-dry cycles. Generally speaking, Mottled Duck productivity appears to be negatively affected during dry periods, within or among years (Bielefeld et al. 2010). Under such a dry period, we might expect decreases in overall wetland availability, reduced size of wetlands, and overall reduction of wet area of wetlands; resulting in elevated salinity levels in remaining wetlands (Sklar and Browder 1998). This has the very real potential to result in reduced productivity through lower breeding propensity (Rigby and Haukos 2012), reduced re-nesting effort (Finger et al. 2003), and possibly lower brood survival (Rigby and Haukos 2014, but see Rigby and Haukos 2015). Ross et al. (2018) documented population responses (abundance declined) during years with an increase in days with extreme 1-day precipitation from June to November (hurricane season) and an increase in drought severity. Wetlands that have salinities in the range of >9–12ppt may result in slower growth and reduced duckling survival (Moorman et al. 1991, Bielefeld et al. 2010) which tend to be exacerbated during dry years or under drought conditions. An alternative to the above under climate change scenarios for the southeastern U.S. (Kunkel et al. 2013) indicated warmer ambient temperatures and more extreme precipitation events. This could potentially have the opposite effects from the dry-to-drought scenario previously described. In any case, higher salinity levels would almost certainly negatively affect some important Mottled Duck demographic parameters. Those tasked with reviewing the Mottled Duck for the Gulf Coast Vulnerability Assessment (Watson et al. 2015) indicated that although there was uncertainty regarding synergistic effects of sea-level rise, climate change, and land use, there was agreement that this species will likely experience negative impacts due to potential interactions of these three key drivers.

Similar to the first example, the decisions and processes required to address this ecological process is socio-politically challenging and will require decisions and actions at multiple spatial scales. At a finer-spatial scale, conservation decisions seem more tenable and conservation delivery on the ground would likely be fairly similar to the previous example. Though the hypotheses are different for this example, they remain multiple and competing for this single ecological process (Figure 9.1). However, with the appropriate study design (Johnson 2002a, 2002b) accounting for landscape-scale (e.g., wetland density, total wetland area, juxtaposition, etc.) and site-scale environmental factors and wetland conditions (e.g., wetland size, perimeter : area ratio, depth, salinity, etc.) with data collected at appropriate temporal and spatial scales, we should be able to tease-out the dominant factors driving the system. Avian metrics of interest related to this priority ecological process (Table 9.3) would be estimating breeding propensity, re-nesting effort, daily survival rates of marked nests, and duckling survival and/or brood survival over a range of salinities and wetland sizes across the GoMAMN geography (Figure 1.2). Ultimately, we are interested in reducing the uncertainty (Williams 2011) associated with this ecological process and potentially competing hypotheses (Lebreton et al. 1992, Williams et al. 2002).

The third ecological process example relates to interactions between organisms. Within this ecological process, such interactions may take several forms from predation, to intra- and interspecific competition (Nudds 1983, 1992). In this case, we will be limiting the discussion to the role of predation on breeding Mottled Ducks, and how weather, altered hydrology, and coastal marsh loss may functionally reduce wetland availability and abundance on the landscape (Table 9.3). This, in turn, can lead to elevated salinity levels in remaining wetlands thereby inducing physiological stresses on adult female Mottled Ducks and their ducklings leading to sub-lethal effects that increase susceptibility to predation. Similar to the previous examples, there are a multiple competing hypotheses and multiple mechanisms operating simultaneously nested within this single ecological process (Figure 9.1).

Addressing this issue from a management actions and/restoration project is relatively straightforward and would follow previous examples above in this section and the last example in the management actions section. Avian response metrics or parameters of interest to evaluate this ecological process and competing hypotheses would include: estimating daily survival rates of marked nests, estimating breeding season survival rates of marked adult females, and estimating duckling and/or brood survival (Figure 9.1). With the appropriate study design (Block et al. 2001, Morrison et al. 2010, Sanderlin et al. 2014) accounting for landscape-scale and site-scale environmental factors and wetland conditions, with data collected at appropriate temporal and spatial scales, we should be able to determine the dominant drivers in the system. One may consider implementation of a predator-removal program, as part of the study design framework as a means of evaluating the importance of mammalian predators on Mottled Duck parameters of interest within the broader context of the entire system (Sargeant and Raveling 1992, Sovada et al. 2001). In the absence of predator-removal program or other management action, monitoring associated with this effort would be clearly linked to monitoring role number three identified by Lyons et al. (2008). If, however, a predator-removal program and/or other management actions

Blue-winged Teal (*Spatula discors*). Photo credit: Tom Koerner

were initiated on the front-end of a larger project to try and increase any of the Mottled Duck demographic parameters, then monitoring role number two would be invoked (Lyons et al. 2008). Ultimately, we are interested in reducing the uncertainty (Williams 2011) associated with this ecological process and learning along the way (Shaffer and Johnson 2008). Irrespective of the types of uncertainty, we would certainly like to control for, account for, or otherwise recognize their influence within the context of evaluating this ecological process and the associated challenges of teasing-out a single hypothesis to explain our results (Williams 2001, 2003).

The waterfowl habitats within the Gulf of Mexico Region and the associated bird species are subject to many ecological processes; e.g., hurricanes, floods, and other extreme weather events, changes in salinity in wetland habitats, and predation (Day et al. 2013). By better understanding these underlying ecological processes, it will allow us to better understand population-level variation (Eberhardt 1978, 1988) and variation in waterfowl responses for cases in which there is some form of management control, as well as factors beyond management control (e.g., confounding effects of the continental population size, weather-induced migration intensity, and habitat conditions elsewhere within the relevant flyways). These issues revolve around environmental variation and partial controllability (Williams 2011). While there are many uncertainties around how waterfowl will be affected by specific restoration projects within the northern Gulf of Mexico wetland ecosystem, there are some additional uncertainties which have been identified elsewhere (NASEM 2017). For example, in the face of human population growth, continued human development, and land-use change in the region (Martinuzzi et al. 2013, 2015; Hamilton et al. 2016) along with sea-level rise (Enwright et al. 2016, Osland et al. 2016, Borchert et al. 2018), how will freshwater flows be maintained? How might emergent marsh habitat distribution and availability change in the face of hydrologic regime shift? Sea-level rise is predicted to shift wetlands landward, through a combination of ecology, geomorphology, and sediment deposition (Kirwan and Megonigal 2013, Raabe and Stumpf 2015), though whether this will ultimately result in a net loss of wintering waterfowl habitat is still unclear (Kirwan et al. 2016). The impacts of changing precipitation patterns, hydrological and fire regime shifts due to climate change, as well as predicted increases in hurricane frequency and intensity may all impact waterfowl (in different ways), but the magnitude of those effects (Johnson and St.-Laurent 2011) is highly uncertain.

Table 9.3. *Uncertainties related to how ecological processes impact waterfowl populations in the northern Gulf of Mexico.*

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck Breeding/ Wintering	Hydrological Processes (Altered Hydrology)	Are MODU populations influenced by wetland abundance, salinity, and inundation frequency?	Breeding propensity, re-nesting effort, estimating nest success, & brood survival estimates	Several previous studies suggested link between habitat conditions (precipitation) & breeding propensity, but data are generally sparse, & no data linking weather/habitat condition impacts on re-nesting or brood survival.	High	High
Mottled Duck Breeding	Hydrological Processes (Coastal Marsh Loss)	Does coastal marsh loss reduce wetland density (availability) thus, elevating salinity levels in remaining marsh/wetlands? Does coastal marsh loss negatively affect MODU productivity? If it does, what parameters are affected & what are the mechanisms?	Breeding propensity, re-nesting effort, estimating nest success, & brood survival estimates	Uncertain about effects of marsh loss, & sea-level rise more directly, on availability of nest sites, breeding propensity, probability of nest flooding (nest success), & brood survival.	High	High
Mottled Duck Breeding	Hydrological Processes (Coastal Marsh Loss)	Does coastal marsh loss reduce wetland density (availability) thus, elevating salinity levels in remaining marsh/wetlands? Does coastal marsh loss negatively affect MODU breeding season survival? If so, what are the mechanisms?	Adult female survival estimates during the breeding season	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	High
Mottled Duck Breeding	Hydrological Processes (Altered Hydrology)	Does altered hydrology reduce wetland density (availability) thus, elevating salinity levels in remaining marsh/ wetlands? Does altered hydrology negatively affect MODU breeding season survival? If so, what are the mechanisms?	Adult female survival estimates during the breeding season & during the molt	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	Unknown
Mottled Duck Breeding	Climatic Processes (Limited water available for wetland management)	Does low/limited water availability for wetland management negatively affect availability of low salinity marsh/wetlands during the spring & summer? Does low/limited water availability negatively affect MODU breeding propensity, re-nesting effort, nest success, & brood survival?	Breeding propensity, re-nesting effort, estimating nest success, & brood survival estimates	Several previous studies suggested link between habitat conditions (precipitation) & breeding propensity, but data are generally sparse, & no data linking weather/habitat condition impacts on re-nesting or brood survival.	High	High
Mottled Duck Breeding	Climatic Processes (Limited water available for wetland management)	Does low/limited water availability for wetland management negatively affect availability of low salinity marsh/wetlands during the spring & summer? Does low/limited water availability negatively affect MODU breeding season survival? If so, what are the mechanisms?	Adult female survival estimates during the breeding season	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	High

Table 9.3 (continued).

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck Breeding	Climatic Processes (Weather, i.e., precipitation)	Do dry/drought conditions reduce wetland availability & increase salinity levels in remaining marsh/ wetlands? Do dry/drought conditions negatively affect MODU breeding propensity, re-nesting, nest success, & brood survival? If so, what are the mechanisms?	Breeding propensity, re-nesting effort, estimating nest success & brood survival estimates + adult female survival estimation during breeding season & the molt	Several previous studies suggested link between habitat conditions (precip) & breeding propensity, but data are generally sparse, & no data linking weather/habitat condition impacts on re-nesting or brood survival.	High	High
Mottled Duck Breeding/ Wintering	Climatic Processes (Weather, i.e., precipitation)	Do dry/drought conditions reduce wetland availability & increase salinity levels in remaining marsh/ wetlands? Do dry/drought conditions negatively affect MODU breeding season survival? If so, what are the mechanisms?	Breeding propensity, re-nesting effort, estimating nest success & brood survival + adult female survival estimation during breeding season & molt; female body condition as a covariate for all parameters	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	Unknown
Mottled Duck Breeding	Interactions Between Organisms	Do dry/drought conditions, altered hydrology, & coastal marsh loss increase salinity levels in remaining marsh/ wetlands? Does predation have a greater negative affect on MODU population dynamics in dry v wet years, in low v high altered hydrology sites, or in areas with low v high wetland availability (low salinity)?	Adult female survival estimates during the breeding season, estimating nest success & brood survival	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	Unknown
Mottled Duck Breeding	Natural Disturbance Regimes	Does coastal marsh loss reduce wetland density (availability) thus, elevating salinity levels in remaining marsh/wetlands? Does coastal marsh loss negatively affect MODU productivity? If it does, what parameters are affected & what are the mechanisms?	Breeding propensity, re-nesting effort, estimating nest success & brood survival + adult female survival estimation during breeding season & molt; female body condition as a covariate for all parameters	Uncertain about effects of marsh loss, & sea-level rise more directly, on availability of nest sites, breeding propensity, probability of nest flooding (nest success), & brood survival.	High	High

Table 9.3 (continued).

Species Season(s)	Ecological Process Category[a]	Question	End point to measure	Uncertainty Description	Uncertainty Category[b, d]	Effect Size[c, d]
Mottled Duck Breeding	Natural Disturbance Regimes	Does coastal marsh loss reduce wetland density (availability) thus, elevating salinity levels in remaining marsh/wetlands? Does coastal marsh loss negatively affect MODU breeding season survival? If so, what are the mechanisms?	Breeding propensity, re-nesting effort, estimating nest success & brood survival + adult female survival estimation during breeding season & molt; female body condition as a covariate for all parameters	At least 1 study suggests breeding season survival decreases during drought, but this contrasts with what we know about MALL, for which drought reduces nesting propensity & thus, leads to reduced mortality.	High	High

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

Abbreviations Used: MODU (Mottled Duck), MALL (Mallard)

SUMMARY & MONITORING RECOMMENDATIONS

Herein, we have identified a number of monitoring priorities related to management actions (Table 9.2), status and trends assessment (see section above), and ecological processes (Table 9.3). We have used a combination of management actions and ecological processes spreadsheets, as well as species-specific influence diagrams (Figure 9.1, Appendix 9) to inform the monitoring priorities for waterfowl species of conservation concerns, and other monitoring targets identified by the GoMAMN Waterfowl Working Group (Table 9.1) within the GoMAMN geography (Figure 1.2).

When attempting to study questions and hypotheses regarding waterfowl, we recommend to the extent practicable, sampling encompass all sex-age classes for a given species and that all experiments have controls, are randomized, and replicated (Hurlbert 1984, Eberhardt and Thomas 1991, Anderson 2001, Block et al. 2001, Johnson 2002a, 2002b). However, when sampling of all sex-age classes is simply not feasible or appropriate per study design, it is a common practice to focus solely on monitoring females, because this sex-class tends to be the cohort that drives population viability and sustainability (see Cooke et al. 1995, Newton 1998). Because females in most waterfowl species exhibit lower breeding season survival, sex ratios of adults in the population tend to be substantially sex-biased toward males, suggesting that this cohort is more expendable (Bellrose 1980, Baldassarre 2014, Koons et al. 2014).

The GoMAMN Waterfowl Working Group has identified some 'measure' of population abundance or density, a high priority avian metric for monitoring wintering waterfowl. However, there are some real concerns about the value of the data generated from the existing Midwinter Waterfowl Survey. The limitations of the Midwinter Waterfowl Survey have been clearly articulated elsewhere (Eggeman and Johnson 1989, Heusmann 1999, Andersson et al. 2015) so are not elaborated here. That said, an over-arching criticism of the Midwinter Waterfowl Survey is that there is no explicit survey design (Reinecke et al. 1992, Pearse et al. 2008a). We believe that to be of value for addressing GoMAMN objectives (Figure 2.2) per status and trends assessment, Midwinter Waterfowl Survey proponents and implementers would need to address the seven recommendations described in Andersson et al. (2015) in conjunction with an effort to account for visibility bias, observer bias, and other detection-related issues (Koneff et al. 2008, Pearse et al. 2008a, 2008b). Additionally, we would have to achieve consensus on a clear definition of what this survey actually is: are we determining absolute population size or is this an index to population size (Gregory et al. 2004)? In the latter case, there would have to be some effort to 'measure' the relationship (i.e., correlation) between the index and the true, but unknown population size. An index may very well be appropriate (see Johnson 2008) if we are not interested in population size per se, but rather we are interested in determining if the population is increasing, decreasing, or stable (Gregory et al. 2004). Finally, an agreed-upon survey design (e.g., stratified random sampling; Gregory et al. 2004, Pearse 2007, Pearse et al. 2008a) with sample units and an *a priori* defined level of precision (Coefficient of Variation) would need to be developed and agreed upon, along with additional transect segments (or survey plots) across the GoMAMN geography (Figure 1.2) in coastal areas of the five Gulf states to address any existing spatial coverage gaps. Specifically for breeding Mottled Ducks, the Waterfowl Working Group believes that the current Western Gulf Coast Mottled Duck population survey (USFWS 2016) provides valuable data. However, there remains concern over spatial variability in associated Visibility Correction Factors and Coefficients of Variation. The group further suggests these concerns warrant further study.

There may be cases when estimates of abundance or density simply cannot be obtained, in which case, occupancy (i.e., presence/absence; MacKenzie et al. 2006) is often the next logical avian response parameter to estimate. An example where this may be appropriate for waterfowl, would be where there was interest in determining if birds (all species) responded positively to a given coastal marsh restoration project and there was interest in relatively efficiently (at relatively low cost) determining 'bird use' associated with the project. In this case, there was a clear recognition that presence-only data (Pearce and Boyce 2006) may not be sufficient to address the objectives, so a decision was made to conduct weekly, bi-weekly, or monthly 'counts' of birds across multiple sites (experimental and control) where both presence/absence data are collected before and after the restoration project was completed. In the process of estimating species-specific occupancies, one also addresses issues associated with the detection process and detection probability (Royle and Nichols 2003, MacKenzie et al. 2006). For waterfowl specifically, occupancy estimation can be problematic in that in many cases, managers and decision-makers desire population estimates (or indices), and occupancy estimation can actually mask large changes in abundance. Occupancy only requires a single individual to be present (i.e., present =1, absent = 0) and, therefore, does not directly provide population or abundance estimates per se (but see MacKenzie and Nichols 2004). Even occupancy estimation can be difficult to assess outside of the breeding season for many waterfowl species, partly owing to the mixed-species assemblages, generally larger numbers of birds, diurnal and nocturnal fluctuations in distribution and abundance, and highly variable environmental and anthropogenic factors (e.g., hunting pressure) that can affect waterfowl abundance and use of habitats in the winter. Though occupancy estimation is not explicitly identified within management actions, status and trends assessments, or ecological processes above; we consider it a potentially valuable avian monitoring tool/technique (NASEM 2017).

Another monitoring priority identified by the GoMAMN Waterfowl Working Group is that for body condition of wintering waterfowl, in particular, pre-departure body condition. The group strongly believes in the value of these data, so much so, that we considered these data equally valuable or even more valuable than abundance surveys of wintering waterfowl. One advantage of these data is that once standardized protocols were in place, data could be relatively easily collected from waterfowl hunters at check stations on state Wildlife Management Areas and federal National Wildlife Refuges. In addition, there would be the potential to collect fairly large sample sizes through time and space, depending on the species. Additional research projects could be conducted to evaluate not only body condition, but also lipid-reserve dynamics, overall carcass composition, and diets of wintering waterfowl. If scaled appropriately, we could learn a lot about how these avian response variables change over time and space.

Frequently, waterfowl managers and researchers are interested in how management actions or ecological processes impact survival or other relevant demographic parameters either within or across seasons, within or across years, or for a specific cohort of the population (e.g., adult females; Cooke et al. 1995:Figure 4.1). Survival can be estimated using a variety of marking techniques (Hestbeck et al. 1990) and a variety of analytical approaches, depending on the study design, objectives, and hypotheses (Lebreton et al. 1992). For the most part herein, when we refer to the term survival, we are limiting the discussion to either individuals marked with standard metal (e.g., aluminum) leg-bands or those fitted with either a VHF transmitter or satellite transmitter. In addition, the term survival is typically a reference to apparent survival and not true survival (see Gilroy et al. 2012), but the definition is often study-specific. There are advantages and disadvantages of each approach, though in general; the key underlying assumptions with each of the marking techniques are similar (Brownie et al. 1985:6). An important difference, however, is that in the case of both VHF and satellite transmitters, one should be cognizant of potential transmitter-related effects on marked individuals (Barron et al. 2010, Bodey et al. 2018), and whether or not the presence of the transmitter itself may negatively affect the parameter of interest, i.e., survival, thus violating one of the key assumptions (Brownie et al. 1985).

The GoMAMN Waterfowl Working Group identified adult female survival for species other than Mottled Ducks, during the fall/winter period as an important avian response metric or parameter of interest. In addition, the group identified adult female survival of Mottled Ducks during the breeding season and molt (Figure 9.1), as well as duckling or brood survival (from hatch to fledging; Flint et al. 1995) for Mottled Ducks is also very important. Clearly, estimating such a relevant demographic parameter is highly valued by this group, as this particular avian response variable seems to be a reasonable and robust indicator for evaluating both management actions (i.e., habitat manipulations, wetland and grassland restorations, predator removal, etc.) and ecological processes (i.e., changes in hydrological or climatic processes that influence wetland availability and salinity levels) (Tables 9.2–9.3). In the case of Mottled Ducks specifically, the Waterfowl Working Group sees the value in marking adult female hens with transmitters in an effort to address data gaps related to structural characteristics of grasslands that are selected for by Mottled Ducks during nesting at both larger spatial scale and nest-site selection scale, as well as habitat selection and specific wetland and vegetation characteristics associated with females and their ducklings during brood-rearing. Lastly, a better understanding of spatial and temporal variation in Mayfield nest success (Shaffer 2004, Jones and Geupel 2007) or daily survival rates of marked nests (Dinsmore et al. 2002, Rotella et al. 2004, Dinsmore and Dinsmore 2007; but see Thompson et al. 2001, Streby et al. 2014) for Mottled Ducks is a high priority. Due to the challenges of locating nests of female Mottled Ducks, many of the studies to date have suffered due to small sample sizes and/or limited geographic or spatial footprints (e.g., Holbrook et al. 2000, Durham and Afton 2003, 2004).

At this point, it seems appropriate to provide a recommendation. We strongly encourage those conducting any form of 'survival' monitoring or analyses to consider employing Program MARK (Cooch and White 2014) and the appropriate models or routines identified therein, rather than estimating survival using some other readily available analytical technique/procedure (e.g., Kaplan-Meier model or Cox Proportional Hazards model, etc.). Program MARK includes a diverse suite of available models, allows one to simultaneously incorporate and evaluate main effects, covariates, and interactions that potentially influence survival, is robust to simultaneously testing multiple competing hypotheses (Lebreton et al. 1992), and uses an information theoretic approach (Anderson et al. 2000, Burnham and Anderson 2002), rather than traditional null hypothesis testing (Johnson 1999, 2002a) to evaluate amongst competing models (Lukacs et al. 2007, Doherty et al. 2012). Specifically, there are major advantages of estimating daily survival rates of marked nests (Rotella 2014) versus calculating either apparent or Mayfield nest success (Klett et al. 1986).

Waterfowl movements during the fall/winter period were briefly discussed previously. This remains a major information gap for wintering waterfowl. Broad-scale movements of a target species of wintering waterfowl may best be achieved using satellite telemetry (Krementz et al. 2011, 2012; Beatty et al. 2014). Whereas finer-scale movements of target species of wintering waterfowl are probably best addressed using VHF transmitters with Yagi antennas on boats or vehicles, VHF transmitters with Yagi antennas affixed to aircraft, VHF transmitters with Yagi antennas and receivers at remote stations, GPS tags, or nanotags with MOTUS stations (Taylor et al. 2017), or some combination of these techniques. Smaller spatial scale movements, in particular, diurnal versus nocturnal use of "refuges" or similar areas relatively free of disturbance, and movements between these areas and foraging sites is an important data gap, at least for some species (Davis et al. 2018). In particular, are there areas on the landscape within the GoMAMN geography (Figure 1.2) where it would be beneficial to wintering waterfowl to establish additional "refuges" as a function of distance between these diurnal disturbance-free areas (i.e., day roosts) to nocturnal foraging sites (e.g., Northern Pintail- Cox and Afton 1996, 1997, 1998)? Information on species-specific movements between known refuges and foraging areas would be valuable from a conservation planning and habitat delivery perspective (Davis et al. 2018). A common question related to Gulf-funded bird habitat restoration projects (DHNRDAT 2016) is, "Are we just moving birds around?" More specifically, are birds simply redistributing (i.e., emigration-immigration) on the landscape given this novel habitat provided by a restoration project? This is an important question if the objective is to "replace" a given number of individuals for a species that was injured by the oil spill (DHNRDAT 2016, 2017). Addressing this and related questions is particularly amenable to telemetry monitoring, but which specific technology should be used depends on a number of factors including project-specific objectives and hypotheses. Questions like those above could potentially be addressed for any of the waterfowl species targets identified herein via a large spatial scale telemetry study given the appropriate attention to survey design, elucidation of explicit objectives, sampling, and attention to minimum sample sizes (Hayward et al. 2015). Clearly, there are some advantages of a telemetry-based marking technique, in that information gain per marked bird is very high when compared to legband-only or legband plus color-mark (i.e., color legband or neckcollar).

However, the cost per bird for any transmitter-type is considerably higher than for either legband-only or legband plus color-mark. In addition, there are concerns for at least some species of waterfowl that the attachment site, attachment type and procedures, transmitter type, and transmitter weight and shape may potentially negatively affect behavior and survival of marked birds (Kesler et al. 2014). Research to date on potential transmitter effects on transmittered ducks has provided variable results (review by Lameris and Kleyheeg 2017). In addition, a recent meta-analysis on tracking devices suggests tags >1% of an individual bird's body mass may negatively affect survival (Bodey et al. 2018). It is becoming increasingly clear that external packages and attachments may negatively affect transmittered individuals of diving duck species (Robert et al. 2006). There is a large volume of scientific literature on this topic as it relates to various species of waterfowl, and we suggest that those interested in telemetry studies of wintering waterfowl consult the literature, the GoMAMN CoP, and members of the GoMAMN Waterfowl Working Group.

Though we have provided some recommendations and suggestions in this section, it is beyond the scope of this document to provide explicit recommendations for a specific transmitter type, specific attachment technique, and specific monitoring protocols to track marked individuals across species identified as monitoring priorities. Finally, it is beyond the scope of this document to provide explicit guidance, protocols, and specific recommendations for a specific technology, i.e., nano tags, GPS transmitters, VHF transmitters, satellite transmitters, etc. (reviews by Robinson et al. 2010, Bridge et al. 2011). We recognize and understand that the decision of whether or not to employ a given technology type for monitoring bird movements (and survival) can be a daunting and extremely complex process, and is not strictly limited to the interaction between available funding and maximizing sample size.

Though we obviously recognize and understand the value and importance of non-avian covariates in monitoring, for brevity purposes, a decision was made to not provide a separate section here. In addition, examples were described previously in text within the management actions, status and trends assessment, and ecological processes sections. Lastly, it is beyond the scope of this chapter to attempt to explicitly describe every potential combination of non-avian response variables and the where, when, and how they may be relevant and appropriate given the range of potential waterfowl-related monitoring and research projects across the Gulf of Mexico. Rather, we suggest that those interested in monitoring wintering waterfowl use this chapter and the references herein as a stepping stone or starting point.

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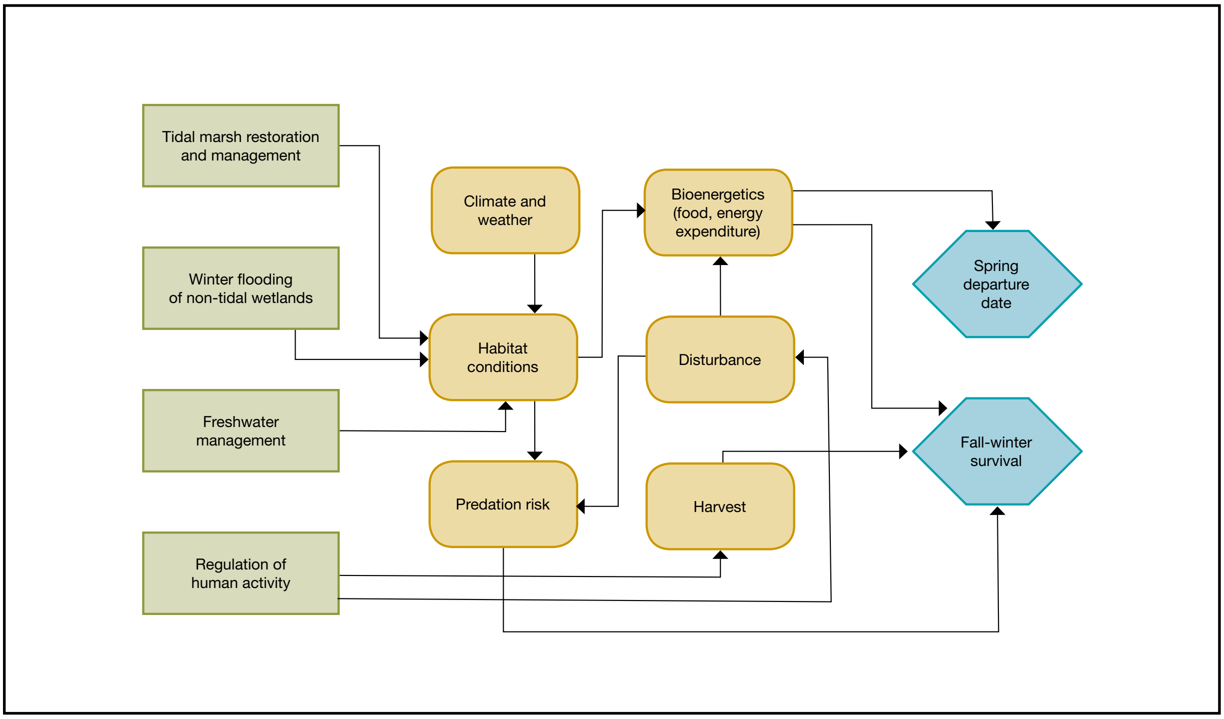
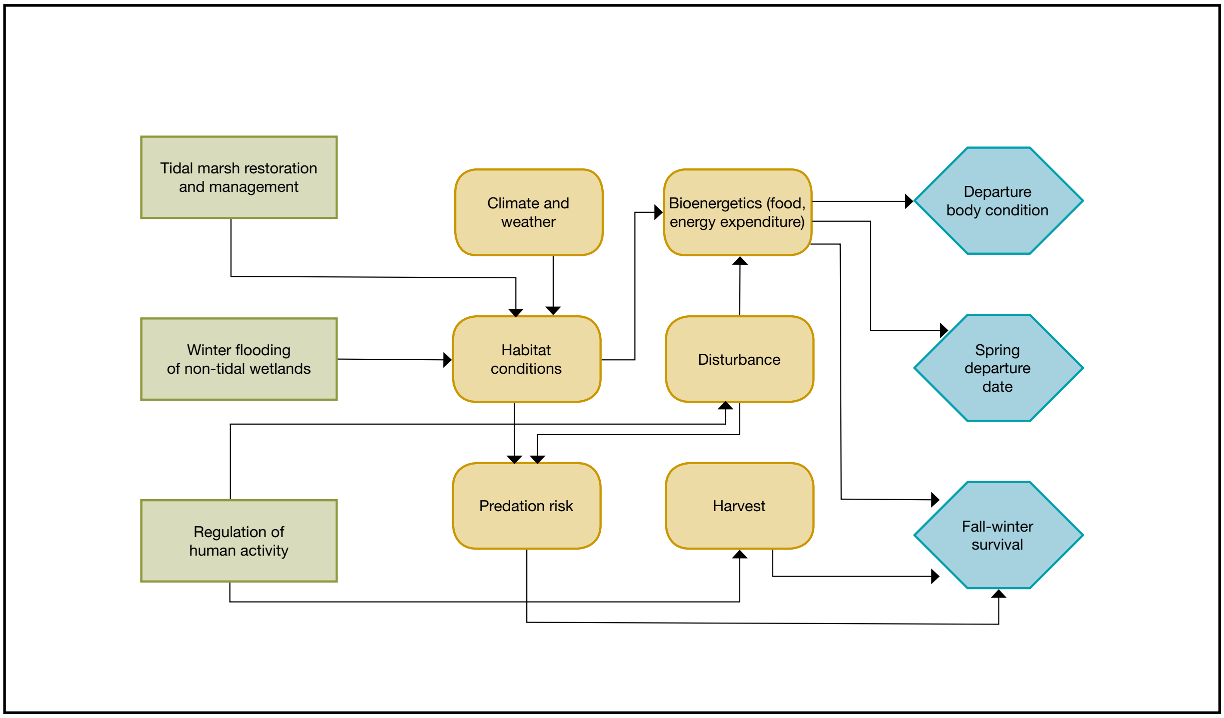
APPENDIX 9

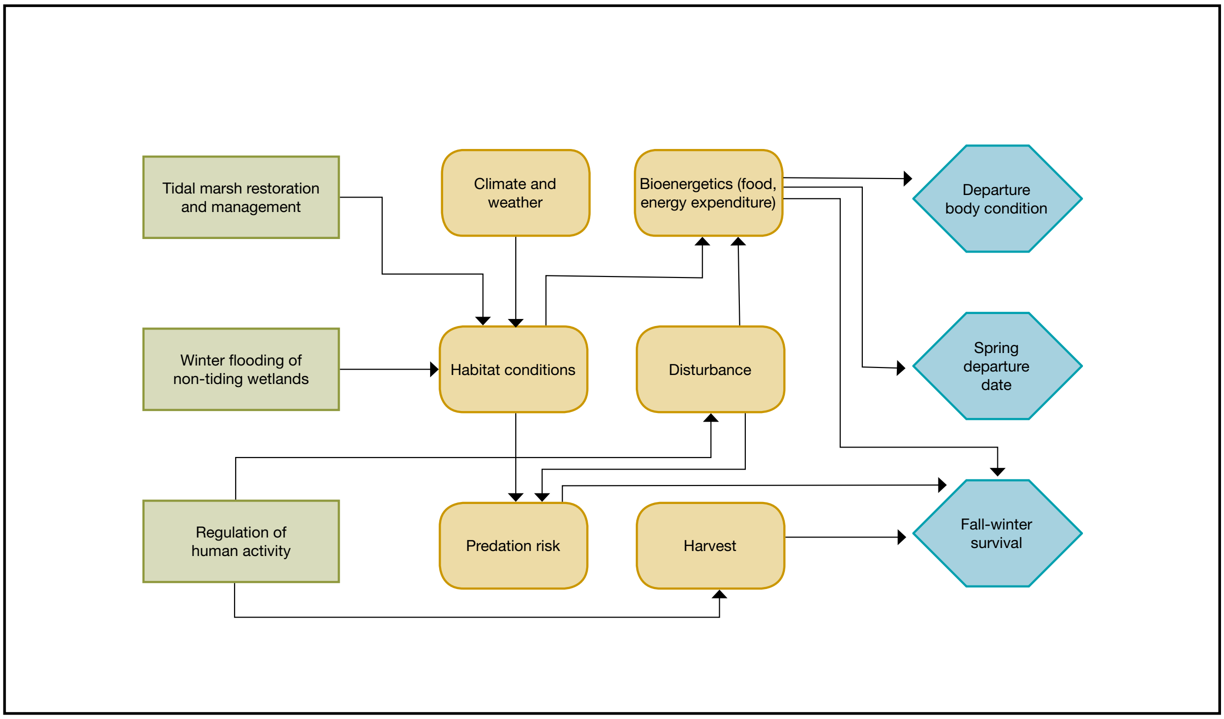
Supplementary influence diagrams depicting mechanistic relationships between management actions and population response of waterfowl.



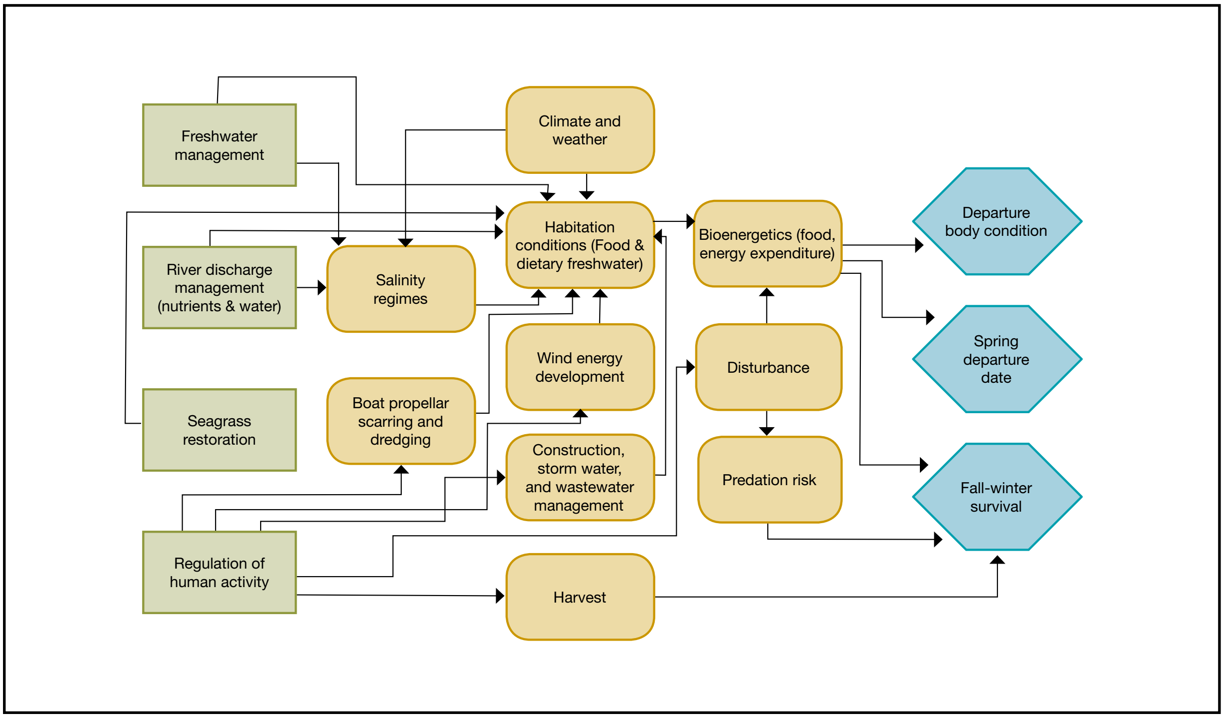
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the **Blue-winged Teal** (Spatula discors) within the Gulf of Mexico Region.*



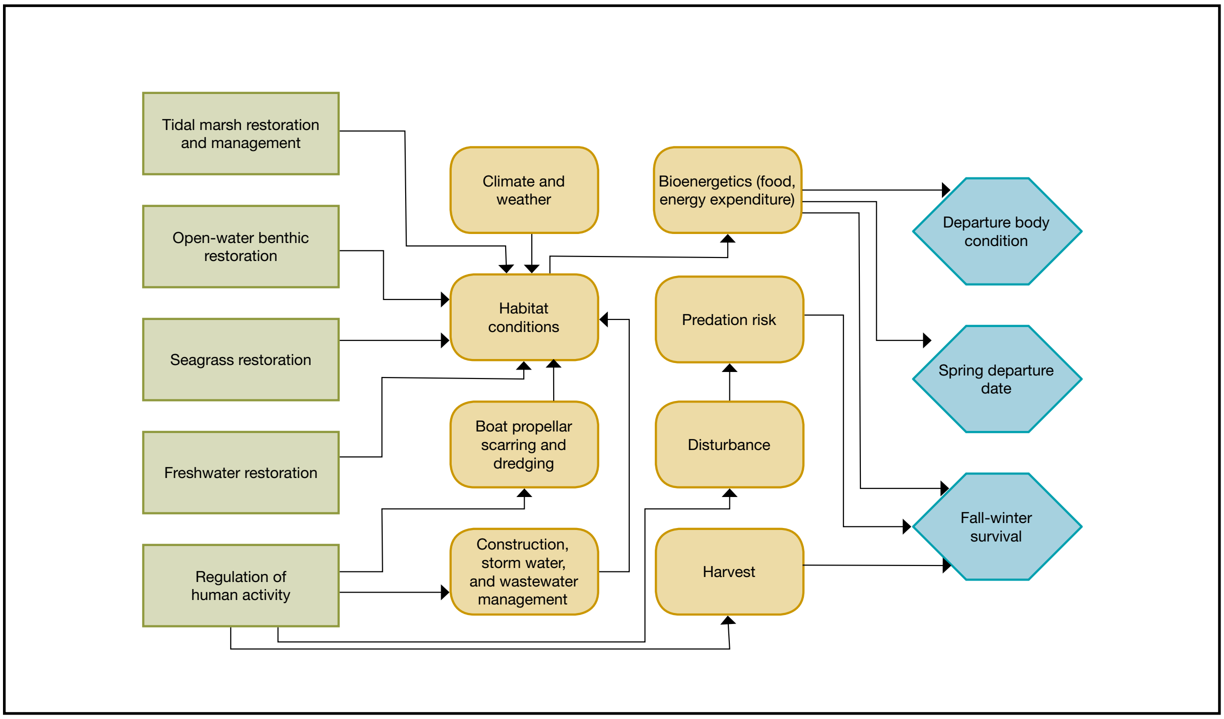
*Influence diagram of the relationship between management actions (green boxes), intermediate processes (gold boxes) and population (metrics) size (blue hexagons) for the **Gadwall** (Mareca strepera) within the Gulf of Mexico Region.*



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



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



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

10

Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

GoMAMN STRATEGIC BIRD MONITORING GUIDELINES: AVIAN HEALTH

Authors:
Mary Ann Ottinger (1*)
Terri Maness (2)
Jacquelyn K. Grace (3)
R. Randy Wilson (4)
Patrick G.R. Jodice (5)

1. Department of Biology and Biochemistry, University of Houston, Houston, TX
2. School of Biological Sciences, Louisiana Tech University, Ruston, LA
3. Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX
4. U.S. Fish and Wildlife Service, Division of Migratory Birds, Jackson, MS
5. U.S. Geological Survey South Carolina Cooperative Fish & Wildlife Research Unit, and Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC

(*) Corresponding Author: **maotting@central.uh.edu**

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Chapter 10

GOMAMN STRATEGIC BIRD MONITORING GUIDELINES: AVIAN HEALTH

INTRODUCTION

THE GULF OF MEXICO (GOM) HAS A RICH DIVERSITY of avian species, comprised of residents and migrants from a wide geographic range (Burger 2018). These birds have encountered substantial changes in the quality and availability of coastal, terrestrial, and marine habitats in the GoM, including anthropogenic and natural stressors. A primary concern for this region is environmental contamination associated with the high concentration of chemical/petrochemical industries (Inglis et al. 2014), and oil and gas operations with associated activities in Louisiana and Texas. Elevated levels of mercury are also commonly found in fish throughout much of the northern GoM, distinct from other environmental chemicals. Habitat quantity and quality is also being directly impacted by increasing rates of urbanization, red tides, and natural weather events such as hurricanes. For example, the full implications of Hurricanes Harvey and Maria are still emerging, especially for avian populations (Burger 2017, Ward 2017). Trends in infectious diseases that impact avian health are also changing as a result of warming and increased rainfall. Stressors such as contaminants and poor habitat quality worsen the impacts of disease on avian populations. Furthermore, runoff from agricultural, residential, and industrial areas often carries substantial concentrations of fertilizers and environmental chemicals, which may result in water quality degradation, toxic algal blooms, or otherwise increase the risk of exposure to both humans and wildlife to potentially toxic chemicals. As such, both migratory and resident birds are exposed to a suite of environmental challenges including complex chemical exposures and weather related events. Collectively, these natural and anthropogenic stressors set the context and provide the impetus for understanding implications to avian health across the northern GoM.

Across the northern GoM, significant restoration efforts are being implemented in the wake of the Deepwater Horizon oil spill by a myriad of conservation partners (DHNRDAT 2016, GCERC 2016, NFWF 2018). To ascertain the effectiveness of these restoration activities, it is imperative that land managers understand both population- and individual-level effects. To that end, avian health metrics can serve as reliable indicators of long-term system restoration and success, separate from, or in conjunction with abundance and reproductive metrics. For example, restoration efforts may increase local bird abundance via immigration and/or increased reproductive success, while long-term, negative physiological outcomes to populations and overall poor ecosystem health may still persist. Short-term increases in abundance (e.g., bird abundance) alone may not be reflective of population health; it is important to have health and fitness metrics in order to make informed conclusions and decisions related to management effectiveness and overall restoration success. Thus, long-term comparisons of health and vitality of avian populations are warranted for land managers to accurately assess restoration activities across the northern GoM.

In this chapter, we review avian physiological adaptations related to migration, survival, and reproduction to provide a foundation upon which an avian health assessment can be conducted. Drawing upon these adaptations and work presented in the previous taxon-specific chapters (Chapters 3-9 herein), we present diagrams and a table to more precisely link physiological attributes to restoration actions to provide a guiding framework for the collection of avian health metrics. For the purpose of this document, we define health to include, but not be limited to selected measures that have been utilized in the field and/or otherwise shown to be indicative of stress-related responses. Further, we define health assessment in the context of birds and as such, encompass the concepts of fitness or condition within the consideration of health assessments. Other aspects of avian health, particularly those that are invasive or not stable measurements for field applications are also often part of health assessments, but are not treated here since they represent more complex approaches that may be beyond basic monitoring. The information and recommendations herein are intended to facilitate the ability of resource managers to establish avian health and fitness baselines. Moreover, these baselines will contribute to the conduct of future avian health assessments that document: 1) positive effects to avian populations afforded by restoration programs; and/or 2) physiological metrics providing an underpinning to assessing success of restoration efforts.

AVIAN LIFE HISTORY AND PHYSIOLOGICAL LINKAGES

Stressors for bird populations in the GoM can take many forms, such as hurricanes, droughts, pollution from industrial sources, pesticides and other pollutants in runoff from agriculture and urban areas, changes in food abundance, predation pressure, and infectious disease (Ottinger et al. 2009; Hooper et al. 2013; Bursian et al. 2017a). Moreover, habitat loss and fragmentation are among the most significant factors affecting avian populations (e.g., Fahrig 1997, 1998, 2001, 2003). Stressors are always present in the environment and as such can impact individuals separately; population-level effects are often the result of a particular suite of stressors experienced at a given time or in a cumulative fashion. The context encountering stressor(s) provides a context for response and potential adverse outcomes. Birds may be differentially impacted by stressors depending on their life history strategies. In short, life history traits reflect a series of events that govern a bird's life—birth, fledging, maturation, reproduction, and death. More specifically, timing of juvenile development, age of sexual maturity, number of offspring, level of parental investment, aging, and lifespan are dependent upon the physical and ecological system within which the bird lives (Lack 1968, Stark and Ricklefs 1998, Martin 2004). Additionally, understanding avian physiological adaptations can provide insight into the potential mechanisms that underlie avian responses to such environmental stressors. While all vertebrate species have similarities in physiological and developmental processes, as a group, birds have developed a suite of unique characteristics. These include specific adaptations to the reproductive, metabolic, immune, visual, and auditory systems, as well as general physiological adaptations including high body temperature, and lightweight bones with specialized microstructure (Sullivan et al.2017). Below, we provide a high-level review of avian life history strategies and physiological processes important for understanding and assessing avian health and response to environmental stressors.

A centerpiece of life history theory is the trade-off between reproductive effort and survival of individuals (Williams 1966), which is widely supported by patterns of fecundity and survival in experimentally manipulated populations of wild and laboratory animals (Stearns 1992). Reproduction is inherently costly for both ecological and physiological reasons. Because reproduction requires extra nutrients, breeders risk predation (Magnhagen 1991), parasitism (Apanius and Schad 1994, Knowles et al. 2009), and other ecological consequences (e.g., competition) associated with increased foraging. In birds, increased foraging effort results in increased reproductive output, but decreased parental body condition and survival (Daan et al. 1996, Golet and Irons 1999), in part due to elevated energy demands (Potti et al. 1999). It is presumed that parents reduce self-maintenance processes (e.g., immune function) and draw from body reserves, in order to fuel the additional physical activity. Hence, short-lived species are expected to invest more in current reproductive attempts and less in overall immune defense, because the reproductive value of their current brood is high relative to potential future broods. In contrast, the reproductive value of the current brood is low relative to potential future broods for long-lived birds because they have fewer natural extrinsic causes of adult mortality (Stearns 1992). Thus, long-lived species should have relatively higher allocations of resources to self-maintenance functions compared to that of short-lived species, particularly related to immune functions.

Looking more closely at avian ontogeny from the lens of physiological process and functional responses reveals two different strategies: 1) altricial chick development; and 2) precocial chick development, suggested by Starck and Ricklefs (1998) as endpoints along a spectrum. Altricial species (e.g., passerines) hatch in a relatively immature state and require parental care until at least fledging. At the other end of the spectrum, precocial species (e.g., waterfowl) are fairly well developed and mobile at hatching and require little parental care. Altricial and precocial birds appear to have differential risk from environmental chemical exposure because sexual differentiation of endocrine and behavioral components of the reproductive system develop later for altricial species compared to precocial species (Adkins-Regan et al. 1990). While exposure to environmental chemicals *in ovo*, especially to endocrine disrupting chemicals can be extremely damaging to individuals in both groups (Ottinger and Dean 2011), precocial birds are primarily impacted during embryonic development, while altricial birds remain vulnerable for an extended post-hatching period. Understanding these physiological processes and functional outcomes, especially related to the response of reproductive, immune, endocrine, and organ systems to environmental chemical exposures can provide invaluable insights into individual and population health status.

The thyroid system modulates and maintains metabolic homeostasis; it is critical for pre-migratory fattening and for migratory energy utilization (McNabb, 2007). Stressors activate adrenal hormones, which can act beneficially as a hormetic to stimulate homeostatic and immune responses. However, chronic stress ultimately impairs fitness through reduced physiological resilience and reproductive success (Calabrese et al. 2001).

Nesting Double-crested Cormorants (*Phalacrocorax auritus*). Photo credit: Donna A. Dewhurst

Birds have a relatively high metabolic rate and body temperature (40.6ºC). A high metabolic rate and elevated body temperature may contribute to altered toxicokinetics with exposure to environmental chemicals. For example, raptors (e.g., Osprey [*Pandion haliaetus*] and Bald Eagles [*Haliaeetus leucocephalus*]) experience high rates of bioaccumulation of pollutants leading to weakening of eggshells (Grier 1982). Further, these bioaccumulated lipophilic compounds including environmental pollutants may be released from storage in fat cells during times of high energy utilization such as with migration. Hence, it is important to link environmental stressors to the health of individual birds and ultimately to avian populations.

Many birds also have unique physiological and endocrine characteristics that support long-distance migration and survival under highly variable and sometimes extreme conditions (Gill 2007, Ricklefs 2010). In addition to having lighter bones and shorter gastrointestinal tracts than mammals, birds have a highly efficient respiratory system in which the passage of air is aided by numerous air sacs (Gill 2007). Feather integrity is critical for flight, and can be compromised by oil exposure, which subsequently impairs flight and thermoregulation (Maggini et al. 2017). As mentioned above, the thyroid system promotes fat storage and modulates energy utilization during flight. Any compromise to these metabolic systems and/or feather integrity can inhibit flight performance or reduce individual body condition during migration, subsequently leading to compromised reproductive success or survival.

The link between environmental stressors and lifespan is a critical factor to assess with regard to fitness as it brings together health, productivity, and longevity of individuals (Haussmann and Heidinger 2015). While it would be predicted that high body temperature and metabolic rate would result in short lifespans, surprisingly many birds, including hummingbirds, parrots, and seabirds exhibit remarkably long lifespans compared to mammals of equivalent body size (Ottinger et al. 1995, Nisbet et al. 1999, Holmes and Ottinger 2006, Ottinger and Lavoie 2007, Finch 2009). Long-lived birds have physiological and behavioral adaptations supporting long life, including resistance to oxidative damage (i.e., the ability to detoxify reactive compounds and repair the damage they cause; Ogburn et al. 2001, Ottinger, 2018) and the ability to prioritize adult survival over annual productivity (Drent and Daan 1980). That is, long-lived birds can forgo breeding in order to survive brief stressors and breed again when conditions improve. As such, long-lived bird species are better able to deal with exposures to pollutants (physiologically) than are short-lived species. However, they are not tolerant, and when long-lived species are affected in a way that increases adult mortality, it has a larger effect on their population stability because of their slow reproductive rate (e.g., Croxall and Rothery 1991). Thus, exposure to chemicals and other health consequences that increase adult mortality can have disproportionate impacts on long-lived species (Congdon et al. 1994).

Dramatic increases over the past century have occurred in the production and use of chemicals in industrial, agricultural, and residential settings that have resulted in a wide diversity of chemical pollutants in the coastal and marine systems of the northern GoM. Increasing exposure to pollutants heightens the risk of adverse effects (Cheek et al. 1995; Ottinger et al. 2009). The potential for adverse effects of these pollutants is a complex issue due to the range of pollutants in our environment, the diversity of actions and potencies, bioavailability, life-cycle of compounds, and myriad of exposure scenarios. Nevertheless, a suite of recent publications has documented adverse consequences from oil exposure stemming from the Deepwater Horizon Oil Spill (DWH) (see Bursian et al. 2017 for review). Specifically, studies of Laughing Gulls (*Leucophaeus atricilla*) and Double-crested Cormorants (*Phalacrocoarx auritus*) showed increased oxidative damage and deleterious effects on cardiac tissue, and mortality of some birds (Horak et al. 2017, Pritsos et al. 2017, Harr et al. 2017). Fallon et al. (2017) documented physiological damage to a range of species from even light levels of oiling. Homing Pigeons (*Columba livia domestica*) showed altered flight paths after light oiling, suggesting both impaired navigational capabilities and flight ability (Perez et al. 2017). Western Sandpipers (*Calidris mauri*) exposed to ingested oil showed reduced blood and liver related responses to contaminant exposure, and histological indicators of a stress related adrenal response (Bursian et al. 2017). Birds also had difficulties with takeoff and flight maintenance following feather oiling with small amounts of crude oil (Maggini et al. 2017). Seaside Sparrows (*Ammodramus maritimus*) living in areas exposed to Deepwater Horizon oil had radiocarbon signatures indicating that the oil entered the terrestrial food-web and demonstrated reduced reproductive success in oiled areas (Bonisoli-Alquati et al.2016). Exposure to sub-lethal levels of contaminants has also been linked to increased susceptibility of avian species to infectious diseases as a result of immunosuppression (Grasman 2002, Fairbrother et al.2004, Acevedo-Whitehouse et al. 2009). As such, it is imperative that both short-term toxicological studies and long-term cumulative assessments on overall fitness (recognizing difference in life history strategies) of individuals and the potential impact on avian populations be implemented to ascertain efficacy of restoration programs.

ECOSYSTEM RESTORATION AND MEASURES OF FITNESS AND HEALTH

The large-scale restoration underway in the northern Gulf of Mexico under the RESTORE Act, National Fish and Wildlife Foundation, and Natural Resource Damage Assessment Trustee Council presents an opportunity to increase wildlife populations and improve their habitats. Collectively, state and federal agencies in partnership with numerous conservation organizations and citizen groups are making substantial conservation investments along the coasts of Florida, Alabama, Mississippi, Louisiana, and Texas. This unprecedented investment in ecosystem restoration along the Gulf Coast requires accountability for the effectiveness of large-scale restoration efforts across a broad geographic area. To that end, the millions of birds using the northern Gulf of Mexico (for all or part of their annual life-cycle) provide an unparalleled indicator of ecosystem health (Burger 2017, 2018). The Gulf ecosystem supports hundreds of avian species that occupy virtually all trophic levels within the northern GoM food web and are direct beneficiaries of most restoration projects, regardless of the resource for which the restoration project was designed. As such, the overall health and fitness of birds may offer an opportunity to assess the collective benefits of diverse and broad-scale restoration efforts. Unfortunately, more information is needed regarding which health metrics are most appropriate, most informative, or most cost-effective/convenient for practitioners to collect in the field.

Frequently used indicators of avian population health are estimates of adult/juvenile survival (e.g., Maness and Anderson 2013) and reproductive success, as articulated in the previous taxa-specific chapters (see Chapters 3-9). However, measuring survival and reproductive success is often logistically difficult and costly. Physiological health metrics provide potential (cheaper/easier) alternative measures of population health. Physiological health metrics can also illuminate mechanisms underlying changes in population health, in that the health of individuals determines their productivity and survival, which ultimately drives both short- and long-term population status. Although data are available about potential impacts of chemicals and other stressors to avian populations, gaps still exist in our ability to directly link life history traits (e.g., reproductive success) to specific physiological metrics (see Lamb et al. 2016), and subsequently, to potential adverse outcomes and risk for wild birds. Monitoring specific health metrics of avian populations in tandem with other monitoring programs (e.g., abundance) will provide essential information about the current status of individuals within a population (Mallory et al. 2010), and possible species-specific differential health effects related to a variety of environmental stressors.

As previously stated, limited data currently exist related to avian health assessments in the northern GoM. This situation is further complicated by the fact that the environmental stressors impacting the system are not mutually exclusive. In that, while we collectively work to restore the northern Gulf ecosystem in the wake of DWH oil spill, there are a variety of concurrent stressors influencing birds and their habitats to include: frequently occurring, relatively small oil spills (BOEM 2018); contaminant laden runoff from agricultural practices and urbanization (EPA 2018); extreme weather events (e.g., hurricanes, drought); and a wealth of complex ecological processes (e.g., predation, parasitism, infectious diseases, competition) being disrupted via loss and fragmentation of habitat. Hence, without very specific and targeted questions, it is and will continue to be, extremely difficult to disentangle all the background noise associated with avian health assessments. Nevertheless, an understanding of the physiological outcomes and ramifications to overall fitness is critical for understanding ecosystem restoration. Towards that end, we present a suite of potentially useful health metrics, brief overview of available tests and procedures, and conclude with next steps for advancing our collective understanding of avian health in the northern GoM.

Given the complexity of the GoM ecosystem, the myriad of interactions associated with avian health assessments, and the vast number of stakeholders involved (e.g., varying objectives and needs), it is beyond the scope of this Chapter to provide specific, testable hypotheses, *per se*. Instead, it is our goal to provide a framework and means to identify the most pertinent and comprehensive health metrics associated with a suite of environmental stressors thought to be driving the system and bring the available data/information to Gulf Coast veterinary schools, rehabilitation facilities, agencies, managers, and others. Below, we provide a brief overview of exposure routes and how each stressor is presumed to disrupt physiological processes, thereby manifesting itself through a demographic response at either the individual or population-level.

Stressors, Exposure Pathways and Physiological Impacts

EXPOSURE PATHWAYS: The detailed and encompassing influence diagram (Figure 10.1) articulates the various exposure routes and associated risks for birds following the DWH oil spill. For some environmental stressors (contaminants), exposure occurs both through external contact with feathers and skin and internally through ingestion (preening and feeding) and inhalation. Hence, the various exposure routes lead to both direct and long-term impacts, which may affect taxa or individuals differently due to variability in life history strategies (see above). For example, we

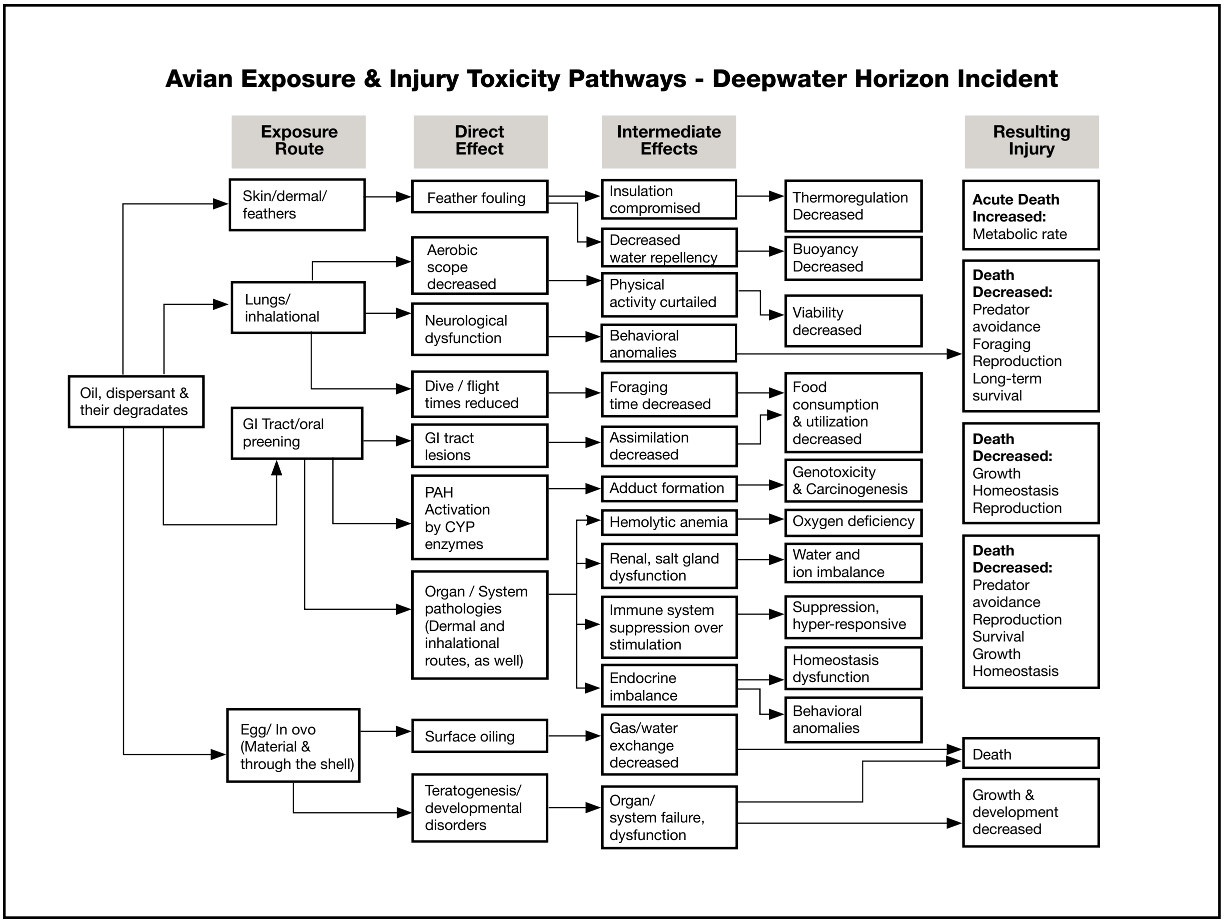

Figure 10.1. *Influence Diagram showing potential routes of exposure, direct and intermediate effects, responses, and fate for exposure to toxicants associated with the Deepwater Horizon Oil Spill (Adapted from Milton et al. 2003 with modifications by Michael Hooper, U.S. Geological Survey).*

know that females deposit both lipophilic and water-soluble compounds into the yolk and albumin, respectively, thereby exposing their embryos throughout development (Lin et al. 2004; Ottinger et al. 2000). Similarly, oils and dispersants on the exterior of the egg are readily absorbed through the eggshell matrix and pores, also exposing developing embryos. The direct and indirect effects of the specific exposure routes also range widely, including physical (e.g., feather fouling), physiological (e.g., neural dysfunction, liver enzyme activation resulting in higher detectable blood enzyme levels teratogenic effects), and functional/behavioral outcomes (e.g., impaired flight and navigation, organ system pathology) thereby impacting individuals through a myriad of mechanisms: all with negative consequences to growth and survival via lethal or sub-lethal adverse outcomes. Hence, the various exposure routes via which some stressors (e.g., contaminants) impact birds, as well as seasonality (e.g., breeding vs. wintering, vs migration), also warrant consideration. The exposure pathways emphasized here are relevant to potential health impacts associated with DWH; however we recognize that there are a variety of other environmental stressors and exposure pathways to also consider, for example sources of contaminants from agrichemicals, wastewater and pollutants allowed under the National Pollution Discharge Elimination Permits, etc.

To facilitate our ability to articulate the physiological relationships, influences, and uncertainties associated with a variety of environmental stressors beyond the DWH Oil Spill, we developed an influence diagram (Figure 10.2) that elucidates the physiological impacts and associated responses for a variety of environmental stressors. In brief, each environmental stressor is associated with one or more physiological and functional responses at the individual-level, while noting the complex interactions and relationships among physiological and functional responses (e.g., disruption of metabolic function can have "trickle-down" consequences for immune function and vice-versa). Further, we link these functional responses with presumed demographic responses and provide a short list of potential monitoring metrics. Details of these metrics, including basic collection protocol, logistical constraints, financial costs and uncertainties associated with each metric are detailed in Table 10.1. Hereafter, we provide an overview of each of the environmental stressors including their impact on physiological processes, as well as an overview of each physiological process with implications to demographic responses. Although decision nodes are not delineated, it is important to consider these in the context of

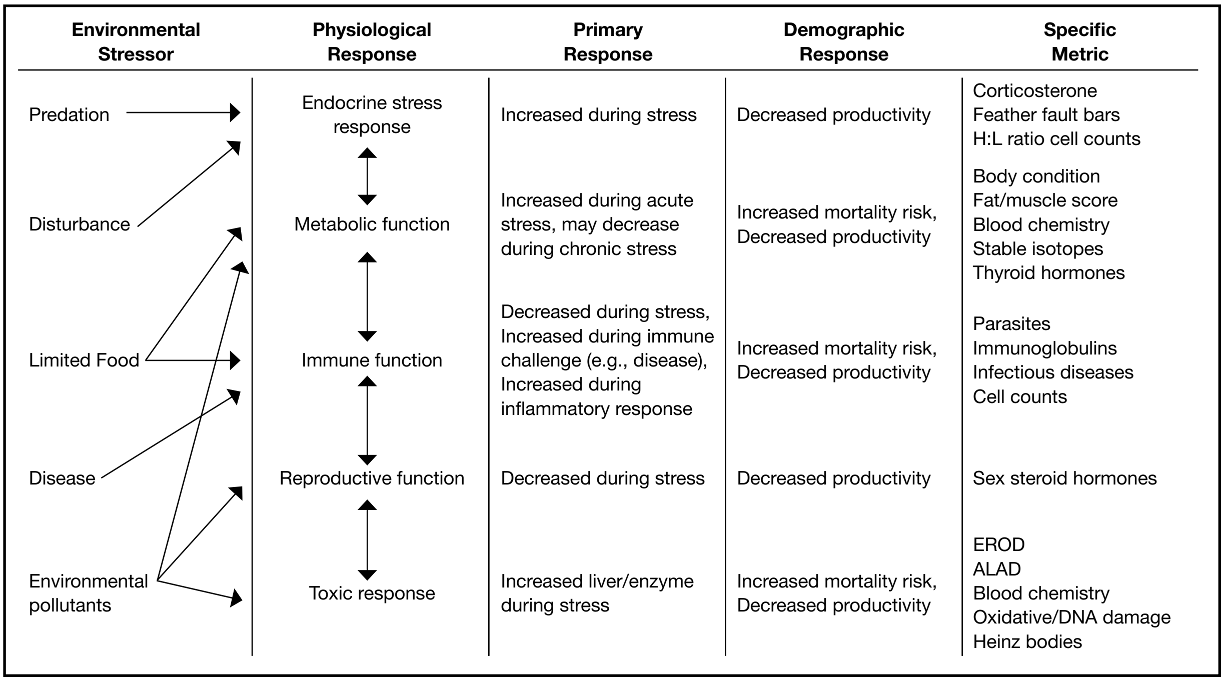

Figure 10.2. *Diagram depicting the physiological responses of individual birds to environmental stressors, the primary and demographic responses associated with that physiological response, and the specific metrics that can be used to measure that physiological response. Double headed arrows indicate that physiological responses interact with each other.*

restoration assessments involving health metrics. Further, the decision nodes will vary with species along with the metrics used to assess health.

Environmental Stressors

PREDATION: Pressure from predation is a biological stressor that can exert short- and long-term impacts (Clinchy et al. 2004), especially during the breeding season (e.g., Ghalambor and Martin 2002), on many avian taxa. Loss of protective foliage and other cover with loss of habitat, urbanization, and other anthropogenic development often contribute to greater vulnerability to predation. Further, climate or weather-related events can also disturb or modify habitat and protective cover, making nests and individuals more visible and vulnerable. Decreased food quality and/or increased energy demands may increase the amount of time spent foraging, when individuals are more vulnerable to predation. The response to heightened risk and frequency of predation includes an endocrine stress response and associated immune system effects. The endocrine stress response will increase during predation events, and can become chronically elevated if predation pressure continues. Management actions including predator control/removal (see all taxa chapters), habitat restoration (see all taxa chapters), provision of safe nesting sites (e.g., nesting islands; see Seabird Chapter 6), or regulation of shoreline development (see Chapters 4 and 7) could mitigate stress associated with predation risk.

DISTURBANCE: Here we define disturbance as any impact stemming from anthropogenic or natural events (e.g., human activities, hurricanes), which may subsequently result in negative effects. More specifically, disturbance leads to an endocrine stress response at the individual level, which subsequently results in negative effects to immune function (Nelson 2005, Burger et al. 2017). This increases indirect mortality risk (e.g., Grace et al.2017), leading to population-level effects. Changes to the energetic demands and the physiological stress response both impact immune functions (Acevedo-Whitehouse & Duffus, 2009). Habitat restoration (see all taxa chapters), regulation of human activities (refer to Chapters 6 and 10) and shoreline development (see Chapters 4 and 7) are management actions that can decrease disturbance-related stress.

LIMITED FOOD RESOURCES: Birds respond to limited food in the short-term by increasing the endocrine stress response and metabolic function (i.e., energy mobilization). However, long-term food deprivation will decrease metabolic function and suppress immune function, with long-term negative effects on productivity and survival. Both food quantity (biomass) and quality (energy density and proximate composition) can strongly affect the reproductive success of avian taxa. The nutritional stress hypothesis posits that food quantity provisioned to chicks affects growth, condition, and survival (Trites and Donnelly 2003), while the junk-food hypothesis posits that food quality is the primary driver (Jodice et al. 2006, Österblom et al. 2008, Lamb et al 2017). These two hypotheses are not necessarily mutually exclusive within a species or systems and may operate differently depending upon the range of available food items in any given year. Changing climate conditions such as drought or excess rainfall events, as well as commercial fishing pressure can impact the quality and quantity of available food (Hooper et al. 2013). Adults and young are also affected by the quantity and quality of prey available during both the breeding and nonbreeding seasons. When food quantity or quality is insufficient, consequences can exist for birds at all stages of their life cycle, including impaired metabolic function, reduced immune system function, and greater vulnerability to disease and parasites. A similar concern of food quantity and quality during the breeding season is also pertinent for birds on staging and wintering grounds in cross-seasonal carryover effects, particularly for waterfowl. Reduction in food quality or quantity can also increase disease prevalence (Lochmiller et al. 1993, Birkhead et al. 1999, Hoi-Leitner et al. 2001, Strandin et al. 2018) through suppression of certain immune functions (e.g., immunoredistribution) when energy is limited (Martin et al. 2006, Bourgeon et al. 2010). The quality of food is also a critical factor in the availability of nutritional resources and this can be particularly important for proper development of young. Regulation of fisheries (see Seabird Chapter 6), removal of invasive species (see Marsh Bird Chapter 4), habitat restoration (refer to Chapters 3-9), prescribed fire (see Marsh Bird Chapter 4), and freshwater management (see Chapters 4, 7-9) are potential management actions that can improve food availability for birds.

DISEASE: Disease-induced mortality diseases and coincident decreases in productivity often occur due to exposure to chronic stressors (e.g., disturbance, predation, limited food, pollutants) that suppress immune functions. Furthermore, changes in global temperature are predicted to expand exposure to certain disease vectors (Harvell et al. 2002, Martin et al. 2010, Pigeon et al. 2013). Chemical contaminants entering the ecosystem via urbanization and agricultural practices can directly or indirectly modify the pathogens present in the environment and diminish the resilience of individuals to disease (Galloway and Handy 2003, Snoeijs et al. 2004, Kelly et al. 2007, Martin et al. 2010, Pigeon et al. 2013, Giraudeau et al. 2014, Lee et al. 2017). Management activities that reduce stress from predation, disturbance, limited food supply and exposure to contaminants should reduce the risk of disease in birds.

ENVIRONMENTAL POLLUTANTS: This environmental stressor may affect avian populations across a range of scenarios, including seasonal exposure for migratory species (breeding versus wintering grounds), spotty exposure for species near agricultural or residential areas (including golf courses) areas, chronic exposure for residential birds living near contaminated areas and waterways, and food chain associated exposure for predatory birds (Lazarus et al. 2016). Pollutants often have direct toxic effects. At higher concentrations, many pollutants may be lethal, while at lower concentration pollutants might compromise reproduction, immune function, predator avoidance, or otherwise reduce survival or overall fitness (Ottinger et al. 2009). Endocrine-disrupting chemicals often have more subtle, non-lethal effects on immune function, thermal resilience, energy balance, and homeostatic maintenance ability (Calabrese and Baldwin 2001; Ottinger and Dean 2011; Carro et al. 2018). Further, there is evidence for multi-generational carry-over effects through epigenetic alterations (Anway et al. 2005). Several management actions could reduce risk of damage to birds from pollutant exposure including promotion of sustainable agriculture (see Chapters 2 and 3), freshwater management (see Chapters 4 and 7), restoration of hydrology (see Chapters 5 and 8), and coastal habitat restoration (refer to Chapters 3-9).

Physiological Response

ENDOCRINE STRESS RESPONSE: Chronic stress can elevate (or in some cases, chronically depress, [e.g., Rich & Romero, 2005]) corticosterone levels, reduce sex steroid hormone production leading to impaired reproductive performance and reduced body condition and overall fitness (Acevedo-Whitehouse and Duffus 2009, Sapolsky et al. 2000), and shorten telomere length (Epel et al. 2004, Hau et al. 2015), which is associated with decreased life span (Heidinger et al. 2012). Immune function also becomes impaired with chronic stress (Sapolsky et al. 2000, Martin 2009) leading to increased vulnerability to disease and parasites, which contributes to diminished lifetime reproductive performance and survival. Measurements of the endocrine stress response include directly measuring corticosterone (feather, fecal, blood), evaluating heterophil/lymphocyte (H:L) ratios as part of a complete blood count (CBC), and counting feather fault bars, translucent bands in the plumage which occur when feathers are being grown under stressful conditions (King and Murphy 1984; Davis et al. 2008, Clark 2015). As such, an assessment of hematocrit and differential blood cell counts can provide critical insight into the health status of individuals.

METABOLIC FUNCTION: Environmental stressors will typically increase metabolic function in the short-term to facilitate rapid response to stressors. However, chronic exposure to environmental stressors will impair metabolic function (Burger et al. 2017). Measures of metabolic function include body condition and fat/muscle score, selected blood chemistry analytes, and stable isotope analysis. Body condition provides a rough measure of available energy reserves and involves mass and body size measurements (Peig and Green 2009). Fat and muscle scoring also estimate body reserves and physical condition. Blood chemistry analyses can provide information about the nutritional status and general health of individuals (Fudge 2000, Campbell 2012, Maness and Anderson 2017). Stable isotope analysis provides information on the dietary sources available to individuals (e.g., Zimmo et al. 2012, Lazarus et al. 2016). Assay of thyroid hormones provides valuable insight into the metabolic status of an individual especially during periods of change, such as maturation and migration. The thyroid system is impacted adversely by exposure to PCBs and other environmental toxicants, resulting in reduced metabolism and impaired pre-migratory fattening; both are essential for survival during migration with cold stress and other environmental conditions (McNabb 2007, Ottinger et al. 2009).

IMMUNE FUNCTION: Several specific measures of immune function are available (e.g., Norris and Evans 2000) and some techniques that are amenable to field collection (Table 10.1) are described in detail. Differential measurements of circulating blood cells can provide insight into the health of individuals, as activation of the immune system and certain pathological states can alter hematocrit and blood cell counts. An increase in hematocrit (packed cell volume) could be due to dehydration (Thrall 2012). On the other hand, a decrease in hematocrit, or anemia, can be caused by blood loss, decreased red blood cell (RBC) production, or increased RBC destruction. Blood loss may be due to gastrointestinal parasites, gastrointestinal ulcers from toxin exposure or foreign bodies, or blood-sucking ectoparasites. Decreased production can result from bone marrow suppression from chronic illness or nutritional deficiencies (Fudge 2000). Increased destruction of blood cells can be due to hemoparasites, oxidative damage from exposure to certain toxins, or inappropriate immune responses (Fallon et al. 2017). An intermediate hematocrit has been associated with increased longevity and lifetime fitness in a migratory passerine (Bowers et al. 2014). The buffy coat is the fraction of whole blood containing white blood cells and thrombocytes. A large buffy coat may indicate infection, inflammation, or injury and is negatively associated with reproductive success in birds (Gustafsson et al. 1994).

REPRODUCTIVE FUNCTION: Reproductive function involves a number of components, including forming pairs and

Table 10.1. *Hierarchical structure of sampling methodologies and avian health metrics with associated logistical considerations to guide decision making by resource managers.*

Invasive Sampling	Sample Collection	Sample	Health Metric	Collection / Preservation of Sample	Information Gained	Cost	Ease of Collection & Processing	Restraints on Sampling or Interpretation
No	Capture & Handling	Direct Assess-ment	Body condition	Measure (wing, culmen, and/or tarsus and body weight)	Current condition (muscle and fat deposits combined)	$	High	High inter-observer variability for some measures
			Ecto-parasites	Count and/or collect visible ectoparasites. If collecting, brush bird and preserve ectoparasites in isopropyl alcohol	Parasite load (negatively correlated with health, and positively correlated with stress)	$	Moderate	Difficult to see and collect small ectoparasites; will vary with breeding status (e.g., increases during incubation); time intensive in the field
			Feather fault bars	Count fault bars on all or a consistent subset of feathers; measure distance between bars (from photograph)	Stress during feather development; feather growth rate	$	High	Difficult to see small fault bars or distinguish large fault bars from many small bars; time intensive in the field, but can be quantified from photographs
			Fat Score	Score fat deposits (clavicle, hips, abdomen)	Rough fat deposit	$	High	Will change with migration, breeding status
			Muscle score	Score keel muscle	Rough muscle condition	$	High	Will change with migration, breeding status
		Feather	Cortico-sterone	In clean ziploc or envelope in dry, cool location (uncontaminated)	Stress during feather growth[a]	$$	High	Must know when feather was grown for accurate assignment of stress causation
			Heavy metals	In clean ziploc or envelope in dry, cool location (uncontaminated)	Contamination	$$$	High	Must know when feather was grown for accurate information gain
			Infectious disease	In clean ziplock, refrigerated or frozen	Susceptibility to specific infectious diseases	$$	High	Not all infectious diseases can be detected in feather pulp
			Stable Isotopes	In clean ziploc or envelope in dry, cool location (uncontaminated)	Nutrition sources during feather growth	$$-$$$	Low	Must know when feather was grown for accurate information gain
	Environ-mental Sampling	Feces[b]	Infectious disease	Collect into tubes, refrigerate or freeze	Susceptibility to specific infectious diseases	$$	High	Not all infectious dieases can be detected in fecal samples
			Cortico-sterone	Freeze (-20°C)	Stress during digestion	$$	Moderate	Best if collected fresh; affected by circadian rhythm, activity, and recent behaviors
			Internal Parasites	Suspention in flotation solution, faecal smear on microscope slide	Presence of gut parasites & eggs	$	Moderate	Difficult to identify species
Yes	Capture & Handling	Blood	Hematocrit	Spun within 30 minutes of sampling	Dehydration, anemia, white blood cell volume	$	High	Best if collected within 10 min of disturbance

Table 10.1 (continued).

Invasive Sampling	Sample Collection	Sample	Health Metric	Collection / Preservation of Sample	Information Gained	Cost	Ease of Collection & Processing	Restraints on Sampling or Interpretation
Yes	Capture & Handling	Blood	Bleeding time test	Gently rock in glass tube containing diatomaceous earth until clotted, room temperature	Clotting ability	$	High	Normal clotting range unknown for many species
			Cell counts	Blood smear on microscope slide & fixed in methanol for 5-10min	Infection, inflammation, stress (heterophil: lymphocyte ratio), hemo-parasites, monocytosis[c]	$	Moderate	Blood smear needs to be fixed immediately; morphology of cells not known in all species
			DNA	Preserve cellular fraction or whole blood in alcohol (e.g., 70% EtOH), buffer, or by freezing (-20°C)	Blood parasites	$-$$$	Moderate	Easily contaminated by outside sources
			Corti-costerone	Freeze plasma/ serum (-20 or -80°C) or preserve plasma/ serum in a 1:2 ratio of 70% EtOH	Current baseline stress	$$	Moderate	Sample must be collected within 3 minutes of disturbance; affected by circadian rhythm, activity, and recent behaviors / interactions
			Thyroid Hormones	Freeze plasma/ serum (-20 or -80°C) or preserve plasma/ serum in a 1:2 ratio of 70% EtOH	Metabolic status	$$$	High	Interpretation depends on detailed individual and population life history knowledge
			Sex Steroids	Freeze plasma/ serum (-20 or -80°C) or preserve plasma/ serum in a 1:2 ratio of 70% EtOH	Breeding investment and territorial behavior	$$	Moderate	Interpretation depends on detailed individual and population life history knowledge
			Immuno-globulins	Preserve plasma/ serum in 1:2 ratio of SDS buffer or freeze plasma/serum (-80°C)	Currently elevated or depressed immune response	$$	Moderate	Normal reference values are not known for many species
			Micronuclei	Blood smear on microscope slide & fixed in methanol for 5-10min	Presence of DNA strand breaks	$	High	Baseline values not known for many species; can be modulated by genotype
			Heinz bodies	Blood smear on microscope slide & fixed in methanol for 5-10min	Presence of denatured hemoglobin in red blood cells	$	High	Can be difficult to detect with light microscopy
			Troponin	Freeze plasma/ serum (-80°C)	Presence of heart damage	$$	Moderate/ Low	Baseline levels not known in most species
			Hemoglobin	Measure with portable hemoglobinometer or estimate from packed cell volume	Oxygen carrying capacity of blood, positively correlated with measures of condition	$	Moderate/ Low	Concentration is strongly affected by age, season and the process of moult; requires equipment (hemo-globinometer) or estimation which is less accurate

Table 10.1 (continued).

Invasive Sampling	Sample Collection	Sample	Health Metric	Collection / Preservation of Sample	Information Gained	Cost	Ease of Collection & Processing	Restraints on Sampling or Interpretation
Yes	Capture & Handling	Blood	Mercury	Freeze whole blood (-20 °C)	Degree of mercury exposure	$$	Moderate/ Low	Cannot distinguish methyl mercury; uptake varies by trophic-level
			Oxidative damage	Freeze plasma/ serum (-80 °C)	Damage due to oxidative processes	$$	Moderate/ Low	Known age populations are best for this analysis, as oxidative damage typically increases with age
			Chemistry[d]	Freeze plasma/ serum (-80 °C)	Nutritional status, liver function, kidney function, metabolism, pancreatic function, muscle injury, immune function	$-$$$	Moderate/ Low	Lipemic or hemolytic samples can interfere with assays; normal reference values are not known for many species (including age- or sex-specific values)
		Liver	Oxidative damage	Freeze (-80 °C)	Damage due to oxidative processes	$$	Moderate/ Low	Known age populations are best for this analysis, as oxidative damage typically increases with age
			Heavy metals	Freeze biopsy (-20 °C), or lyophilize sample	Contamination	$$$	Low	Lethal sampling
		Muscle	Stable Isotopes	Freeze biopsy (-20 °C)	Nutrition sources during muscle tissue growth (higher cell turnover than feathers)	$$-$$$	Low	Usually lethal sampling, but can be biopsied on live birds
		Eggs	Egg shell thickness, quality	Collect and preserve at room temperature	Potential exposure to DDT and certain metals	$	Low	Requires species reference values or a control population for comparison
			Corti-costerone	Sample albumin, freeze	Stress during egg formation, and in ovo exposure	$$	Low	Primarily reflects maternal deposition; sampling can cause embryonic death
			Heavy metals	Heat dried	Contamination and *in ovo* exposure	$$$	High	Reflects maternal deposition
	Post Mortality	Necropsy	Full examination	Refrigerate of freeze fresh caracasses	Cause of death	$	High	Need fresh carasses

[a]Few numbers of fault bars that are small in size reflect good health
[b]Collection of feces requires capture and handling within some avian species.
[c]Cell counts include several different measures. For most of these, high or low values are indicative of poor population health and species reference values must be consulted to determine if values are within an acceptable range for good health. Blood smears can also be used to identify and count hemoparasites, for this measure a low number of parasites indicates good health.
[d]Avian and Exotics advanced chemistry panel: Amylase, Asparate Aminotransferase (AST), Blood Urea Nitrogen (BUN), Creatine Kinase, Calcium, Cholesterol, Chloride, Bicarbonate (CO2), Creatine Phosphpkinase (CPK), Gamma Glutamyltransferase (GGT), Glucose, Lipase, Magnesium, Phosphorus, Potassium, Sodium, Total Protein, Albumin, Triglycerides, Uric Acid

associated pair-bond behavior, copulation and fertilization, nesting behavior, follicle development and egg production, nesting success, productivity, fledging success and parental care. Environmental stressors typically decrease reproductive function of individuals, potentially resulting in a risk for population level impacts both on reproduction and aging processes (Ottinger et al. 1995; Hau et al. 2015; Lamb et al 2016). All components of reproductive function are essential for the overall fitness of the population. Reproductive function is often measured physiologically with sex steroids (e.g., testosterone, estradiol). Testosterone increases in the pre-breeding and early breeding season in the male; estradiol and progesterone in the female are critical to producing sufficient number of eggs to ensure viable offspring and fledging chicks (Adkins-Regan 2005). Interpretation of sex steroid concentrations requires population reference values and a detailed understanding of individual and population life history.

TOXIC RESPONSE: Exposure to contaminants can be assessed by direct measurement of compounds in the tissues and/or eggs of birds. The primary route of exposure in birds is through the diet and secondarily through maternally deposited contaminants into the egg (Lin et al. 2004, Ottinger et al. 2000, 2009). As such, analysis of the egg shell, egg membrane, and egg contents following hatch provide information about the presence of contaminants and potential exposure of the chick. Samples from feathers and feces also provide information on contaminant exposure and cumulated load in the case of feather analyses; fecal analyses provide exposure information over the 24 hour period. Similarly, blood chemistry and analysis for contaminants provide a current dynamic view of exposures to the individual. Physiological responses to contaminants/toxins are measurable by aminolevulinic acid dehydratase (ALAD) to assess exposure to lead (e.g., Scheuhammer 1989); ethoxyresorufin-O-deethylase (EROD) provides a measure of the activation of liver enzymes in response to exposure to toxicants (e.g., Bohannon et al. 2018). Exposure to pollutants can damage DNA leading to negative health effects (Maness and Emslie 2002). Some types of DNA damage can be assessed by the presence of micronuclei in blood cells (e.g., Baesse et al. 2015). Micronuclei are small nuclei created by double strand breaks and chromosomal instability. Proteins exposed to oxidizing agents and pollutants can denature and precipitate inside cells. Denatured hemoglobin forms Heinz bodies in red blood cells which can be detected by light microscopy from blood smears (e.g., Harr et al. 2017).

SAMPLING METHODOLOGIES AND GUIDE FOR DECISION MAKING

In practice, choice of avian health monitoring metric will depend upon the species and question(s) being asked. That is, what information is needed and can the sample be collected from this species safely/ethically? Remember, there is no "silver bullet." As previously discussed, assessing avian health is a complex and inter-twined endeavor given the various concurrent stressors and inter-relationships of physiological functions. Hence, researchers and resource managers will need to clearly articulate the questions, objectives, and data needs. Once the question is identified, a suite of additional issues (e.g., species and life history traits, feasibility of sample collection, validity of assay tests, costs, etc.) will need to be considered. To facilitate decision making, Table 10.1 provides additional information related to a variety of potential health metrics. To that end, we have organized the table in a hierarchical fashion grouped by sampling strategy (invasive vs. non-invasive), type of sample (blood vs. feather vs. tissue), and potential health metric(s) as a means to structure the information. It is our hope that information within Table 10.1 will provide: 1) a foundation to assist researchers and resource managers in identifying the most appropriate avian health metric given a specific question; 2) a means to evaluate trade-offs between costs, field application, value of specific-metric; and 3) a basis to initiate further discussions and coordination as we work collaboratively to unravel the complexities and interconnectedness of avian health issues across the northern GoM.

NEXT STEPS

This section provides suggested next steps that would facilitate the identification and use of health metrics by managers for assessing the success of restoration projects during the process of restoration and for proactively adjusting the project components.

- ★ Create an ad-hoc working group (aka Community of Practice) of scientists and land managers to develop adverse pathway models and further refine the list of appropriate physiological metrics with respect to specific, agreed upon objectives/data needs.

- ★ Conduct literature reviews of avian health assessments across the northern Gulf of Mexico to facilitate communication, coordination, and future collaborations. Laboratory and field studies have characterized physiological response to a range of environmental stressors. However, few regional reviews exist that draw together published literature from the perspective of management and assessment of restoration effectiveness.

- ★ Link physiological metrics with reproductive success, as a means to further evaluate restoration success. Stressors and many identified health metrics ultimately relate to reproduction and successful fledging of chicks. However, it is often difficult to simultaneously monitor individual adult pairs, egg and nest fates, health and growth of nestlings, fledging success, and first year survival, at a spatial and temporal scale that matters. As such, establishing clear linkage of selected physiological metric(s) with reproductive success may provide an opportunity to more easily assess reproductive success and thereby population status. Also, identification of non-invasive and non-destructive biomarkers.

- ★ Develop standardized avian health measurement endpoints and protocols to promote the collection of consistent and comparable avian health data across the northern GoM.

- ★ Develop a data repository for the storage of samples and an online data portal for the collection and sharing of publications, diagnostic reports, etc., as a means of facilitating communication, coordination, and collaboration. Creation of a data repository that is available to researchers and resource managers will provide a dynamic record to assess and predict the efficacy of restoration and management projects.

- ★ Collect and maintain mortality data from wildlife disease diagnostic laboratories serving the GoM to detect trends in health impacts and cause of death in avian species. This information can be maintained within the online data portal referenced above.

- ★ Partner with groups in different regions, including stakeholders and Citizen Science, where appropriate.

CONCLUSION

In summary, avian health assessments represent a literal "Pandora's Box," given the myriad of non-mutually exclusive stressors, potential for multiple physiological processes to be disrupted, compounded by the complexities of different life history traits expressed across the avian community. Our goal here was to: 1) provide a high-level overview of the subject; and 2) put forth a suite of potential metrics and their associated collection costs and logistical considerations as a means to increase awareness and provide resource managers with a basis from which to start thinking about avian health assessments. As the conservation community works to restore the northern Gulf of Mexico, our ability to fully understand and evaluate holistic ecosystem restoration will be improved if we supplement other avian monitoring efforts targeted at abundance and reproductive success, with information to better capture consequences to avian fitness.

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Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

INTEGRATION AND COLLABORATION ACROSS THE GULF OF MEXICO

Authors:
Evan M. Adams (1*)
Auriel M.V. Fournier (2,3*)
Mark S. Woodrey (3,4)

1. Biodiversity Research Institute, Portland, ME
2. Forbes Biological Station–Bellrose Waterfowl Research Center, Illinois Natural History Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Havana, IL
3. Mississippi State University, Coastal Research and Extension Center, Biloxi, MS
4. Grand Bay National Estuarine Research Reserve, Moss Point, MS

(*) Corresponding Authors: **evan.adams@briloon.org, auriel@illinois.edu**

Nelson's Sparrow (*Ammospiza nelsoni*) on marsh surface. Photo credit: Michael Gray

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Chapter 11

INTEGRATION AND COLLABORATION ACROSS THE GULF OF MEXICO

INTRODUCTION

THE GULF OF MEXICO AVIAN MONITORING NETWORK (GoMAMN) partners seek to develop and implement a Gulf of Mexico-wide, coordinated, and integrated avian monitoring program to inform and advance bird conservation, and evaluate restoration efforts in response to the Deepwater Horizon Oil Spill (Fournier et al. this volume, Burger 2017, Baldera et al. 2018). There are other models of coordinated monitoring and research efforts in North America, including: The Northeast Coordinated Bird Monitoring Program (Lambert et al. 2009), the Midwest Avian Monitoring Network (Roth et al. 2015) and the Saltmarsh Habitat and Avian Research Program (SHARP 2018). These organizations have similar goals to GoMAMN; they are trying to make research and monitoring efforts more collaborative and integrative to facilitate conservation successes and learning about the natural world at large spatial scales or across complex ecosystems.

There are many types of bird monitoring efforts in the Gulf of Mexico (GoM); ranging from small-scale, project-based assessments of habitat restoration to state-based surveys coastal bird of populations. Project leads range from those looking to answer scientific questions within a hypothesis testing framework to managers who want to know how many more birds use a newly created marsh island. Such a diversity of projects, objectives, and funding agencies presents the avian monitoring community with a real challenge for understanding population trends, the effects of management actions, and large scale ecological processes throughout the GoM.

COLLABORATION AND INTEGRATION BEFORE MONITORING

Integration

Large scale bird conservation depends on the integration of multiple datasets at the region-wide scale, which requires a community who are working in a coordinated and integrated way (Baldera et al. 2018, Fournier et al. this volume). To maximize the utility of individual monitoring projects, field data should be collected and managed in ways that facilitate timely Gulf-wide analyses that provide assessments of population status and trends, increase our understanding of management and restoration activities, and/or address scientific hypotheses related to ecological processes. Furthermore, it is imperative that data collection for use at the program-level be done in a manner to not diminish the utility of the data to project-level evaluation (NASEM 2017).

Integration is essential to bird conservation. Projects that are integrated with one another may not necessarily have the same objectives, but they are conducted in a complementary manner or allows data collected to be aggregated together. In the context of RESTORE Act-related activities in the Gulf of Mexico region, the integration across project-level monitoring is required to understand bird response at the program-level, or regional scale because of the extreme mobility of birds (Woodrey 2017). From a stakeholder value perspective (Fournier et al. this volume), effectively integrated monitoring projects will be:

Designed to support assessments or analyses that combine multiple project-level efforts to address questions at the program level. Such projects would be:

1. Aligned with existing monitoring priorities,
2. Collaborative and communicative with partners inside and outside of the project, and
3. Focused on data accessibility and data sharing.

The GoMAMN Community of Practice plays a critical role in integrating monitoring projects across a broad geographic scale. Through the sharing of ideas, expertise, methods, and data via the Community of Practice, Trustee Council members and their representatives will be able to reliably report the effects, at least for birds, of the billions of dollars being spent to make the GoM "whole again."

In this chapter, we describe how integrated monitoring efforts across the GoM inform not only the bird conservation community but also provide critical data to State Trustee Implementation groups, the RESTORE Trustee Council, federal, state, and non-governmental funding agencies, etc. to confidently report back to the citizens around the Gulf regarding the outcome of their restoration efforts. Further,

Grassland bird workshop. Photo credit: Mark Woodrey

we provide guidance for integrated bird monitoring across the region. Integration must occur both before and after a monitoring project begins and we use these two periods to structure our narrative and recommendations.

Alignment and Collaboration

Monitoring efforts in the GoM should be aligned with established regional priorities. The taxonomic chapters (Chapters 3-9) were written to identify and integrate priorities from across state and federal conservation plans throughout the Gulf. Sources include state wildlife action, joint venture, bird conservation region, Partners In Flight, and species specific plans (FWC 2012, TPW 2012, ADCNR 2015, Holcomb et al. 2015, MMNS 2015, PIF 2017). Consulting these plans as part of the study design process is essential to ensure integration of a particular project within a state-wide or regional context. Further, following these priorities directs monitoring practitioners to the selection of appropriate species and habitats, monitoring endpoints, and appropriate methods for data collection and storage. Following established priorities facilitates data from all monitoring projects to be integrated together to address larger scale questions.

Collaboration is a second important consideration for any monitoring effort. Through a collaborative process, practitioners can increase the long-term sustainability of a project, reduce inefficiencies and redundancy in monitoring efforts, and maximize long-term conservation success at the GoM-wide scale. Projects involving several partners can work together towards a larger goal, and also leverage more resources to make a project more cost-effective. Such collaborations can be difficult to achieve as they take extensive time and coordination. To provide some assistance with promoting region-wide collaborations, the GoMAMN Community of Practice, regular meetings and website are designed to help monitoring practitioners identify potential project partners or collaborators as well as promote communication.

Study Design

Development of a rigorous, question-driven study design is a critical step in science-based conservation, including a robust monitoring program. Following this principle, we outline several explicit elements to be present in a study which would be statistically sound and maximize data integration (Figure 2.2). These include having a clear objective/hypothesis, appropriate sampling units, and focal species, standardized data collection practices, appropriate analysis outlined, and alignment with existing conservation priorities and monitoring endpoints (Figure 2.2). Because these are common elements of a rigorous study design, we do not go into detail here, as many other resources exist (e.g., Quinn and Keough 2002). We strongly recommend those designing new avian monitoring efforts around the GoM should consult the taxonomic chapters in this document (Chapters 3-9), consult the GoMAMN website, and engage the GoMAMN Community of Practice to assure alignment and integration with current monitoring priorities (see resources at: gomamn.org/products).

Response Variable Selection

Once a clear objective/hypothesis is defined, an appropriate sampling unit (be it a bird, a feather, a wetland, restoration project, a county, a state, or a region) needs to be established. An effective sampling unit is one that not only provides the correct scale of inference for the respective question, but can also be rolled up to larger spatial contexts for integration with other datasets. At the same time, taxa-appropriate sampling frames, stratification, and randomization should be carefully incorporated when determining the correct sampling unit, to ensure that monitoring data from each project can be rolled up for larger scale inference.

A necessary component of coordinated and integrated bird monitoring is having agreed upon monitoring endpoints (Figure 2.2). Table II.4 in NASEM (2017) provides a recommended set of monitoring metrics for construction and performance monitoring, and the Bird Restoration Monitoring Chapter covers these topics in more depth. Baldera et al. (2018) provides a suite of 10 performance metrics that are applicable to multiple project types. While there are many endpoints a project might employ to measure the taxonomic group, the taxa specific chapters of this document (Chapters 3-9) provide specific recommendations related to both avian response metrics and non-avian covariates.

COLLABORATION AND INTEGRATION AFTER MONITORING

After monitoring has been implemented, the primary mechanism for collaboration and integration is data sharing. Over the past several decades the types and amounts of data that are available have increased dramatically. As a result data management has become even more important for post-monitoring project collaboration, with the usefulness of data sets being defined by its stability, understandability, and accessibility (British Ecological Society 2015, Broman and Woo 2017, White et al. 2013). Well-managed data sets have incredible power to answer questions and fuel collaborations but dedicated effort and expertise are required to maximize their utility to the larger GoM community. To this end, this section first describes the components of a healthy data management system then provides data management recommendations for the GoMAMN Community of Practice to maximize the integration goals of the group (Figure 2.2).

The role of data management is clearly valued by regional stakeholders and GoMAMN partners, and vital to achieving integration and collaboration to support large scale inference about birds at the program scale (Strasser et al. 2012, British Ecological Society 2015). Data management begins with data observation/collection and ends when the data are stored, stable, well-described by metadata, and available for other researchers to use (Strasser et al. 2012, Broman and Woo 2017, Borer et al. 2009, Hart et al. 2016).

The complete data life cycle comprises the following general steps:

1. Data collection and/or generation,
2. Metadata definitions and descriptions,
3. Quality assurance and quality control,
4. Data storage, and
5. Data sharing and accessibility.

While there are more aspects to data management than just these points (see NASEM 2017), this broadly framed data life cycle relates to GoMAMN stakeholder data management values (Figure 2.2). There are several broad recommendations that would benefit the GoMAMN Community of Practice. First, coordinating across project-level monitoring efforts, with others working with the same species or similar species suites, habitats or questions should be done whenever possible. Second, all data collection should have a data management plan to ensure availability to the broader scientific community in a timely manner. Third, for any given project, additional non-avian covariates (e.g., abiotic data, habitat information, survey conditions, prey availability, etc.) identified in the Taxa chapters (see Chapters 3-9) should be collected and properly stored wherever practicable.

A data management plan should address the acquisition, development, storage, and transfer of data, and include information about the management of metadata, including which metadata standard will be used. What follows are a description of recommendations for each of these areas of the data life cycle for the GoMAMN Community of Practice:

DATA COLLECTION: Data should be collected in a standardized way (i.e., using standard format hard copy field data sheets and standardized digital data entry formats) for the entirety of the monitoring project and among collaborative, or program-level projects. Once data are collected, free and open tools like R (www.r-project.org/) and SQL should be used to help track and organize any data manipulation that subsequently occurs. R and SQL allow for the documentation of data manipulation and management through scripts, which promotes transparent communication and reproducibility of these tasks. These scripts should be archived with data, and published with all papers and reports and take advantage of cloud-based code archiving in combination with version control through resources such as Github and BitBucket that support collaboration and documentation (Huang and Gonzalez 2016, http://swcarpentry.github.io/git-novice/). Resources such as the Data Carpentry Ecology Spreadsheet and R lessons are openly available for learning about data management practices for entering, and working with data in a reproducible and open way (Bahlai and Teal

2017, Michonneau et a. 2017, Martinez and Poisot 2017, datacarpentry.org/R-ecology-lesson/, datacarpentry.org/spreadsheet-ecology-lesson, datacarpentry.org/sql-ecology-lesson/). The GoMAMN Community of Practice, through its members, serve as a forum for the development of guidance for data management plans content and documentation. This guidance will ensure consistent, clear, and accessible data management plans across taxa as well as the region.

METADATA: Standardized and detailed descriptions of the data itself, notes regarding methodology used to collect the data, and other data-related comments, are all a part of metadata and are necessary to provide the appropriate context to future data users. There are many different metadata standards available for a variety of types of data (NASEM 2017); the most appropriate metadata standards will depend on the nature of the monitoring data and the needs of the monitoring practitioner. The Federal Geographic Data Committee (FGDC) and International Standards Organization (ISO) have commonly used metadata content standards for geographic data. For ecologically-oriented data the Ecological Society of America has developed an Ecological Metadata Language (EML) (Michener et al. 1997, https://knb.ecoinformatics.org/#tools/eml). While there are many options, it is important to identify which is the best for your project and determine what others in your community consistently use. Standards for consistently describing methodologies and concepts in a community (i.e., a controlled-vocabulary) are also considered metadata and are critical to successful communication with a scientific community (NASEM 2017).

QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC): All data collection protocols in the Gulf of Mexico should have QA/QC protocols to ensure data entry mistakes are minimized, and errors that do occur are detected and corrected before data are stored, analyzed, or shared. Necessary and sufficient QA/QC processes vary depending on the type of data and methodology used for data collection and management. The Environmental Protection Agency has a series of standards for measuring contaminants (epa.gov/measurements/resources-assessing-measurements) and the U.S. Integrated Ocean Observing System (IOOS) has described detailed procedures for standards in dealing with ocean data (http://www.earthobservations.org/geoss_dsp.shtml). It is important for QA/QC procedures to occur before data are submitted for long-term storage because errors will be more difficult to detect and correct as time passes.

DATA STORAGE: Considerations for both short and long-term data storage plans are needed for data security, stability, and standardization over the course of the project and beyond. A plan for managing physical data sheets is important to prevent damage, destruction, or misplacement. Onsite digital storage of data is also important to consider and should include digital backups on multiple physical drives or servers. Digital storage with backup protections is also important to ensuring that each individual storage device has the longest lifespan possible, and that data are stored in many places to ensure the lifespan of the data itself is as long as possible. There are many secure online data portals for storing ecological data for the GoM: the Gulf of Mexico Coastal Ocean Observing System (GCOOS), the Gulf of Mexico Initiative Information and Data Cooperative (GRIIDC), the Data Integration Visualization Exploration and Reporting (DIVER) tool, the Natural Resource Damage Assessment and the National Oceanic and Atmospheric Administration Environmental Response Management Application (ERMA), among many others (NASEM 2017). Choosing a data portal is a complex decision but several important characteristics should be considered, including selecting a portal that is reliable and accessible to the Community of Practice, can hold a wide variety of data types, and has sufficient documentation for ease of use as a data contributor as well as a data user.

DATA SHARING: All data collected should have a data sharing agreement that allow access to the data for the broader scientific community as quickly as possible. The quicker the data becomes available the quicker it can be used to inform GoM bird conservation. Once storage has been established, a plan for data sharing and long-term accessibility should be implemented. Program-level questions relating to conservation and management can only be met with robust data sets that are created with forward-thinking data sharing plans from each individual project. Clearly data storage and sharing are linked, particularly via online data portals, but data accessibility is only achieved through buy-in from individual project leaders. Data accessibility can vary depending on the source of the monitoring funds and the preferences of the principal investigators, but all data management plans need to account for sharing data among scientists and managers.

There are several accepted categories of data sharing:

1. Open and fast - data are made available immediately after the project is completed, or perhaps even before the project is completed
2. Open after embargo - data are archived immediately after a project is completed, but an embargo is put on their accessibility to others for a set amount of time to allow the creator's first chance at publication,
3. Open to a select group - data are archived immediately after a project is completed but access to those data is only open to a select group of people,
4. Open with permission - data are archived immediately

Integration Recommendations

The stakeholders value integration of data sets for a variety of reasons, perhaps most importantly that this approach will allow scientists and managers to reduce uncertainty around hypotheses at both the project- and region-levels. Below is a list of stakeholder values with respect to study design, data collection, and data management and sharing. While these are mentioned in the previous sections, highlighting them here emphasizes both their importance and their broad applicability in this developing regional avian monitoring strategy. Adherence to this guidance will ensure an effective, efficient, and widely applicable framework to address regional concerns and questions.

★ Communicate with the GoMAMN Community of Practice before the beginning of monitoring project to coordinate data collection and management.

★ Have a written data management plan as a part of every monitoring project.

- Reference the NAS Gulf Monitoring document for specifics on data management and additional data management references (NASEM 2017).
- Include metadata standards as a part of every data management plan.

★ Collect all monitoring data in a standardized way (i.e., using hard copy field data sheets and standardized digital data entry formats).

★ Use the same sampling protocols as others in the Gulf of Mexico who work with the same species or similar communities, are addressing similar questions, or evaluating the same habitats in a different area of the Gulf.

★ Enter data such that it is usable and readable by people and computers (learn how here: www.datacarpentry.org/spreadsheet-ecology-lesson).

★ Use open access tools like R (www.r-project.org/) and SQL to help track and organize data manipulation (learn how here: Michonneau et a. 2017, www.datacarpentry.org/R-ecology-lesson/ www.datacarpentry.org/sql-ecology-lesson/).

★ Discuss monitoring project ideas and designs with stakeholders, including the GoMAMN Community of Practice to coordinate and integrate critical study design and data management principles before embarking on a project (see resources at: gomamn.org/products).

★ Archive all data as soon and openly as possible. The faster data become open and available, the faster we can apply these data to critical conservation questions regarding bird resources of the Gulf of Mexico.

★ All published data sets using our stakeholder values should reference the group, the protocol used, and should include the data set, where applicable. This approach will allow researchers and land managers to more easily, openly and readily access the experience and practical knowledge of more seasoned researchers across the region.

While each of these recommendations are suggestions, the GoMAMN partners hope that these rules provide assistance for those who have not worked extensively in the field of data integration and management. If such guidelines are adopted consistently in the Community of Practice, then regional goals of estimating population status or understanding the effects of management actions will be more achievable.

after a project is completed, but are not accessible without first contacting the data collectors as obtaining permission, this would be appropriate for datasets that contain sensitive information about species, places or people.

The bird conservation stakeholders across the Gulf of Mexico strongly value an open and fast data sharing policy when every possible, because it provides the fewest impediments for evaluating and exploring time-sensitive program-level questions.

IDENTIFYING PROGRESS IN MONITORING INTEGRATION

Integration, just like reducing uncertainty around questions involving management actions and ecological process, is a goal to be worked towards. We note below several signs of progress, that would indicate integrated and coordinated bird monitoring in the Gulf of Mexico in five years.

★ **GoMAMN** Community of Practice meetings occurring on a regular basis with results from old projects and collaborations being used to develop and support for new projects.

★ **A GoMAMN** monitoring project self reporting portal is created and being actively populated by stakeholders, including the GoMAMN Community of Practice, such that all monitoring data collection efforts can be tracked and reviewed to better connect members of the community to promote collaboration more broadly and serve as the basis for reporting on our successes toward bird conservation in the Gulf region.

★ **Monitoring** data across species, taxonomic groups, habitats, and questions are being collected in a coordinated framework to support region wide analyses. Progress towards this goal will be evaluated during regular GoMAMN Community of Practice meetings. Many of our stakeholders view program-level analyses as being the most feasible in the next five years, as well as being highly valued.

★ **Data sharing** becomes a common ethos across our stakeholders, including the GoMAMN Community of Practice. Further, as individual monitoring projects are completed, data—along with their respective metadata — are being archived in suitable and supported repositories.

★ **Consensus** among stakeholders and the GoMAMN Community of Practice regarding the selection of a specific online data portal that is consistently used for storing and archiving all avian monitoring data in the Gulf region.

Coordinated, collaborative, integrated avian monitoring is essential to advancing bird conservation in the GoM, and to supporting full GoM ecosystem restoration in response to the Deepwater Horizon Oil Spill. By working together in a deliberate way GoMAMN partners can ensure that their data has the greatest possible value to the birds they monitor, as we work together to conserve bird populations at many scales and through many challenges.

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Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico

CONCLUDING REMARKS

Author:
R. Randy Wilson*

U.S. Fish and Wildlife Service, Migratory Bird Program, Southeast Region, Jackson, MS
(*) Corresponding author: randy_wilson@fws.gov

Lesser Scaup (*Aythya affinis*) with snail. Photo credit: Ron Bielefeld

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Chapter 12

CONCLUDING REMARKS

Following the Deepwater Horizon oil spill in 2010 (DHNRDAT 2016), early efforts to determine pre-spill baseline conditions for birds highlighted the lack of adequate data to inform decision-making, as well as, the lack of any comprehensive, integrated approach that would permit the evaluation of future on-the-ground restoration efforts (see Bjorndal et al. 2011). Using this lack of coordination and inadequate data as an impetus, the bird conservation community organized themselves (e.g., Gulf of Mexico Avian Monitoring Network [GoMAMN]) to facilitate discussions and monitoring in a more coordinated and structured approach to better understand bird-habitat relationships and inform conservation decision-making across the northern Gulf of Mexico (GoM). These collective experiences and discussions led to the creation of these Strategic Bird Monitoring Guidelines.

Not surprisingly, there are many data gaps and uncertainties in our current knowledge of bird-habitat conservation along the northern GoM (Brasher et al. 2012, Love et al. 2015, Vermillion and Wilson 2018). Furthermore, the bird conservation community has historically struggled to integrate monitoring into large-scale management questions nor addressed underlying assumptions due to a myriad of challenges (e.g., lack of agreed upon goals and/or objectives, differing agency and organization mandates and data needs) as outlined by the U.S. North American Bird Conservation Initiative Monitoring Subcommittee (NABCI 2007). Yet meeting these challenges and understanding the many intrinsic (e.g., fitness, productivity) and extrinsic (e.g., habitat, food resources) factors governing bird populations is critical for the conservation of >500 species of birds that utilize the northern GoM for all or part of their annual life cycle (Burger 2017, 2018).

A review of large-scale bird monitoring efforts by Bart (2005) suggested that most monitoring efforts focused on bird abundance (population-level metric) with relatively few efforts incorporating measures of fitness (individual-level metric) as a means to understand changes in bird populations. Accordingly, we need to understand the mechanistic factors affecting individuals (e.g., physiological stressors; see chapter 10) to interpret population-level responses. For example, Lamb et al. (2016) found Brown Pelican (*Pelecanus occidentalis*) chicks with lower body condition and higher corticosterone levels were less likely to fledge; with reproductive success and nestling corticosterone levels strongly related to nutritional condition. Given the potential for immigration and emigration of individuals between and among sites, the decoupling of individual fitness from a population-level response has the potential to lead to erroneous conclusions when monitoring habitat restoration projects at different spatial and temporal scales (Frederick et al. 2009 and references therein). Hence, it is important for the conservation community to embrace a set of agreed upon objectives that reflects both individual-level and population-level metrics in the context of reducing uncertainty surrounding large-scale restoration efforts (Doren et al. 2009, NASEM 2017, Baldera et al. 2018).

This document represents a thoughtful and long-term response to the problem of monitoring birds across the northern GoM. As suggested by Lyons et al. (2008), monitoring data are most valuable when collected in a cost-effective and scientifically robust fashion that facilitates learning and is relevant to stakeholder needs and values. To that end, it is important to recognize the distinct roles monitoring can play within a decision context: 1) provide information related to changes in dependent variables, 2) evaluation of restoration effectiveness, and 3) facilitate improved management through learning by

Brown Pelican (*Pelecanus occidentalis*) with chicks. Photo credit: Juliet Lamb evaluation of key uncertainties and assumptions (Nichols and Williams 2006, Lyons et al. 2008). Within these Strategic Bird Monitoring Guidelines, the chapter authors utilized stakeholder values (see chapter 2) and fundamental objectives articulated by Fournier et al. (In Press), in concert with the above referenced roles of monitoring (Lyons et al. 2008) to articulate a vision for bird monitoring across the northern GoM. Specifically, the authors have: 1) identified a suite of key data gaps and associated uncertainties underpinning bird-habitat conservation, and 2) proposed recommendations to advance our collective ability to monitor bird-habitat relationships using a coordinated and structured approach to facilitate the implementation and evaluation of restoration actions in an adaptive management context (DHNRDAT 2017).

The information presented herein provides a means to design avian monitoring programs that address key uncertainties and assumptions that are relevant to multiple stakeholders at large spatial-scales. Due to the myriad of potential ecological interactions and inter-relationships of ecological and climatic events presumed to drive bird populations, this agreement on large-scale data gaps and *a priori* hypotheses is an essential tool for the evaluation of restoration actions across the northern GoM (see NASEM 2017). Recognition and acceptance of the key data gaps and uncertainties presented here, not only provides a strong foundation to further collaboration and integration of monitoring efforts across agencies and organizations implementing avian monitoring projects, but also provides a basis to enable collaboration and integration across resource groups (e.g., fisheries, water quality, etc.). For example, a review of data gaps underpinning restoration and management issues across avian taxa groups (Chapters 3-9) suggests that a large degree of uncertainty exists across taxa about the effects of coastal development (e.g., habitat loss/fragmentation), climatic processes (e.g., storms, sea-level rise), and altered freshwater flow regimes (e.g., changes in salinity). All of these system stressors disrupt a variety of ecological processes and are beyond the avian Community of Practice's ability to track or assess without assistance from the larger conservation community. Thus, it will be imperative that the conservation community work in a collaborative and integrated manner across the various monitoring Community of Practices (e.g., water quality, habitat mapping, fisheries, etc.) to evaluate system stressors and ecological processes that span resource groups in a manner that reduces uncertainty and improves decision making (see chapter 11). To that end, the identification of values and priorities within and across other resource groups (e.g., fisheries, marine mammals, sea turtles, water quality, habitat, etc.) is an important first step.

From the onset, GoMAMN has endeavored to create a forum by which the conservation community can identify and agree upon a set of core values and monitoring needs as a means to maximize the usefulness of bird monitoring data to inform decision making and advance bird conservation across the northern GoM. The publication of these Strategic Bird Monitoring Guidelines represent the collective views of more than 100 scientists, land managers, and program managers (i.e., stakeholders in both bird conservation and restoration outcomes). It is with this same partnership mindset that GoMAMN anticipates the implementation of a coordinated and collaborative avian monitoring program and future refinements to the strategies outlined herein as new data and knowledge become available. To that end, these Strategic Bird Monitoring Guidelines represent significant progress towards: 1) the identification and agreement of key data gaps and assumptions underpinning bird conservation across the northern GoM, and 2) providing a platform to integrate monitoring into conservation decision-making across a diverse group of stakeholders. Both of which address obstacles that have historically hindered large-scale, coordinated bird monitoring, especially at scales as large as the GoM. The challenge now lies within the realm of acceptance and implementation. To address this new challenge, GoMAMN anticipates the various conservation partners (e.g., trustee implementation groups, restoration program managers, bird conservation groups, non-bird conservation groups, academia, etc.) will utilize information presented here to guide and focus their respective work to address key data gaps and assumptions underpinning bird-habitat conservation. Furthermore, acceptance of the values and priorities outlined herein will foster increased collaboration and integration not only within the bird monitoring Community of Practice, but also across other monitoring Community of Practices and stakeholders, such that we (collectively) work to reduce uncertainty and advance bird-habitat conservation in an efficient and effective manner across the northern GoM. ❦

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The Gulf of Mexico Avian Monitoring Network is a self-directed, non-regulatory network of conservation professionals. Partners within the Network share information and expertise to facilitate and coordinate development of monitoring plans that address contemporary and future needs of bird populations and their habitats across the northern Gulf of Mexico region.

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