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A COMPREHENSIVE PLAN FOR IN-WATER SEA TURTLE DATA COLLECTION IN THE US GULF OF MEXICO

June 2023

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Table of Contents

List of Tables

List of Figures

Executive Summary

The *Deepwater Horizon* Open Ocean Trustee Implementation Group (OO TIG) released a Final Open Ocean Restoration Plan 2 in 2019, which included a project titled *Developing a Gulf-wide Comprehensive Plan for In-water Sea Turtle Data Collection.* This document, *A Comprehensive Plan for In-water Sea Turtle Data Collection in the US Gulf of Mexico* (Plan), is the culmination of that OO TIG project. This Plan serves as the OO TIG project's technical report as well as a framework for a biologically and statistically-sound plan to support coordinated in-water sea turtle data collection in the United States (US) Gulf of Mexico (GoM) to determine sea turtle abundance and population trends.

The purpose of this Plan is to act as a guide for collecting biologically and statistically robust, in-water sea turtle data in a comprehensive, coordinated, and standardized fashion in the US GoM. Several sea turtle in-water monitoring efforts are underway in the GoM; however, additional coordination and standardization of these efforts will benefit current restoration and recovery objectives. These efforts will aid in restoration project design, assess long-term effectiveness of restoration activities, and create abundance and distribution baselines across the GoM. This Plan provides guidance for researchers investigating sea turtle abundance and demographic questions, as well as for management agencies and restoration planners.

A Steering Committee (SC) was assembled to develop this Plan and to recommend a coordinated approach to the formulation of an improved understanding of sea turtle population baselines in the GoM, from which determination of large-scale population changes, effects of specific threats (e.g., oil spills, anthropogenic hazards), and effects of changes in ocean conditions (e.g., climate change) can later be evaluated. In crafting this guidance, the SC considered species distribution and life history characteristics, spatial and logistical considerations, level of effort required to detect trends, methods available and the pros and cons of each, associated assumptions and biases with suggested monitoring methods, and standardization of data collection.

Given the current level of data available, the SC has recommended species monitoring in two main phases in neritic and oceanic waters, with additional recommended sampling for surface pelagic drift communities.

The two phases in this Plan focus on 1) monitoring a limited number of sites in the first 5 to 8 years, followed by 2) a refined monitoring design. To support implementation of this Plan, the SC also considered broader programmatic needs, including supplemental data collection, program and data management, potential international partnerships, program expansion, and applications including future technology.

Abbreviations

AUV	autonomous underwater vehicles
CMR	capture-mark-recapture
cm	centimeters
CPUE	catch per unit effort
DWH	*Deepwater Horizon*
eDNA	environmental DNA
EFH	Essential Fish Habitat
ESA	Endangered Species Act
GoM	Gulf of Mexico
GoMMAPPS	Gulf of Mexico Marine Assessment Program for Protected Species
GPS	Global Positioning System
LCE	Lead Coordinating Entity
NOAA	National Oceanic Atmospheric Administration
nm	nautical miles
NOAA Fisheries	NOAA National Marine Fisheries Service
NASA	National Aeronautics and Space Administration
OO TIG	Open Ocean Trustee Implementation Group
PDARP	[DWH Final] *Programmatic Damage Assessment and Restoration Plan*
Plan	*Comprehensive Plan for In-Water Sea Turtle Data Collection in the US Gulf of Mexico*
PSAT	pop-up satellite archival tags
SC	Steering Committee
SCL	straight carapace length
SCUBA	Self-Contained Underwater Breathing Apparatus
SPDC	surface-pelagic drift community
Stantec	Stantec Consulting Services Inc.
UAV	uncrewed aerial vehicle
US	United States

1.0 Introduction

Five species of sea turtles inhabit the Gulf of Mexico (GoM): Kemp's ridley (*Lepidochelys kempii*), loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*). Kemp's ridley, loggerhead, green, and hawksbill sea turtles are in the family Cheloniidae (i.e., hard shells), whereas leatherback sea turtles are in the family Dermochelyidae. Kemp's ridley, hawksbill, and leatherback sea turtles are globally listed as endangered under the federal Endangered Species Act (ESA) (16 United States [US] Code Section 1531 et seq.). Loggerheads in the GoM belong to the Northwest Atlantic Ocean distinct population segment and are listed as threatened under the ESA. Loggerheads are the only sea turtle for which ESA critical habitat has been designated in the GoM. Green turtles in the GoM belong to the North Atlantic Ocean distinct population segment and are listed as threatened under the ESA.

Sea turtles exhibit complex life histories, highly migratory behavior, delayed maturity, and long lifespans. They are challenging to sample in-water, and assessments of abundance and trends have principally focused on information collected on nesting beaches and from aerial surveys. Sampling challenges (spatial constraints due to the overall size of the GoM, logistical constraints due to cost and lack of long-term funding availability, timing, and lack of human resources/staffing required to survey the entire GoM in all regions, etc.) have resulted in an insufficient understanding of GoM sea turtles. In an assessment by Valverde and Holzwart (2017), this knowledge gap was described as, "The in-water abundance of the five species of sea turtles that inhabit the waters of the Gulf of Mexico is difficult to ascertain given the lack of long-term, systematic studies. Indeed, the Gulf may arguably be the most data-deficient basin in terms of its sea turtle populations."

Despite remaining important information gaps, numerous localized sea turtle in-water (i.e., non-nesting) studies have been undertaken in the GoM (Eaton et al. 2008; Valverde and Holzwart 2017). Coordination, standardization, and expansion of these efforts would be the basis for a thorough assessment of sea turtle population change. Further, there is a need for a biologically and statistically sound plan, and the resulting data, to guide restoration project planning, assess long-term effectiveness of restoration activities, and create abundance and distribution baselines across the GoM. Coordinated and standardized monitoring protocols will facilitate integration and comparisons across multiple projects and evaluation of region-wide restoration efforts. More comprehensive and standardized data collection and analysis will improve on and provide critical baseline information that was incomplete when the *Deepwater Horizon* (DWH) spill occurred (e.g., in-water relative abundance, in-water distribution, immigration/emigration). Not having that information hindered the ability to fully assess certain aspects of the injury (McDonald et al. 2017) and is still a problem today.

The purpose of this *Comprehensive Plan for In-water Sea Turtle Data Collection in the US Gulf of Mexico* (Plan) is to act as a guide for collecting biologically and statistically robust, in-water sea turtle data, in a comprehensive, coordinated, and standardized fashion. Data collected according to this Plan will be used to inform GoM sea turtle population assessments and will improve the ability to assess rates of change. This Plan considers the following: data collection; scientific approaches; existing methodologies and technologies; complementary data; data and program management; and future considerations, such as key partnerships and emerging technologies. This Plan is intended to guide the future formation of coordinated sea turtle in-water survey and population monitoring activities in the GoM.

Funding for this Plan was provided by the Open Ocean Trustee Implementation Group (OO TIG) through selection of the project in the *OO TIG Final Open Ocean Restoration Plan 2/Environmental Assessment: Fish, Sea Turtles, Marine Mammals and Mesophotic and Deep Benthic Communities*. The National Oceanic and Atmospheric Administration (NOAA) serves as the Implementing Trustee for the project, with support from the Department of the Interior. NOAA entered into an agreement with the National Fish and Wildlife Foundation to provide project management and Plan development.

The overarching goal of sea turtle restoration in the GoM following the DWH oil spill is to implement an integrated portfolio of restoration approaches to address all injured species and life stages (hatchling, juvenile, and adult) in areas of the GoM and Atlantic Ocean with geographic and temporal relevance (DWH NRDA Trustees 2016). Standardized monitoring protocols and Gulf-wide monitoring will provide important context for the evaluation of sea turtle restoration efforts across the GoM.

The ability to detect and monitor long-term sea turtle population trends is essential to informing population status assessments, threat assessments, and tracking recovery progress, and will help inform ESA Status Reviews, ESA Section 7 Consultations, and ESA Section 10 permits. This concept was outlined in the DWH NRDA *Programmatic Damage Assessment and Restoration Plan* (PDARP; DWH NRDA Trustees 2016), which stated, “Information on sea turtle spatiotemporal distribution, migration patterns, life history parameters, and habitat use is critical for interpreting population trends, improving sea turtle population models, and helping assess progress toward recovery goals.”

This Plan is primarily focused on broad-scale *in-water* data collection. Other broad-scale data collection programs, such as aerial surveys, are recognized as essential for sea turtle population assessments across the GoM and are integral to successfully determine and monitor population trends. Aerial or other non-strictly in-water data collection programs have been covered in other documents but are not discounted; accordingly, Section 4 of this Plan discusses supporting data collection methods.

1.1 Rationale

The goal of this Plan is to provide strategic guidance for coordinated in-water data collection efforts in the GoM and to establish standardized monitoring protocols. This Plan will guide future surveying and sampling to fill critical data gaps to assess trends in sea turtle populations and collect associated information. Demographic information such as age-specific and sex-specific survival, age at sexual maturity, and other vital rates are necessary to interpret population changes. Changes in these rates drive changes in abundance over time and space. This information is fundamental to evaluating the overall effectiveness of GoM sea turtle restoration projects, habitat conservation measures, and potential impacts from climate change and other human activities.

This Plan provides guidance for in-water data collection methodologies. The rationale for long-term implementation is as follows:

- Data collected will inform understanding of sea turtle distribution, survivorship, recruitment, population structure, abundance, and trends.
- Data collected will inform the development and evaluation of ongoing DWH sea turtle restoration efforts.
- Data collected will inform regional sea turtle recovery and conservation programs.
- Data and analyses will span inshore, nearshore, and offshore habitats to provide US GoM data. It is anticipated that future GoM studies would seek collaborations with international partners to expand monitoring outside of US waters.

1.2 Objectives

The four major objectives of this Plan are:

- Identify and characterize biologically and statistically appropriate in-water sea turtle data collection and analyses to measure population change, including vital rates, abundance, distribution, and other demographic data.
- Provide a roadmap for the collection of data to improve sea turtle management and restoration efforts in the GoM.
- Recommend a comprehensive, coordinated, and standardized evaluation of the status and trends of sea turtle populations in the GoM.
- Identify processes needed for successful implementation of this Plan, including protocols for in-water sea turtle data and program management, and partnerships.

1.3 Development Approach

This Plan was developed by a Steering Committee (SC), assembled to recommend a coordinated approach to the formulation of an improved understanding of sea turtle populations in the GoM. The SC was assembled by the initially contracted project manager based on a combination of subject matter expertise as well as a desire to balance agency and non-agency input. The SC was supported in development of this Plan by a Project Management Team comprising Stantec Consulting Services Inc. (Stantec) staff and National Marine Fisheries Service (NOAA Fisheries) employees (Table 1). The SC and Project Management Team met regularly over a period of two and a half years and conducted a series of virtual calls and in-person meetings, with additional contributions from other outside subject matter experts, through one-on-one discussions and peer review of an initial draft of this document.

Table 1 Steering Committee and Project Management Team Members

Steering Committee[1]	Project Management Team
Kristen Hart, USGS Pamela Plotkin, Texas A&M University Chris Sasso, NOAA Fisheries Blair Witherington, Inwater Research Group, Inc.	Christy Fellas, NOAA Fisheries Sara Wissmann, NOAA Fisheries Andrea Ahrens, Stantec Carl Ferraro, Stantec Emma Heffernan, Stantec Francis Wiese, Stantec

Key:

A&M = Agricultural and Mechanical College of Texas; NOAA Fisheries = National Marine Fisheries Service; Stantec = Stantec Consulting Services Inc.; USGS = United States Geological Survey

Notes:

[1] The Steering Committee members listed above are the four core individuals who participated throughout the Plan development and brought this Plan to completion. Other individuals who have participated in this process are included in Section 8.0 (Acknowledgements).

Data that currently inform assessments of sea turtle population change come predominantly from nesting beaches (NRC 2010). As such, estimates of sea turtle abundance and population vital rates apply principally to adult females, eggs, and terrestrial hatchlings (Witherington et al. 2009; Brost et al. 2015). Eaton et al. (2008) summarized existing in-water sea turtle research in Florida to identify research gaps and recommended how to structure a state-wide program for coordination and standardization of in-water sea turtle research. Many authors and expert panels have recommended more comprehensive assessments of sea turtle population change, to include information from turtles in the water (Thompson 1989; Bjorndal and Bolten 2000; Turtle Expert Working Group 2009; NRC 2010; Schroeder et al. 2020). These recommendations have included both logistical and statistical attention to sampling design, standardized data collection methods, and modeling of estimates and trends. Key conclusions from these previous efforts included a stated need for assessments of in-water sea turtle abundance and trends to take place within a coordinated, integrated network of sampling projects (NRC 2010). Lack of abundance and trends data to describe population baselines has been identified as an impediment to detecting or understanding recovery and decline of sea turtle species in the GoM (Bjorndal et al. 2011). A later report by the National Academy of Sciences, Engineering, and Medicine (2017), reiterated these needs, with particular consideration of GoM sea turtle restoration monitoring. This Plan builds on these workshops and expert recommendations to present an implementable, structured plan for conducting strategic in-water sea turtle surveys to detect abundance and trends in the GoM.

1.4 Scope

The sections below outline what is included in this Plan regarding species, spatial extent, life history, appropriate levels of sampling effort, and methods.

1.4.1 Species Considerations

Although all five species of sea turtle in the GoM share basic life history characteristics (e.g., multiple developmental habitats, varying degrees of nest site fidelity, varying nesting intervals), there are also important species-specific differences to consider. All juvenile hardshell sea turtles undergo a shift from surface pelagic to benthic neritic habitat, although some individuals may seasonally migrate to pelagic habitats (Bolten 2003). This contrasts with leatherback sea turtles, which spend proportionally more time in deeper waters, though they periodically forage close to shore (Sasso et al. 2021).

Historically, most capture-mark-recapture (CMR) studies of sea turtles focused on adult females encountered on nesting beaches (Davis and Whiting 1977; Hatase et al. 2004; Phillips et al. 2014; Lamont et al. 2014; Galloway et al. 2016) with fewer studies focused on neritic juveniles captured in-water (Sasso et al. 2006; Ehrhart et al. 2007; Turtle Expert Working Group 2009; Eaton et al. 2008). Recent aerial survey studies have focused on collecting information on turtles greater than 40 to 45 centimeters (cm) straight carapace length (SCL; Schroeder et al. 2020; Roberts et al. 2022).

This Plan provides species-specific guidance for all five species and proposes a phased approach to the collection of in-water sea turtle data (see Section 3.0) according to the following generalized groupings: 1) green, Kemp’s ridley, and loggerhead sea turtles; 2) hawksbill sea turtles; and 3) leatherback sea turtles. These groupings were made in recognition of the different life history characteristics of each species as well as spatial and behavioral differences. Recommended sampling and survey methodologies were then tailored to result in the most efficient data collection possible by species, as further detailed in Section 3.1.3.

1.4.2 Spatial Considerations

All species of sea turtles are highly migratory and have wide geographic ranges. Sea turtles in the GoM cross US state and federal, as well as international, boundaries. They rely on terrestrial breeding habitats and on a series of nursery habitats distributed in inshore and nearshore waters. Therefore, comprehensive sea turtle population assessments for the GoM require an international context, even if management decisions are ultimately governed independently by the US, Mexico, and Cuba (Shamblin et al. 2023). The GoM is not an enclosed water body, as such, effects on vital rates outside of this basin also affect populations in the GoM (Phillips et al. 2022; Shamblin et al. 2023). As a result, population terms used in this Plan will largely be relative (e.g., ‘relative abundance’) and reflect the scale of possible survey coverage. This Plan does not attempt to capture the full biological population or range of any of the species addressed (Shamblin et al. 2018).

In the DWH NRDA PDARP and *Strategic Framework for Sea Turtle Restoration Activities* (DWH NRDA Trustees 2016, 2017), the Trustees provided goals for sea turtle restoration activities, including that restoration will occur in the geographic and temporal areas within the GoM and Atlantic Ocean that are relevant to sea turtle species and life stages. As such, the focus of this Plan is sea turtle data collection in US GoM waters, including the

Florida Keys (i.e., excluding the waters of Mexico and Cuba in the southern region of the GoM, and excluding areas outside the GoM). This focal area matches the "US GoM" region identified by Rooker et al. (2019). The SC acknowledges that monitoring sea turtles in the GoM outside US waters is a necessary component to fully evaluate sea turtle populations in the GoM, and it is an important future consideration discussed in Section 6.1. This Plan also recognizes important connections between the GoM, the Caribbean Sea, and the wider Atlantic Ocean. These connections correspond with shared population genetics, and sea turtle developmental and reproductive migrations between the GoM and the western North Atlantic (Girard et al. 2009; Shamblin et al. 2012, 2018; Chabot et al. 2021; Evans et al. 2021; Phillips et al. 2022). Migrations into and out of the GoM connect sea turtles to monitored in-water sea turtle study sites and nesting beaches in the western North Atlantic. Vital rates and abundance measures of sea turtles for these areas outside the GoM are necessary for population assessments of sea turtles that use the GoM.

1.4.3 Life History Considerations

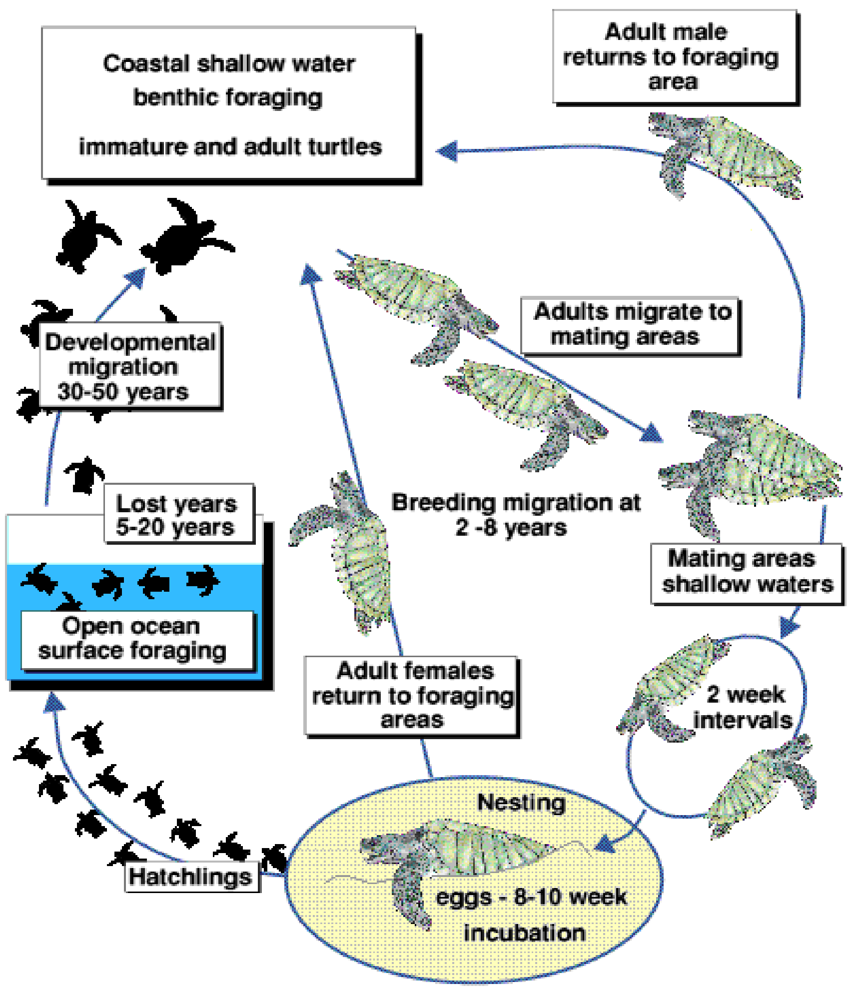
Important sea turtle life history stages occur on land at nesting beaches (including nesting, egg incubation, and hatchling emergence and dispersal), but sea turtles spend most of their lives in the water. Nesting beach studies are essential to a comprehensive understanding of population dynamics (Heppell et al. 2003), but they do not provide direct information on non-nesting females or males, nor on habitat use during most of their lives. Once sea turtle *hatchlings* emerge and enter the ocean, they spend the first several years as *surface pelagic* ('oceanic') *juvenile* turtles at or near the surface, usually associated with convergence zones in open ocean areas far from land (Bolten 2003), where floating material, such as *Sargassum*, provides food and shelter during this critical life stage (Witherington et al. 2012). After a few years, juveniles of hardshell species migrate back to nearshore habitats, where they feed primarily on benthic organisms, and are considered *neritic juveniles*. Life history information on leatherbacks of this life stage is largely unknown.

The DWH NRDA Trustees (2017) defined life history classifications by species, but there is no industry standard for life history terminology, thus life history classifications vary between entities and/or individual researchers. Figure 1 illustrates the typical sea turtle life cycle, and for the purposes of this Plan, the SC will use the above italicized terms when referring to the different major life stages, as they apply to in-water habitats.

Sea turtles do not attain sexual maturity for many years (decades for some species), but once mature, most hardshell *adults* establish a preferred home foraging area to which they are generally faithful (Bresette et al. 2010; Vander Zanden et al. 2010; Shaver et al. 2013; Hart et al. 2013, 2014, 2015; Phillips et al. 2021). Reproductively active females migrate varying distances to nesting beaches to which they are also relatively faithful to for the duration of their reproductive lifespan. Reproductively active males may also make breeding migrations away from home foraging areas to mate with females along migratory routes, including offshore nesting beaches (Shaver et al. 2005; Cuevas et al. 2020; Ashford et al. 2022). After the mating period (males), and after the last egg clutch is laid (females), adults from both sexes generally undertake return migrations to their home foraging areas, where they may remain until their next reproductive cycle.

In-water sampling enables the sighting and/or capture of neritic juvenile and adult sea turtles, including those smaller than can typically be observed in aerial surveys (i.e., smaller than 45 cm) and provides critical information during these extensive times away from shore. The PDARP recommended that restoration "target adult and older juvenile life stages. Adult and older juvenile sea turtles are extremely valuable to the population, because they are either already reproductively active or have a high likelihood of surviving to reproduce (Crouse et al. 1987; Heppell 2005)" (DWH NRDA Trustees 2016). To meet this recommendation for restoration, and out of practicality, this Plan focuses efforts on inshore and nearshore waters, which are principally used by neritic juveniles and adults.

Figure 1 Generalized Life Cycle of Sea Turtles (Naro-Maciel et al. 2011)



1.4.4 Level of Effort to Detect Trends and Estimate Annual Survival

The SC identified 17 in-water sea turtle CMR studies published in the peer-reviewed literature that reported both individual turtle survival and recapture probabilities—Heppell et al. (1996); Limpus and Chaloupka (1997); Chaloupka and Limpus (2001, 2002, 2005); Bjorndal et al. (2003, 2005); Seminoff et al. (2003); Campbell and Lagueux (2005); Sasso et al. (2006); Koch et al. (2007); Casale et al. (2009); Patricio et al. (2011); Bell et al. (2012); Redfoot and Ehrhart (2013); Strindberg et al. (2016); and Grossman et al. (2019)—but none of these studies were in the GoM. Most of these studies captured only one species, with eight focused on loggerheads, six on green turtles, two on hawksbills, and one on loggerhead and green turtles. The most common model used was the Cormack-Jolly-Seber. Although other sea turtle CMR studies exist outside these 17, they were focused on nesting females or do not directly present survival and recapture probabilities on in-water turtles and, therefore, are not relevant for this Plan.

Across these 17 studies, only four present assessments of trends in annual sea turtle abundance (Chaloupka and Limpus 2001, Bjorndal et al. 2005, Redfoot and Ehrhart 2013, Grossman et al. 2019). Only Bjorndal et al. (2003; 24-year time series) and Chaloupka and Limpus (2005; 8-year time series) reported a significant trend. Grossman et al. (2019) hypothesized that the detection of a biologically significant trend would require 18 years of data at the power of their reported data set. Redfoot and Ehrhart (2013) were unable to detect an annual trend in juvenile green turtle abundance across their 14-year time series.

This review of the literature revealed that estimates of apparent sea turtle survival and recapture probabilities were only possible when studies were relatively long term (6–10 years) and when consistently sampled projects/sites had annual sea turtle recapture rates of 32 percent or greater. Total numbers of sea turtles tagged in these studies ranged from 17 to 1,600 (median = 273 individuals) with a median derived recapture probability of 0.5 percent. The longest study was 24 years, with an average of 9.4 years. Where catch per unit effort was reported (5 of the 17 studies), 7- to 10-day sampling durations were most common, with a maximum sampling duration of one month per year in the Great Barrier Reef (Chaloupka and Limpus 2002). Reporting of confidence intervals around annual estimates of survival and probability of sea turtle recapture was inconsistent; therefore, no general guidance could be derived.

The SC notes that it would be valuable in future CMR studies to assess how long it takes until the confidence intervals (or credible intervals) around these metrics begin to narrow. Until such time, the SC suggests individual projects developed in support of this Plan, and that meet the initial criteria to qualify as a potential index site, be undertaken for a minimum of 10 years. Once initial data are collected and analyses are complete, and where estimation of abundance, distribution, and vital rates are possible, this information should be used to conduct a power analysis or likelihood-based approach to re-evaluate data and sampling designs (more on this in Section 3.0).

1.4.5 Methodological, Analytical, and Administrative Considerations

This Plan evaluates available in-water sea turtle data collection methodologies, including pros and cons, biases, type of data that can be obtained, and applicable habitats. This Plan focuses on in-water sea turtle data collection techniques with some minor exceptions as they relate to certain species and life stages (see Section 3.1.3.3). Aerial surveys have been the primary method to obtain estimates of relative abundance of sea turtles across the US GoM, and the SC recognizes the need for this method to continue to gather broad-scale distribution and relative abundance information for sea turtles greater than 40 cm SCL. Funding to continue those surveys is uncertain but has come from federal agencies in the past. As such, the recommendations previously discussed during a NOAA working group (Schroeder et al. 2020) are reiterated; currently, these surveys are optimized/planned for marine mammals, but it is crucial to optimize them for sea turtles. Satellite tagging programs included in this Plan will also support future sea turtle aerial survey programs by providing information on availability bias, and thus the correction factors needed for more robust aerial survey estimates for sea turtles (as further discussed in Section 4.1).

This Plan also provides guidance on in-water sea turtle index site selection criteria, but without dictating specific sites. Similarly, it does not dictate analysis or modeling approaches, but takes into consideration data needs to comprehensively analyze collected information in a Gulf-wide context. As such, the SC has made suggestions regarding data management, recognizes that new technologies are continuously emerging and need to be considered when mature, and considers other administrative needs to make its implementation successful.

1.5 Implementation Vision and Intended Audience

It is the SC's vision that the data collection program outlined in this Plan will be led by a formal Lead Coordinating Entity (LCE). The LCE would manage a coordinated network of individuals with appropriate experience, permits, and understanding of the assumptions and biases described in this Plan. At the time this Plan was written, the LCE had not yet been designated. Data collected pursuant to this Plan will be subject to the implementation and data management approach outlined in Section 3.3 and 5.0. The SC acknowledges that the efforts proposed here represent a large undertaking that would require a major and long-term source of funding and that overall goals would need to be prioritized accordingly; however, it is also the SC's opinion that this undertaking is necessary to meet the objectives listed in Section 1.2. Further guidance on the implementation of this Plan and data coordination will be released separately once the LCE is established.

The SC proposes a long-term, phased, and adaptive approach to the collection of in-water sea turtle data, in the following order of priority:

1. Phase 1: Exploration and identification of a limited number of prioritized sites in neritic waters in the US GoM.

2. Phase 2: Continued monitoring of effective Phase 1 index sites and site refinement, based on initial results and sampling considerations per Phase 1, in the US GoM.

3. Future In-Water Plan Considerations: Monitoring of non-US GoM waters. To allow for expansion and aggregation of data collected in a systematic way over a large spatial scale, additional regions can be added as international partnerships develop over time. Integration with other programs and incorporation of emerging technologies would also be considered during this stage.

Phases 1 and 2 are described in further detail in Sections 3.1 and 3.2. Future in-water Plan considerations and approaches to potential future studies are identified in Section 6.0.

Partners critical to success of this Plan include the following: holders of historical sea turtle data; researchers with active monitoring projects willing to collect data in a manner outlined in this Plan; researchers willing to commit to long-term monitoring; permitting agencies; and administrators of project-network monitoring, data, analyses, communication, and facilitation.

The primary intended audiences for this Plan are researchers who might contribute to understanding sea turtle population changes within waters of the GoM. Secondary intended audiences for this Plan are funding agencies, program administrators, and resource managers who will be interpreting and utilizing results of the suggested measures in this Plan. These contributors would be guided by this Plan, with additional guidance and facilitation from the LCE. The SC's intent is to have this Plan be part of the essential communication and strategic planning shared among groups providing funding, resource management direction, and science that help achieve Plan objectives. A key leadership role played by the LCE will be to facilitate this communication, address needs of contributors, and coordinate human-dimension components of this Plan.

2.0 Data Collection Plan Considerations

In the NRDA *Strategic Framework for Sea Turtle Restoration Activities*, the DWH NRDA Trustees (2017) noted that "some information currently exists on sea turtle population structure, spatiotemporal distribution, life history parameters, migration patterns, and habitat use during their long oceanic and neritic life stages, but there are temporal and spatial gaps in these data sets (National Marine Fisheries Service and the US Fish and Wildlife Service [USFWS] 2008; National Marine Fisheries Service et al. 2011)." This Plan aims to identify and characterize biologically and statistically appropriate in-water sea turtle data collection strategies that, once implemented, will begin to fill some of these gaps.

Within this section, the specific demographic data and parameters are identified that are necessary to answer future population trend, recovery, and restoration questions, and that should be collected during field programs. The need for such effort is well captured by the DWH NRDA Trustees, as follows:

> *Monitoring and scientific support are necessary to address key information needs and data gaps, and to help inform the temporal and spatial implementation of future restoration projects. Because sea turtles are broadly distributed within and outside of the northern GOM, coordinated monitoring of restoration activities across sites, states, and potentially beyond the GOM will be necessary to enable the detection of effects of successful restoration. In particular, Gulf-wide monitoring of sea turtle populations and the implementation of standardized monitoring protocols for specific activities and life stages (e.g., nest productivity, nest abundance, in-water abundance) would provide important context for project-level monitoring at individual sites where restoration is implemented and would allow comparisons across multiple projects […]* DWH NRDA Trustees, 2017; pp. 20

2.1 Metrics for Population Assessment

Monitoring of vital rates is needed to parameterize population models and assess population trends. These rates can vary among subpopulations, life stages, sexes, and sampling locations. Some of these parameters (e.g., age/size class structure, survival rates) may serve as early signs of negative or positive impacts before such changes can be measured in direct abundance parameters (e.g., Arendt et al. 2021, 2022). Table 2 lists metrics that inform population assessments and the data/samples and analytical methods required for their measurement.

Table 2 Sea Turtle Population Assessment Metrics and Analytical Methods required for their Measurement or Estimation

	Abundance (age/size-class specific)[1,2]	Occurrence	Survival Probabilities (age/size-class specific)	Immigration / Emigration (age/size-class specific)	Spatial Distribution	Genetic Stock, Diversity and Population Structure	Population Age (Size) Structure	Sex Ratio by Life Stage	Stage Duration
Required Data/Sample*									
Species	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spatiotemporal Effort Associated with Observations or Captures	✓	✓			✓				
Behavioral Measures Applied to Detection Assumptions, Availability, and Movement	✓		✓	✓					
Turtle Identities	✓		✓	✓					
Turtle Sex	✓		✓					✓	
Turtle Life Stage	✓		✓						✓
Number of Turtles Counted on Transects (by Age/Size-Class)	✓								
Age/Size-Class Specific CPUE	✓						✓		
Length/Weight	✓		✓	✓			✓	✓	✓
Blood/Tissue Samples	✓					✓		✓	
Method*									
Presence		✓							
CMR[3]	✓		✓	✓					
Distance Sampling[4]	✓								
Western Blot Immunoassay[5]	✓		✓					✓	
CPUE[6]	✓	✓							
Sea Turtle Observations, Stranding, Non-Systematic Data		✓							
Satellite Tagging			✓[7]	✓	✓				
Genetic Analysis						✓			
Close-kin Mark Recapture[8]	✓		✓			✓			
Time-Varying Matrix Models and Other Models							✓		
Hormone Analyses								✓	
Somatic Growth Rates by Life Stage and Length Frequency Analysis							✓		✓

Key:
CMR = capture-mark-recapture; CPUE = catch per unit effort
Notes:
* Suite of data and samples possible is dependent on field method.
[1] For the purposes of this Plan, the term "abundance" is meant to convey metrics representative of population measures (e.g., relative abundance or absolute abundance at a site) as opposed to mean population abundance.
[2] Sex determination from blood is a technical assessment done in a laboratory setting.
[3] CMR methodology discussed in White and Burnham 1999; Williams et al. 2002
[4] Distance sampling methodology discussed in Buckland et al. 2001
[5] Western blot immunoassay methodology discussed in Tezak et al. 2020
[6] CPUE examples and caveats surrounding use of these data are discussed in Bjorndal and Bolten 2000; example provided in Arendt et al. 2012
[7] Known-fate survival
[8] Close-kin mark recapture methodology discussed in Bravington et al. 2016

2.2 Site Selection Criteria

2.2.1 General Considerations

Sampling should represent all states across the US GoM. Where it makes sense to do so for the species of interest, the number of sampling sites in each state's waters should be roughly proportional to the length of each state's coastline. However, as detailed in Section 3.1, researchers are encouraged to use additional biologically relevant considerations when planning sampling efforts, as appropriate. Ideal sampling should include a combination of local focused sites nested within larger-scale transect-based surveys for abundance. In all instances, sampling effort must be measured and recorded.

Sampling sites should have monitoring value based on some, or all, of the following considerations:

- State coastline representation
- Habitat representation
- Species and life stage representation
- Capture and recapture probabilities
- The extent of any ongoing or prior time series of metrics specified in Table 2
- Repeatability and consistency of effort

As further detailed in Section 3.0, sampling locations will be based on the ability to employ proven sighting and/or capture methods (i.e., effective given the location's particular water depth, water clarity, habitats, currents, and sea state) without violating key analytical assumptions when determining abundance and/or survivorship. For example, the CMR approach would require the possibility for regular repeat sampling over 10 years or more and large enough sample size, including recaptures (see Section 2.1.4 for more details).

2.2.2 Logistical Considerations

The following sampling site logistics must be considered to improve feasibility and repeatability:

- Site allows sampling at different times of year (i.e., can represent different seasonal time periods).
- Site is monitored by organizations with a commitment to multi-year sampling and data sharing.
- Site and sampling methods have the potential to be expanded over time to increase sampled (observed, captured, recaptured) sea turtles.
- Site is represented by evidence (e.g., published studies, unpublished data, inference from published analyses) indicating that sea turtles are present in spatial

densities that would yield sufficiently dense observations or captures. This may include sites that add sampling representation outside ”hotspot” locations.

- Site is characterized by habitat where expected detectability is high enough to yield significant observations or captures.
- Site does or could provide supplementary data sets that assess availability, sea turtle movements, stock identification, life stage and sexes present, and regionally relative spatial density.
- Site has the potential to contribute significant numbers of observations, or captures and recaptures, to represent one or more species, life stages, habitats, or a GoM region. See the benefits of expanding site representation described in Section 2.1.4.3.

Ideally, sampling will occur in both new sites and currently sampled sites, should they be amenable to the survey techniques detailed in Section 3.1 and the above assumptions. Organizations and/or researchers must also have the available skills, the ability to obtain necessary/applicable permits, and appropriate facilities to employ the suggested sampling methods. The more of these logistical considerations that can be met, the more useful the data will be. Sites that only meet a few of the above considerations are less likely to be suitable for integration into a large-scale, long-term, Gulf-wide monitoring program.

2.3 In-water Monitoring Methods

A comprehensive evaluative comparison of sea turtle in-water monitoring methodologies is beyond the scope of this Plan; however, previous efforts have been considered in this Plan and adapted to the GoM as appropriate.

Although not a full comprehensive evaluation, Table 3 lists a summary of the SC’s expert opinions and conclusions on commonly applied in-water sea turtle sampling methodologies, associated in-water assessment metrics, considerations and tradeoffs, and recommendations for inclusion of the methodology in this Plan. Section 6.3 further discusses emerging technology and future potential methodologies. The in-water assessment metrics listed in Table 2 are possible outcomes according to appropriate project design and their focus is aligned with the long-term objective of monitoring population trends. The SC recognizes that there are other ecological variables that could be collected (e.g., diet), but such studies are not the focus of this Plan.

It is understood that permit-related requirements and/or funding may impact the choice of methodology; however, the SC has made recommendations based on ideal sampling scenarios.

Table 3 Evaluation of In-water Field Sampling Methodologies for the US Gulf of Mexico to Determine In-Water Assessment Metrics

Field Sampling Method	In-Water Assessment Metrics Yielded by Method	Considerations and Tradeoffs	Recommendations for this Plan
Ship-based transect surveys (non-capture)	• Occurrence • Abundance • Spatial Distribution	• Pros: Covers broad area • Cons: Poor detectability and reduced data detail	The SC does not recommend this sampling method due to poor detection of sea turtles.
Small-vessel and UAV-based transect surveys (non-capture)	• Occurrence • Abundance • Spatial Distribution	• Pros: Effective in clear, shallow waters. Surveys can represent scales of 100 km or more. • Cons: Not effective in turbid waters; for relative abundance, this method relies on visual target identification by in-situ humans or RGB video review by human observers (so limited to human visual capabilities) • Other Considerations: Deep-water and turbid water surveys record only near-surface turtles and would require understanding availability bias from representative dive data; active sonar and LiDAR may enhance detectability during these surveys in deep and turbid waters.	The SC recommends that this method overlap spatially with site-specific captures providing greater data detail (turtle size, sex, genetics). Abundance estimates are limited by violations of distance sampling assumptions.
Snorkel, SCUBA, or towed diver transect surveys (non-capture)	• Occurrence • Abundance • Spatial Distribution	• Pros: Effective in clear, waters approximately 10- to 30-m depth. • Cons: Surveys represent localized scales less than 1 km. Detectability data are challenging to collect.	The SC recommends this method for sampling hard-bottom and coral reefs.
Direct capture (dipnet, hand capture, hoop net, snorkel/SCUBA capture, strike net)	• Occurrence • Abundance • Survival Probabilities • Immigration/Emigration • Spatial Distribution • Genetic Stock, Diversity, and Population Structure • Movement and Connectivity • Sex ratio by Life Stage • Stage Duration	• Pros: Effective in clear and relatively shallow water; No bycatch. Strike netting also effective in shallow, turbid waters. SCUBA capture effective in clear water to 30-m depth. Can be effective for pelagic juveniles that have not transitioned to neritic habitat. Effective to capture leatherback sea turtles at the surface. • Cons: Hand capture not as effective in turbid water or depths greater than 3 m; Limited to catching a single individual at a time. Sampling represents relatively small spatial scales (<1 km)	The SC recommends this method for sampling hardshell turtles in shallow, clear water. The SC recommends recording effort and detectability data associated with captures, and suggests this method is most useful in conjunction with small vessel transect surveys that allow extrapolation of spatial density estimates.

Field Sampling Method	In-Water Assessment Metrics Yielded by Method	Considerations and Tradeoffs	Recommendations for this Plan
Trawl capture	• Abundance • Survival Probabilities • Immigration/Emigration • Spatial Distribution • Genetic Stock, Diversity, and Population Structure • Movement and Connectivity • Sex ratio by Life Stage • Stage Duration	• Pros: Surveys can represent scales of 100 km or more; effectiveness is independent of water clarity; effective over sandy, muddy habitats. • Cons: Detectability is low (recaptures are few); sensitive habitats (e.g., seagrass, high relief areas, live hard-bottom) cannot be sampled; surveys covering large spatial scales are expensive. • Other Considerations: Can use either otter or skimmer trawls to adapt to varying water depth between 1 and 20 m.	The SC recommends this method for larger sampling areas, with turbid and/or deeper waters (to 20 m).
Tangle netting, drift net, and "entrapment net"[1]	• Abundance • Survival Probabilities • Immigration/Emigration • Spatial Distribution • Genetic Stock, Diversity, and Population Structure • Movement and Connectivity • Sex ratio by Life Stage • Stage Duration	• Pros: Can be effective in both clear and turbid waters to moderate depths (up to 6 m). Tangle netting effort can be measured for CPUE, and entrapment netting can apply to spatial density estimates. • Cons: Bycatch can be high; depth limitations (up to 6 m); net must be continually attended as a permit requirement because of the potential for lethal take.	The SC recommends these sampling methods in areas where other techniques have been less successful or not appropriate.
Telemetry	• Movement and Connectivity • Turtle Survival Probabilities • Spatial Distribution	• Pros: Provides data that strengthen inferences from sightings and captures (availability corrections for distance transect surveys, emigration in CMR); short-term survival over tag life (approximately 1 year); movements can reveal potential sampling locations • Cons: Challenge in distinguishing tag failure from death; tag failure biased by life stage and habitat; small timescale measured relative to lifespan; expensive	The SC recommends that behavioral data from telemetry be used to strengthen inference from transect surveys; this method is complementary to other methods such as aerial surveys or remotely sensed data.

Key:
CMR = capture-mark-recapture; CPUE = catch per unit effort; km = kilometer; m = meter; LiDAR = light detection and ranging; RGB = red, blue, green, refers to a type of component video signal used in the video electronics industry, consisting of three signals; SC = Steering Committee; SCUBA = Self-Contained Underwater Breathing Apparatus; UAV = uncrewed aerial vehicle
Notes:
[1] Entrapment nets detailed in Meylan et al. 2011

2.4 Assumptions and Biases

The primary means to collect relative abundance, distribution, and survival metrics for sea turtles in the water is with distance sampling and CMR studies (Buckland et al. 2001; Williams et al. 2002). This section provides a summary of the main assumptions and biases associated with these methods and their associated data analyses and refers the reader to further literature for more in-depth reading on these topics.

2.4.1 Distance Sampling

Sea turtles are often sampled in the water using point counts or line transects from small vessels to estimate relative abundance in an area. Distance sampling has been successfully applied to a variety of habitats and species (Buckland et al. 2001, 2015). There is an extensive body of literature on assumptions and study design considerations necessary before starting line transect survey studies. Buckland et al. (2001) is an excellent reference on estimating abundance from line transect data and will help plan study design and analysis of data.

Basic assumptions of line transect distance sampling (as summarized in Buckland et al. 2001) are as follows:

1. Transects are a random sample of the sea turtle population present at the study area.
2. Sea turtles on the transect line are detected with certainty.
3. Sea turtles do not move before being counted.
4. The measurement of sea turtle distance from the transect line is exact.

Along with understanding these basic assumptions and biases, several survey-design considerations affect data and hypothesis testing. Sample size and the placement of transect lines should meet the precision, resolution, and representation required by the study objectives (Buckland et al. 2001). Sea turtle detectability is affected by size, motion, background habitat (camouflage), and sheltering; and species identifications and size approximations vary with distance.

Consistency and training of observers is also important as individuals may have variations from each other. Steps can be taken to reduce or quantify those variations such as training observers to have a minimum level of accuracy and/or having multiple individuals complete transects in tandem to compare results. Controls need to be considered early to negate this potential bias.

A key objective of this Plan is to measure local abundance annually (and seasonally, if possible), and to assess trends in abundance over time. The length of transects and effort required to meet those objectives requires knowledge of encounter rates from pilot work in the study area or from comparable studies.

Surveyors should define the area, habitat, and water depth to be surveyed prior to selecting locations of transect lines. Initial selection of transect lines in the defined area should use some form of pre-determined systematic or stratified random sampling to ensure the area is appropriately surveyed and does not rely on subjective selection of transect locations. Common layouts of transects are a series of parallel lines or a saw tooth pattern, depending on the overall area being surveyed. Transects need to be a sufficient distance apart to avoid detecting sea turtles on neighboring transects that have not been sampled yet (that is, to limit spatial autocorrelation). The same spatial strata should be sampled repeatedly among years or seasons (again applying random starting points) at the same level of effort to ensure estimates are comparable. The SC does not recommend repeatedly sampling in the exact same locations within strata each year or season; rather, each year or season, a similar number of stratified random transects should be deployed in order to capture variation within each stratum. Specifics on defining strata and sampling within those strata are presented in Section 3.0.

CMR studies (see below) are likely to be performed in areas that have already been surveyed. If conducting transect surveys and sea turtle captures in an area, it is important to complete these methods at different times since pursuits necessary to capture sea turtles will likely influence their distribution in the area, violating a basic assumption of line transect sampling. The appropriate sampling regime would be to survey the area using the preselected line transects and then, once complete, perform the capture study in the area to collect data on demographics and population parameters. The software program Distance (Thomas et al. 2010; Miller et al. 2019) has a built-in survey design tool, with integrated geographic information system, to assist in planning and assessing different design properties via simulation before deciding on the best survey design for a study area (Buckland et al. 2001). To provide informative abundance estimates, the SC notes that transects should be of sufficient length and coverage to meet classic distance transect theory recommendations, and that a minimum of 40 individuals are observed, with 60 to 80 preferred (Burnham et al. 1980).

Estimates of detection probability should incorporate a variety of environmental and/or supplementary covariates that affect sighting sea turtles in the water. Typical environmental covariates are depth, water clarity, water temperature, sea-surface state, wind speed and direction, cloud cover, sun angle, observer height, and observer identity. Because these variables are likely to change over the course of a transect, these data should be captured after each change is identified and for each side of the vessel.

2.4.2 Capture Mark Recapture

CMR studies are commonly used to measure animal population dynamics. These studies are used to estimate abundance, survival, recruitment, movement, life stage transition, and population growth rate (Williams et al. 2002).

The basic assumptions among mark-recapture analysis methods are similar and need to be considered and incorporated into the design of CMR studies. Those assumptions (as summarized in White and Burnham 1999) are:

1. Sea turtles are marked with individually identifiable tags and released.
2. Sea turtles previously marked have their tag numbers read and recorded and are released.
3. Marked and unmarked sea turtles present during sampling have the same probability of capture at each sampling occasion (homogeneous catchability).
4. Sea turtles retain tags throughout the study.
5. Tags are read and recorded accurately.
6. Sampling is instantaneous (i.e., sampling occasion is short relative to period between sampling occasions). More complex CMR models allow for incorporation of observations outside the sampling period and area.
7. Survival probabilities are the same for all sea turtles (marked and unmarked) between sampling occasions (homogeneous survival). Survival probabilities of the sampled population are representative of the overall population.
8. The study area should be constant. Effort should be measured to account for instances when it is not constant and can be used to assess detection as a function of effort.

There are many different CMR models to accommodate different data types and study situations; however, before undertaking any study, it is imperative to consider the assumptions of CMR models and ensure that effort in space and time is consistent among survey occasions to generate valid results from the models. Proper study design, before initiating data collection, is fundamental to generating the data needed to understand sea turtle population dynamics.

Program MARK (White and Burnham 1999; Williams et al. 2002; Laake et al. 2013) and the accompanying reader, *Program MARK – A Gentle Introduction* (Cooch 2017), are excellent resources to understand what CMR models are available (open, closed, spatially explicit, etc.), how to collect and analyze the data, and how to select the best models for data collected.

2.4.3 Sites with Both Distance Sampling and CMR Studies

Spatially expansive distance surveys may have transects that intersect with a more localized study area where CMR is conducted. CMR studies and distance sampling complement each other with differing geographic scales and levels of data detail. Where and when there is spatial overlap between these two sampling methods, detailed population data on sea turtle life stage, sex, genetic stock, and survival, can be obtained. Space overlap also allows comparison of trends in abundance estimated by different approaches and to integrate the two approaches into one estimate. In cases where surveys and captures are planned for the same geographical area, the SC recommends that these do not occur simultaneously; that capture only start once the entire survey has been completed.

2.4.4 Catch per Unit Effort

The SC considers catch per unit effort (CPUE) data to be a potentially useful addition to CMR or Distance transect estimates of abundance, rather than a substitute for these more statistically powerful and population-representative methods. CPUE is an important metric to report counts using a standardized measure of effort and capture efficiency. Measures of effort in targeted capture studies include net length and net soak time (tangle net; Ehrhart and Ogren 1999; Metz and Landry 2013, 2016), headrope/footrope length, and tow time (trawl). Arendt et al. (2012) present a helpful paper on how a multi-year randomly distributed regional trawl survey can be used to assess the relative abundance of loggerhead sea turtles in southeast US waters. Schroeder et al. (2020) further summarize some of the CPUE survey methods associated with both trawl and non-trawl capture surveys, and review some of the associated challenges and biases. Capture efficiency (equivalent to capture probability of CMR) is best measured through CMR methods, and best standardized by keeping gear type and use constant. CPUE examples, and caveats surrounding the use of these data, are in Bjorndal and Bolten (2000).

Important considerations for the collection and use of CPUE data include:

- Standardization that reduces CPUE bias includes attention to standardized capture gear, its configuration, and its presentation relative to marine conditions.
- Sampling that reduces CPUE bias includes systematic seasonal sampling, a randomized sampling design, and pooling of multiple sampling sites.
- CPUE data are least useful as a quantitative index of abundance when there are sample biases, and low or highly variable catch rates, but may remain useful as a qualitative indicator.

Additional guidance on CPUE methods applied to sea turtles can be found in Bjorndal and Bolten (2000), NRC (2010), and Schroeder et al. (2020).

3.0 In-water Monitoring Plan Approach

In the PDARP and *Strategic Framework for Sea Turtle Restoration Activities*, the DWH NRDA Trustees (2016, 2017) identified the need for more standardized data collection and analyses to improve our ability to track sea turtle population trends in the GoM. The goal of this Plan is to provide a framework for researchers that guides a phased, in-water monitoring program that will fill that gap and obtain population data that were incomplete when the DWH oil spill occurred, and still are today.

The objectives and scope of this Plan aim to address considerations for sampling and measurement of sea turtle population change in the GoM. Although there is considerable published information on sea turtle presence and distribution within the GoM, it is the SC's opinion that there are still important spatial gaps, gaps in data detail, and likely biases for these projects to constitute a regional sampling effort.

Existing information is not complete, detailed, or GoM specific enough to guide a statistically robust, Gulf-wide, in-water monitoring study design. As previously described, a global review of the published literature (see Section 1.4.4), revealed only 17 studies that reported sea turtle survival and recapture rates for individuals sampled in-water, and none of them were in the GoM. The inconsistent reporting of important metrics (recaptures, sampling days and effort, immigration and emigration) led to an even lower number of studies with results that could inform future study designs.

Similarly, Roberts et al. (2022) assessed dive and movement data collected in the GoM from 136 in-water captured turtles over 10 years to gain a better understanding of the influence of ocean surface parameters and also found data gaps there. The study noted deficiencies in the tagging efforts and revealed that most individuals tagged ranged from Florida to Louisiana, missing the western GoM. Significant historical data, however, indicate that the northwest Gulf represents key in-water foraging habitat for loggerhead and green sea turtles, and nesting Kemp's ridleys (see Fujisaki et al. 2020), including those tagged after nesting on beaches in Mexico (Shaver et al. 2013; Gredzens and Shaver 2020).

Although these broad geographic insights are helpful for preliminary planning, known spatial heterogeneity in movement patterns and abundance dictate that reasonable geographic-specific parameters are required to develop a statistically robust monitoring program for any given region. Development of a statistically-sound design requires a preliminary understanding of the species- and region-specific patterns and distributions of habitats. Such insights enable power analyses and other planning tools to more accurately recommend minimum sampling sites and frequency with a reasonable level of confidence for achieving the population parameter and trend objectives fundamental to this Plan.

To achieve the objectives listed in Section 1.2 and in consideration of the broad spatial area and sampling complexities previously discussed, this Plan recommends sampling considerations in a phased approach. Insights from existing data and preliminary surveys would then be used to design the fully realized US GoM sea turtle in-water monitoring program. Therefore, the envisioned phased approach is as follows:

- **Phase 1 (pilot; ~5–8 years).** Phase 1 entails an initial surveying and sampling period over the first few years. The purpose of this initial phase is to provide sufficient data, evaluated annually, to narrow down survey and sampling locations and capture methods, identify index sites for the long-term CMR and Distance transect programs, and support preliminary modeling and power analyses or likelihood-based approach to design an expanded and statistically robust, US GoM in-water monitoring plan (see Section 3.1 for more details). Data collected during Phase 1 would be used in conjunction with appropriate past data to conduct a power analysis to evaluate data at each site, the number of sites overall, spatial distribution of species sampled and surveyed, and sampling frequency needed to enable detection of change in trends in abundance and survivorship within reasonable confidence bounds.
- **Phase 2 (adaptive sampling and long-term monitoring).** The purpose of Phase 2 is to implement the findings of Phase 1 by adapting the sampling regime (survey and sampling locations, sampling frequency, geographical range, species coverage, life history coverage, etc.) and implementing a coordinated, comprehensive, statistically robust, US GoM-wide, long-term, index sea turtle in-water monitoring program (see Section 3.2 for details).

Whereas the recommended sampling approaches for these two phases are based on currently proven, well-established, and easily repeatable survey, capture, and analysis methods, other tools and analyses such as those outlined in Section 6.0 may be considered in the future.

3.1 Phase 1

The purpose of Phase 1 is to provide appropriate and sufficient demographic data (see Table 2 and Table 3) across species, habitats, sexes, and life stages to support preliminary modeling and management-guided power analyses needed to design a statistically robust, US Gulf-wide, in-water monitoring plan for sea turtles. As such, this phase involves the continuation and evaluation of applicable ongoing studies in the US GoM, as well as an exploration of new potential sites across the US GoM.

To align ongoing studies with the intent of this Plan, researchers should closely examine considerations listed in previous sections, and standardize data and metadata collection accordingly so data can be included in the Phase 2 analysis. Specific questions about these considerations and standards should be directed to the LCE, once established.

To address the full scope of this Plan, sampling will need to occur at new sites and currently sampled sites, should the latter be amenable to the survey techniques detailed in sections below and the site selection criteria previously described in Section 2.1.2. The goal of this approach is to cover a sufficiently comprehensive spatial view of the GoM by combining data collected by different entities. To inform locations and feasibility of potential new sites, knowledge about sea turtle presence may come from a variety of sources, including from citizen science, formal interviews with boat captains, local wildlife rehabilitation centers, fisheries bycatch data, and publicly available stranding data. As appropriate, some of these data could be evaluated using the ‘wisdom of crowds’ approach (Budescu and Chen 2015; Simoiu et al. 2019; Gray et al. 2020).

Some brief reconnaissance work may be required when sampling at a new location to evaluate surroundings and to assess the potential for implementing the standardized surveys and sampling. Initial assessment of a site is a regular part of conducting field surveys and sampling. Such initial efforts should aim to employ conventional and standardized methodologies as much as possible, but other less reproducible or statistically robust methods (e.g., Haphazard Unmarked Nonlinear Transects [Bresette et al. 2010], snorkeling surveys, or dive surveys) may be applied in the first season to help assess the potential for application of standardized methods at new sites. Unconventional sampling such as these should be brief and should not be repeated each time a field team mobilizes. Once a new site has been explored and the LCE determines that it meets the criteria for formal study design, standardized data collection should commence, following one or more of the different sampling protocols recommended for all sea turtle species based on methods and assumptions previously outlined in Section 2.0.

Ideally, an approximate but comprehensive spatiotemporal distribution of sea turtles in the US GoM would guide the distribution of exploratory counts at smaller scales. It is likely that not all sites sampled during Phase 1 will meet the criteria for continued sampling during Phase 2.

To implement Phase 1, the SC considers spatial structure, standardization of data collection, species-specific issues, and specifics regarding offshore surface habitats in the sections that follow.

3.1.1 Spatial Structure

For the purpose of this Plan, Phase 1 spatially segregates sampling across the US GoM into four regional strata as well as into inshore, nearshore, and offshore areas, and the surface-pelagic drift community (SPDC). Suggested spatial structure outlined in the following sections was derived from a combination of SC experience, existing literature, and previously described data gaps.

3.1.1.1 Inshore and Nearshore Surveys and Regional Strata

To ensure adequate sampling across all regions of the US GoM, the SC has identified four regional strata based on an adapted version of the Commission for Environmental Cooperation (2022) marine ecoregions and discussions during the 2008 NOAA workshop (Eaton et al. 2008). These strata represent four major regions across the US GoM coastline, as illustrated in Figure 2: 1) Texas, 2) Central, 3) Northwest Florida, and 4) Southwest Florida and Keys. Further stratification of sampling within each of these four strata into inshore (defined as inland bays and estuaries), nearshore (defined as the area between bays/estuaries, extending to 12 nautical miles [nm] offshore), and offshore (beyond 12 nm) areas (Figures 3–6) will allow for extrapolation of information within each region.

Although recommended survey methodologies are similar across sea turtle species, as described in Section 1.4.1, there are some distribution/behavioral differences that require tailored approaches. As such, additional spatial structure (including habitat type, depth, etc.) was applied in the recommendations for species-specific sampling in Section 3.1.3. In short, the regional strata would primarily be used in developing the sampling program for green, Kemp's ridley, loggerhead, and hawksbill sea turtles (Sections 3.1.3.1 and 3.1.3.2) and focus on inshore and nearshore habitat. The seaward boundary of 12 nm was selected due to logistical considerations. Any sampling occurring beyond 12 nm (i.e., in the 'offshore') is likely to require additional funding, vessels, and coordination. In all cases, researchers are encouraged to use additional biologically relevant considerations when planning sampling efforts (depth, substrate type, bay and drainage systems, etc.), as appropriate.

Recognizing that data collected within these inshore and nearshore areas will not easily be extrapolated to cover offshore waters or adult sea turtle foraging areas, the SC suggests supplemental data that offshore surveys can provide, as detailed in Section 3.1.1.2 and Section 3.1.4.

3.1.1.2 Offshore Surveys

From a logistics standpoint only (i.e., survey platform requirements and potential coverage area in a single survey-day), the term 'offshore surveys' is used in this Plan to include waters beyond 12 nm from the coast, as illustrated in Figure 2. Owing to the extensive nature and more challenging survey environment in the offshore portions of the US GoM, this area is treated separately in this Plan, and will likely require collaborative efforts using other survey techniques (e.g., aerial surveys and support). No oceanographic or territorial implications are intended through the use of the term 'offshore'. Suggestions for offshore surveys are included in Section 3.1.4.

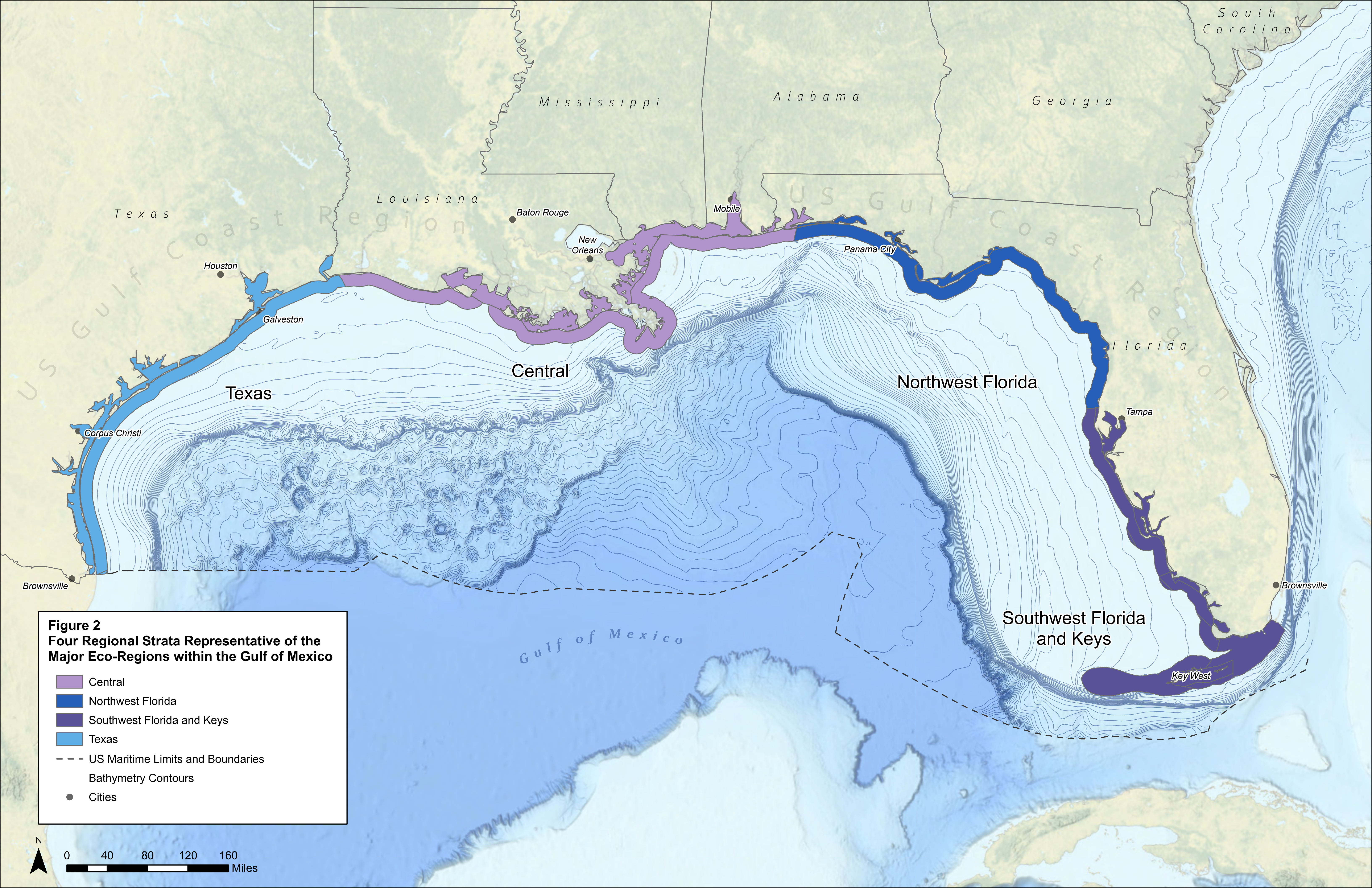


Figure 2
Four Regional Strata Representative of the Major Eco-Regions within the Gulf of Mexico

3.1.2 Standardization of Data Collection

To collect data for all five species in habitats across the US GoM, a variety of methods, logistical, statistical, and other considerations need to be considered. Importantly, key auxiliary data and variables, aside from the target demographic metrics, need to be recorded and reported to allow for integration of this diverse information into US GoM demographic estimates. The SC suggests that the LCE oversee the standard collection of the following information representing each sampled location:

- Survey sampling effort data (e.g., counts per kilometer, net soak time)
- Sea turtle detectability data (e.g., distance data and detection covariates)
- Spatial data describing search area and transect lengths (and durations)
- Global Positioning System (GPS) locations of actual transects, depths, and habitats surveyed
- Capture data (i.e., individual identifications and mean lengths and weights by age class and GPS locations)

Other data collection that is not essential but could be complementary include satellite telemetry on a subset of animals to estimate surface and spatial availability; genetic samples to conduct mixed stock analysis, potential for close-kin CMR, and sex determination; and blood samples for sex determination and hormone analyses to evaluate maturity status. Additionally, regardless of which sampling method is used, all data collection must consider the assumptions and biases detailed in Section 2.1.4.

3.1.3 Recommended Sampling by Species

Recognizing different life history characteristics, and spatial and behavioral differences, sampling recommendations are made within the following generalized groupings: 1) green, Kemp's ridley, and loggerhead sea turtles; 2) hawksbill sea turtles; and 3) leatherback sea turtles.

3.1.3.1 Green, Kemp's Ridley, and Loggerhead

Green, Kemp's ridley, and loggerhead sea turtles are present throughout the waters of the GoM. As previously stated, all hardshell sea turtles in the US GoM undergo a shift from surface pelagic to benthic neritic habitats during the juvenile life stage, although some may seasonally migrate to pelagic habitats (Bolten 2003).

Hardshell sea turtle sampling has been most effective in the inshore and nearshore environments in the GoM (e.g., Phillips et al. 2014; Chabot et al. 2021; Roberts et al. 2022). As such, in addition to recommending sampling within the four regional strata identified in Figure 2, the SC recommends additional stratification into inshore and nearshore areas. It is in these two areas where green, Kemp's ridley, and loggerhead sea turtles are most easily observed and/or captured based on previous studies and SC experience (Shaver et al. 2016, 2017; Hart et al. 2018).

The best methods for a particular site within strata and areas will be largely determined by water clarity, exposure (e.g., in a protected bay or out in open deeper habitat), and water depth. All assumptions and biases should be considered during reconnaissance prior to field work. Transects should be optimized based on previous or reconnaissance work to determine the extent of the study area (the physical area and sea turtle encounter rate) and must be completed in one contiguous time-period.

The SC recommends a minimum of 8 sampling sites in each regional strata and area (i.e., 4 sampling sites in the inshore areas and 4 sampling sites in the nearshore areas) for a total of 32 sampling sites across the US GoM. Additionally, reasonable spacing between sampling sites within each strata and area should be implemented (i.e., greater than 30 miles, which is considered by the SC as a generalized mean home range of satellite tagged adult sea turtles) such that the sites are not clumped too closely in any strata or area (i.e., to reduce spatial autocorrelation), and for roughly equidistant spacing along the coastlines. Appropriate spacing will increase the probability that separate segments of the population are being monitored at each study site, and the collective of all sites combined will be representative of the population dynamics for sea turtle species in the US GoM. Distance required between sampling sites may be adjusted as part of the refinement of methodology in preparation of Phase 2.

Based on the SC review of sea turtle survival papers for CMR studies, a minimum sampling duration at any one site should be 5 data collection days within a 2-week period. Such a duration would increase the likelihood of capturing and recapturing sufficient individuals to generate survival estimates, and to meet the assumptions of instantaneous sampling. For distance sampling, transects should be designed to meet standard assumptions, and with the goal of observing the minimum recommended animals over the course of the sampling event (i.e., 40 individuals, but ideally 60–80 individuals). Both survey types (CMR and distance sampling) should be performed at least annually and ideally seasonally (i.e., four sampling events per site per year) to understand the inter-season variability.

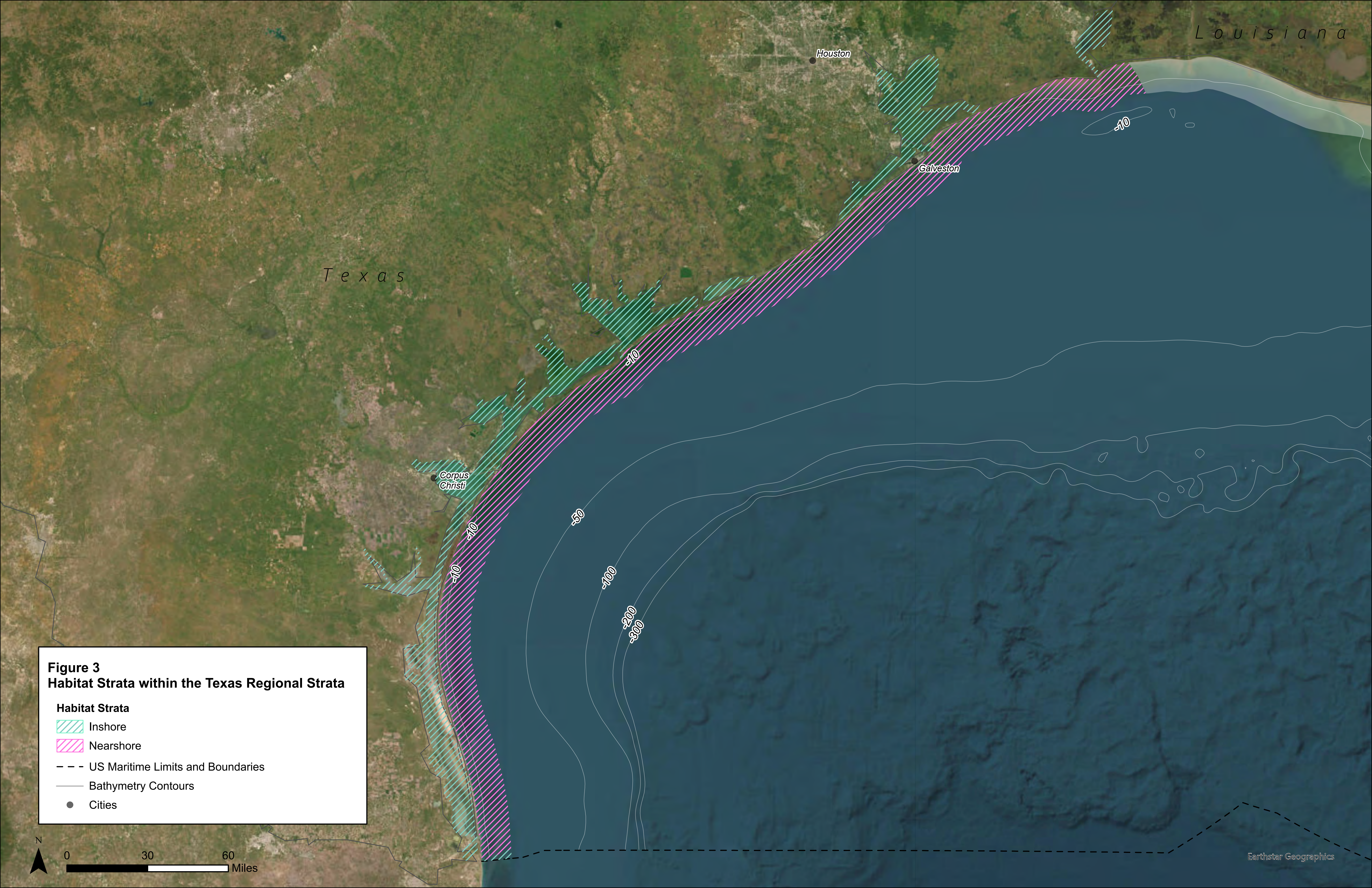


Figure 3
Habitat Strata within the Texas Regional Strata

Figure 4
Habitat Strata within the Central Regional Strata

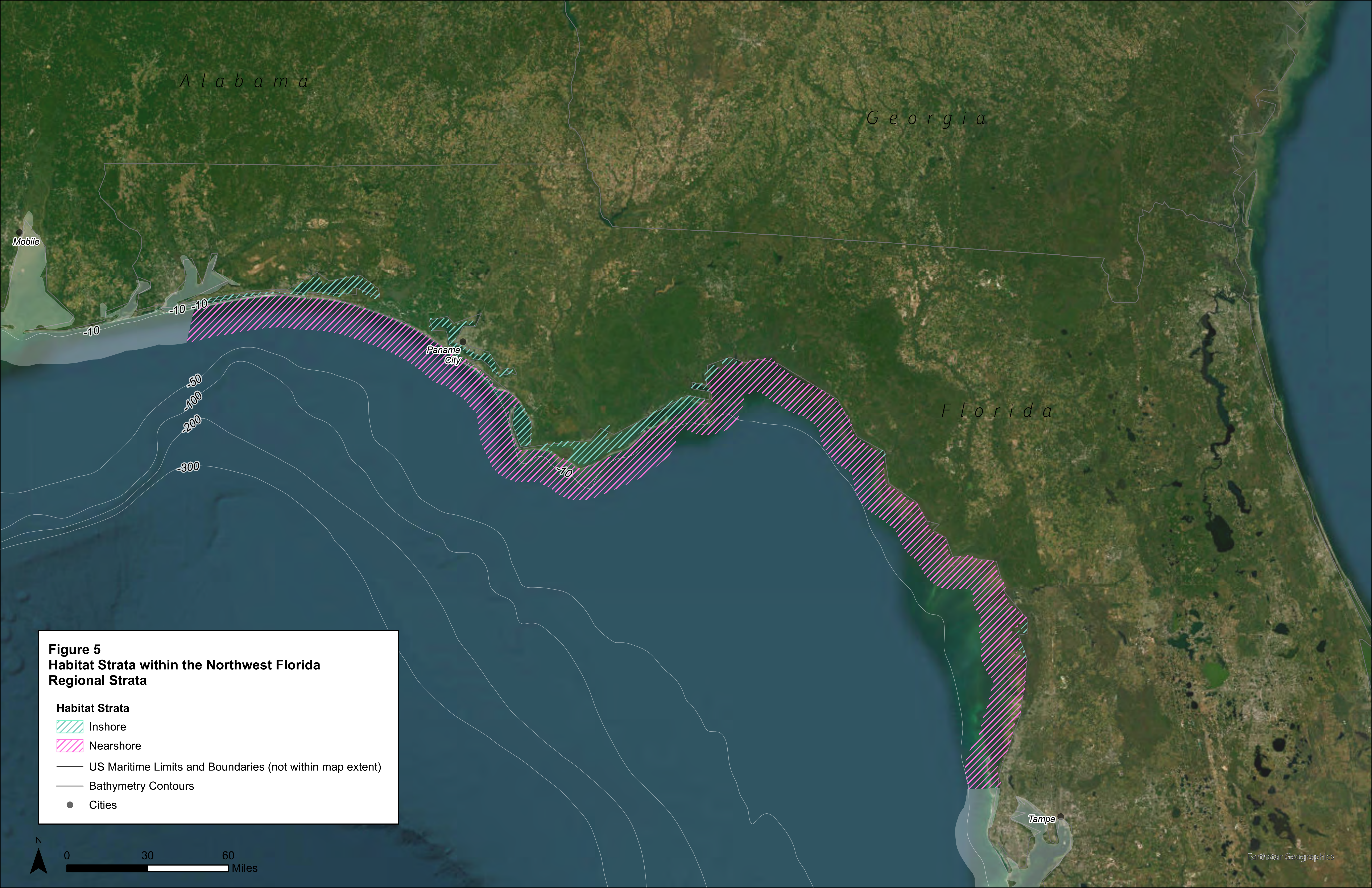


Figure 5
Habitat Strata within the Northwest Florida Regional Strata

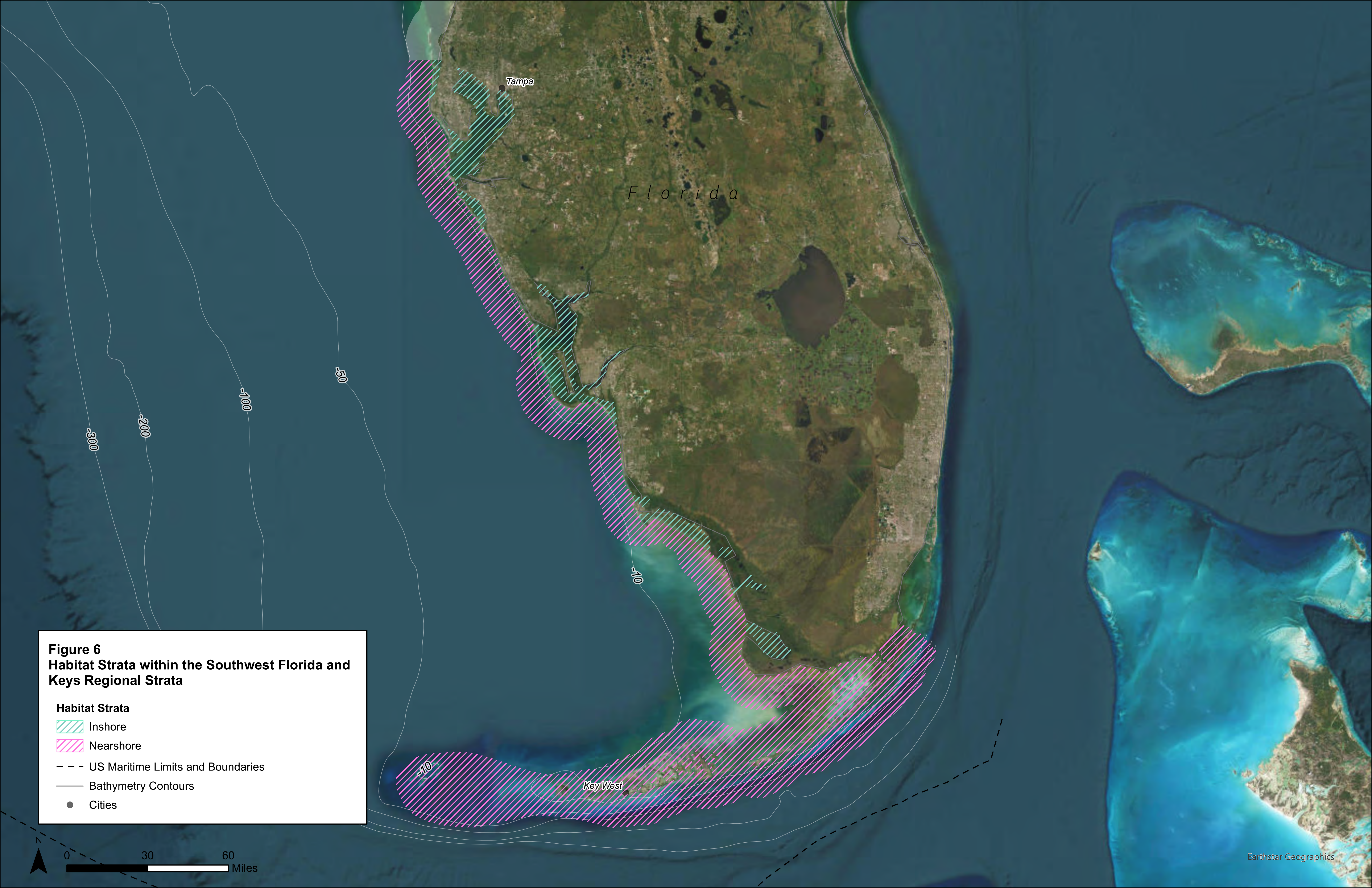


Figure 6
Habitat Strata within the Southwest Florida and Keys Regional Strata

3.1.3.2 Hawksbill

The SC considers hawksbill sea turtles in a separate category to the other hardshell sea turtles because they are patchily distributed in the US GoM and occur only in specific habitats. Hawksbill sea turtles primarily use waters associated with coral reef and hard-bottom habitat (Witzell 1983; Bell et al. 2012). During early years, hawksbill sea turtles use oceanic habitats for feeding on a variety of organisms floating on the surface (Bolten 2003; Witherington et al. 2012), prior to shifting to coral reefs and seagrass meadows in neritic habitats (Meylan 1988; Bjorndal and Bolten 2010; Strindberg et al. 2016).

In the US GoM, there are two National Marine Sanctuaries with prevalent coral reef habitat: Flower Garden Banks (including McGrail Bank) and Florida Keys. Additional potential habitat may also be found in coral reef Essential Fish Habitat (EFH) and coral reef Habitat Areas of Particular Concern, as designated by NOAA Fisheries. As illustrated in Figures 7 through 10, coral reef habitats in the GoM are generally located offshore (greater than 12 nm from shore). The exception is a relatively large designated EFH area off the coast of south and central Florida that is in shallow water, on the continental shelf, and relatively close to shore (Figure 10). Hawksbill sea turtles may also be associated with rock jetties, artificial reefs, oil rigs and reef-associated seagrass beds in the US GoM (Gorham et al. 2014; Valverde and Holzwart 2017).

The US GoM is at the northern margin of the distribution of hawksbill sea turtle populations in the Caribbean. Although the goal of this Plan is to collect data US Gulf-wide, there are limited sampling opportunities for hawkbill sea turtles. Permanent residents are likely limited to the preferred habitats outlined above. As such, the SC recommends surveying and sampling in locations where the species has been recorded historically, viewing the data as more of a census of the known residents instead of being representative of overall US GoM population levels (Lopez-Castro et al. 2022).

Potential hawksbill sea turtle habitat polygons have been identified per regional strata in Figures 7 through 10. Other potentially suitable habitats such as oil rigs, coral EFH, coral Habitat Areas of Particular Concern (illustrated in these figures), and seagrass beds (not illustrated in these figures as they are transient habitats) could be sampled for hawksbill sea turtles; however, sampling in these habitats may yield fewer detections than sites with more suitable habitat, where turtles occupy resident home ranges.

The SC recommends sampling in five locations in each of the four regional strata, somewhere in the potentially suitable habitat areas identified in Figures 7 through 10, for a total of 20 individual sampling locations in the US GoM. Given the lack of suitable habitat in the Central regional strata, no sampling areas have been suggested for Phase 1. Ideally, sampling would be conducted at least once during each season but at a minimum once annually at the same time of year. Recommended sampling methodologies for hawksbill sea turtles on coral reefs include Self-Contained Underwater Breathing Apparatus (SCUBA) diving and/or snorkeling (Strindberg et al. 2016). The SC also recommends other complementary approaches in addition to SCUBA and snorkeling methods, such as hand captures, which would at least provide estimates of local abundance, survival, growth rates, age distributions, etc. given that US Gulf-wide estimates would likely not be possible at this time. As time goes on, the goal will be to have more successfully documented sampling locations from international collaborative efforts as detailed further in Section 6.1.

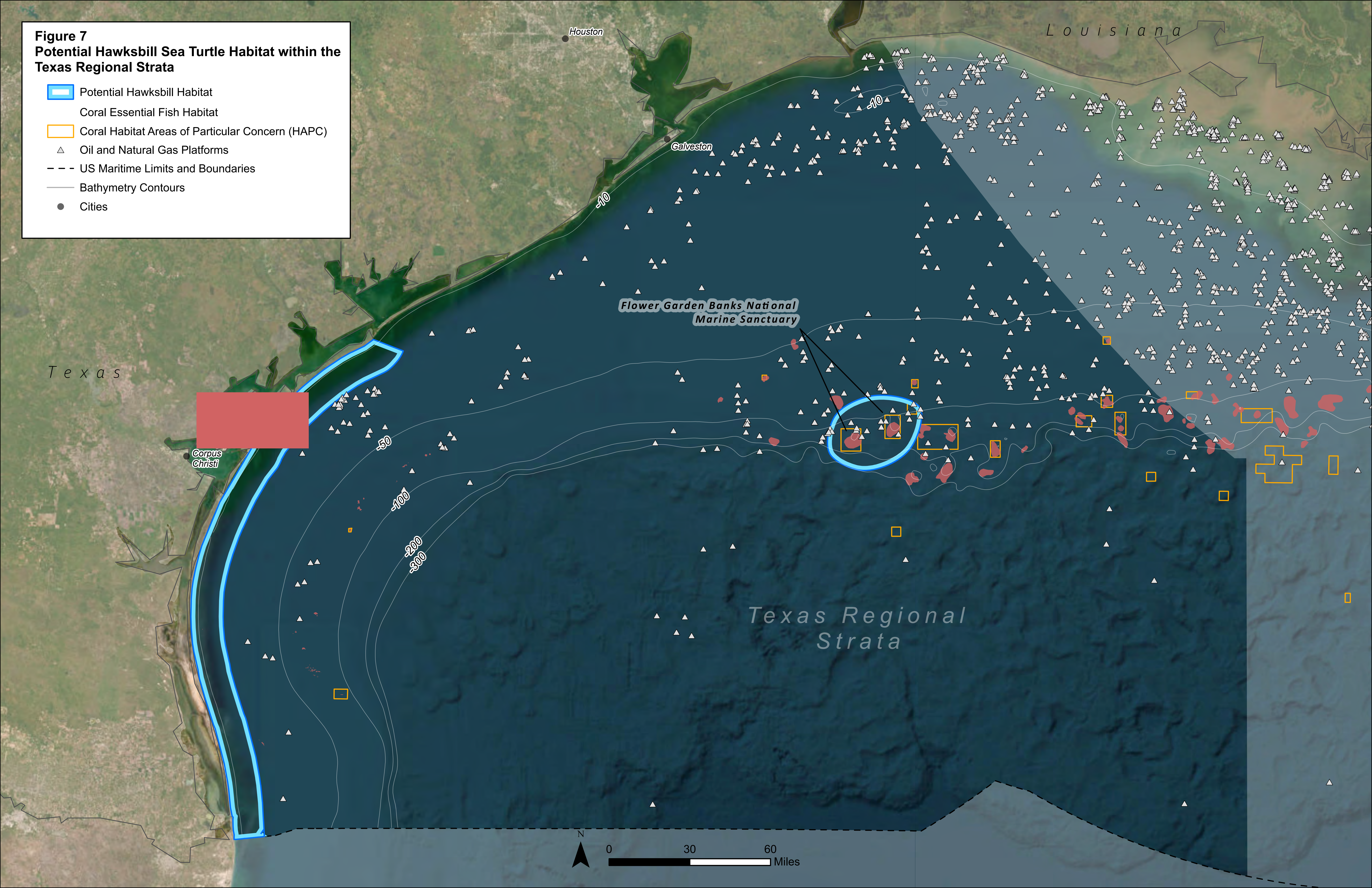


Figure 7
Potential Hawksbill Sea Turtle Habitat within the Texas Regional Strata
Potential Hawksbill Habitat
Coral Essential Fish Habitat
Coral Habitat Areas of Particular Concern (HAPC)
Oil and Natural Gas Platforms
US Maritime Limits and Boundaries
Bathymetry Contours
Cities
Houston
Galveston
Corpus Christi
Louisiana
Texas
Flower Garden Banks National Marine Sanctuary
Texas Regional Strata
-10
-50
-100
-200
-300
N
0
30
60
Miles

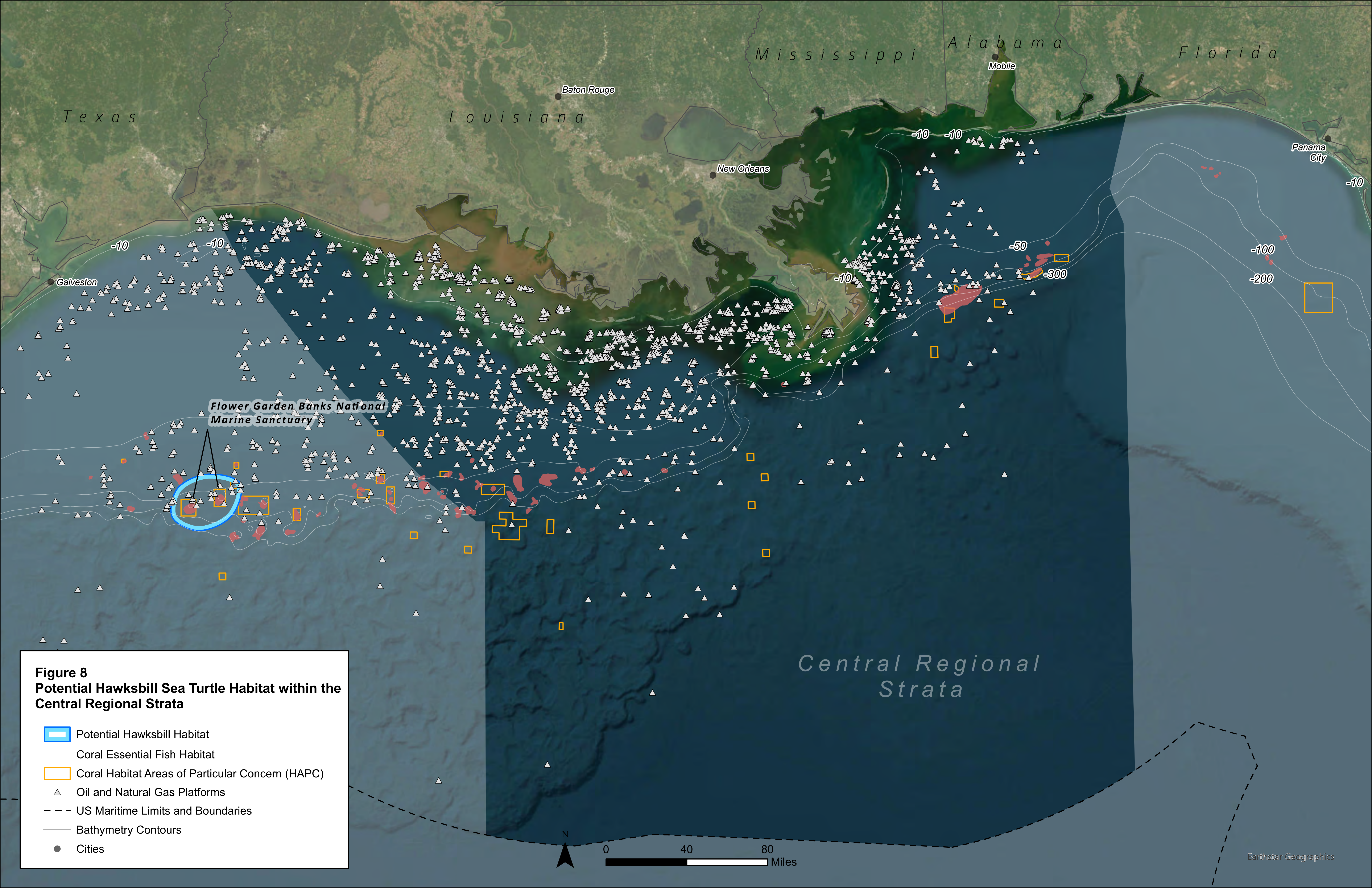


Figure 8
Potential Hawksbill Sea Turtle Habitat within the Central Regional Strata

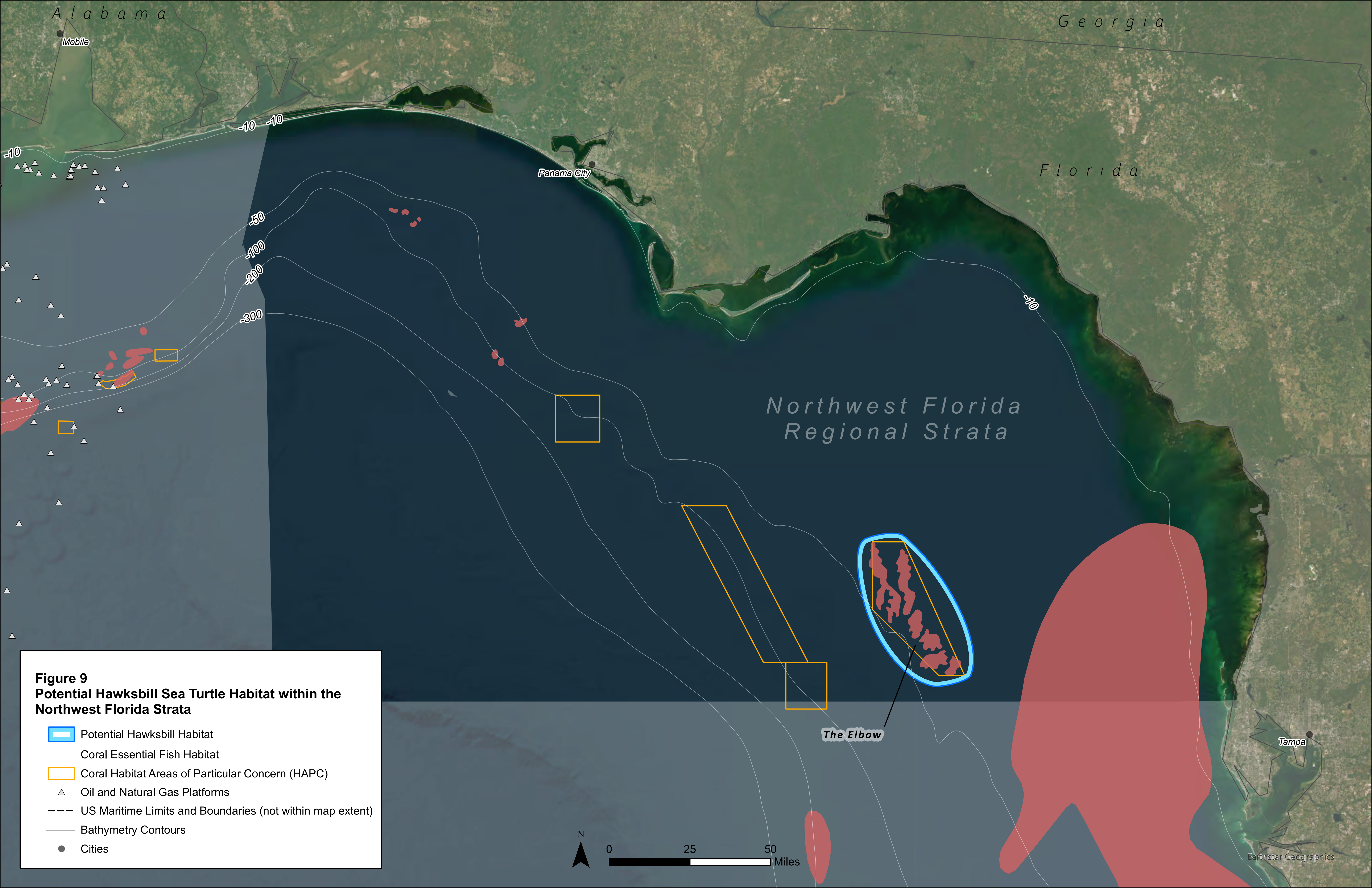


Figure 9
Potential Hawksbill Sea Turtle Habitat within the Northwest Florida Strata

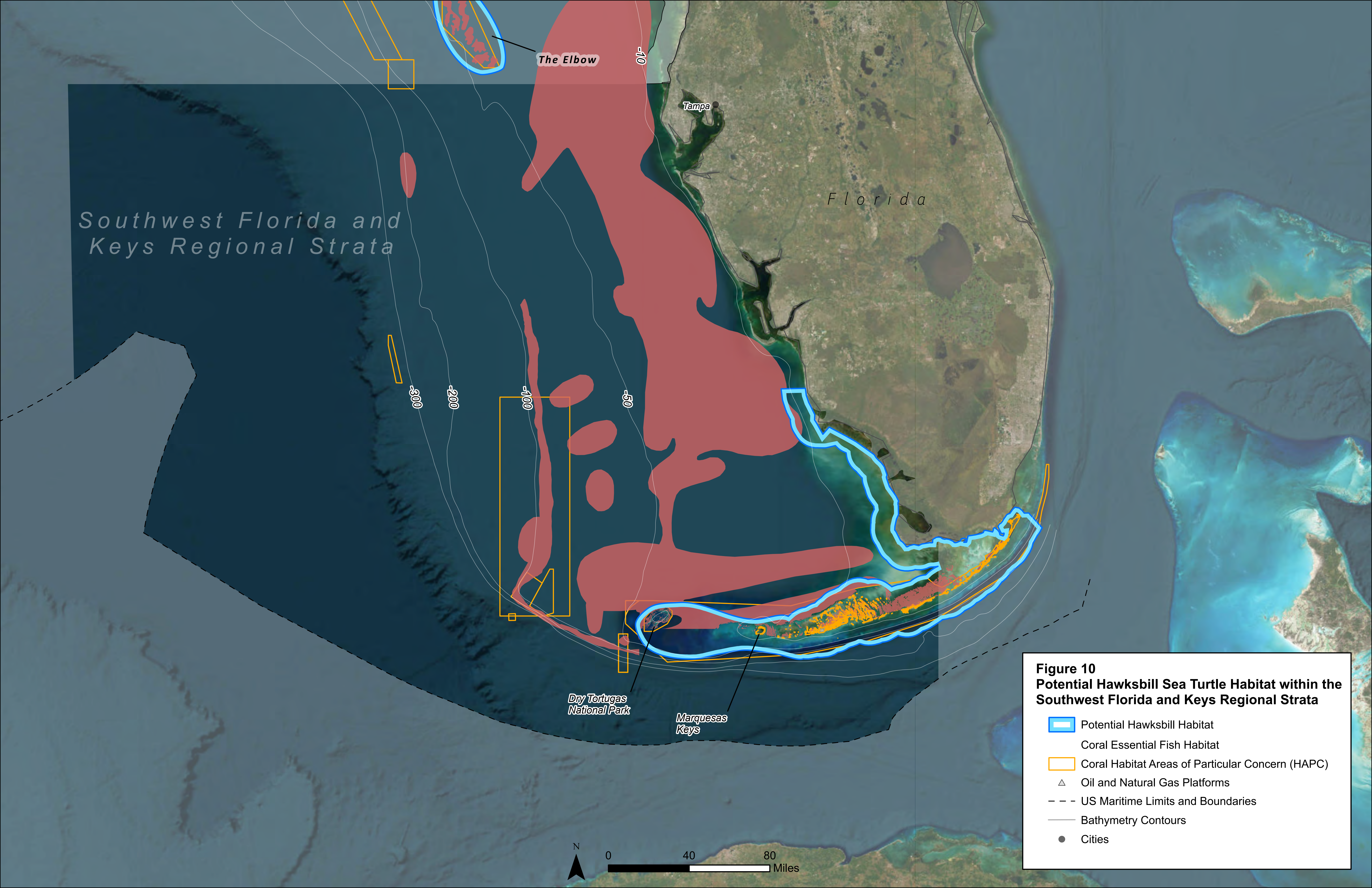


Figure 10
Potential Hawksbill Sea Turtle Habitat within the Southwest Florida and Keys Regional Strata

3.1.3.3 Leatherback

Leatherback sea turtles do not regularly nest in the US GoM but use the northeast GoM as a foraging area throughout the year (Sasso et al. 2021; Evans et al. 2021). Most leatherback sea turtles in the US GoM originate from Caribbean nesting assemblages (Stewart et al. 2016; Evans et al. 2021). Abundance is highest in the summer and autumn when adult females have returned from their nesting beaches to forage. In US GoM waters, leatherback sea turtles predominantly reside on the Florida shelf in the northeast GoM; those that migrate to the Caribbean to nest do so from late October through December (Sasso et al. 2021).; those that migrate to the Caribbean to nest do so from late October through December (Sasso et al. 2021).

Leatherback sea turtle distribution in the northeast GoM is dependent on jellyfish availability, which is affected by salinity, temperature, nutrients, distance from shore, and water movements (Aleksa et al. 2018). This Plan does not explicitly address aerial surveys; however, aerial surveys are generally considered the most effective method to survey leatherbacks for abundance and density information given their wide geographic range and the changing distribution of their jellyfish prey. Aerial survey design should consider the multiple biases associated with this method (even when techniques originally designed to sample marine mammals are adapted for sea turtles). Chief among these biases is the lack of data on leatherback sea turtle surface time to dive ratios. Therefore, this Plan recommends that direct capture and satellite tagging is necessary to provide data for leatherback sea turtle surface intervals, thereby improving abundance estimates from aerial survey data (see Section 4.0).

The SC recommends that aerial surveys cover as much of the US GoM as possible to assess distribution and abundance of all sea turtle species from the coastline to the shelf break and be conducted at least once per season. Satellite tagging should be conducted on the Florida shelf in spring and late summer/early autumn to increase capture probabilities and so that tagging data would overlap with aerial surveys.

3.1.4 Juvenile Sea Turtles in the Surface-Pelagic Drift Community

Green, Kemp’s ridley, loggerhead, and hawksbill sea turtles all pass through a surface-pelagic juvenile stage before recruiting to benthic habitats in neritic waters. The duration of this stage varies among and within species (1–12 years) and has important demographic implications because survival rates for this life stage are assumed to be low (Bjorndal et al. 2005). This life stage is associated with a SPDC (Witherington et al. 2012), which is commonly dominated by *Sargassum* macroalgae but may contain significant masses of cyanobacteria, terrestrial plants, and other floating material including plastics and petroleum (Qi et al. 2022).

SPDC in the GoM occurs at zones of oceanographic convergence and downwelling that range widely in patch size and density. The most frequent origin of SPDC, either in oceanic or neritic GoM waters, is likely to be windrows formed by Langmuir circulation (Lapointe 1995). Sea turtles recorded from US GoM SPDC include post-hatchlings and surface-pelagic juvenile green, Kemp’s ridley, loggerhead, and hawksbill sea turtles (Witherington et al. 2012; Phillips et al. 2022).

Measuring abundance and vital rates for juvenile sea turtles in SPDC is challenging. SPDC and *Sargassum* patches are known to move, break up, and re-form under varying sea-states, and the sea turtles in these areas disperse and redistribute over a large spatial scale as they are active swimmers and have species-specific differences in active orientation (Putman and Mansfield 2015; Mansfield et al. 2021). Target sampling areas occur throughout remote areas of the GoM, and although these patch dynamics are measurable from remote sensing (Hardy et al. 2018), current sensing technology is likely to underestimate this habitat (Goodwin et al. 2022).

Aerial and ship-based transect surveys in these remote areas could be considered but would not be expected to detect small sea turtles. Distance sampling and dipnet capture from small vessels (8–18 meters) within 160 kilometers from ports has been successful in estimating spatial density and abundance of sea turtles within the SPDC (Witherington et al. 2012) and in collecting size and genetic data, but recaptures are rare. Recapture probabilities may be low due to the dynamic nature of SPDC target areas (e.g., *Sargassum* patches) and the dispersal behavior of this life stage. That is, return sampling to a fixed location would be expected to draw from an unsampled population that was previously “upstream” or dispersed elsewhere.

Extensive, representative spatial density estimates of juvenile sea turtles, and next-generation estimation of habitat extent (i.e., improved remote sensing capability coupled with oceanographic modeling), would be necessary for representative extrapolations of population abundance for trends assessments. The vast sampling required for this effort would be an expensive annual effort. At present, sampling surface-pelagic turtles in the GoM for annual trends in abundance should be considered challenging. Recapture probabilities of sea turtles occupying the SPDC are likely to be too low to allow abundance-trends estimates from CMR methods alone. Although challenging, estimation of abundance and survival for this life stage will not come from other sampling efforts. This early life stage is known to be severely affected by plastic ingestion and petroleum. Surface-pelagic juvenile sea turtle mortality attributed to DWH was estimated to be approximately 25 times higher than mortality in all neritic (benthic) stages combined (Wallace et al. 2017).

3.2 Phase 2

The purpose of Phase 2 is to learn from existing data and new data collected during Phase 1 to refine and implement a comprehensive, statistically robust, US Gulf-wide, long-term, index site sea turtle in-water monitoring program. Although most of this evaluation should occur at the end of Phase 1 data collection, especially for capture/recapture data, survey information should be evaluated annually throughout Phase 1. Alterations to survey designs are key after initial data collection to achieve robust analyses (Starcevich et al. 2018).

Phase 2 is envisioned to include various components, including a demographic rate estimation, power analysis, monitoring program design, data standardization, and crafting of an Implementation Plan.

3.2.1 Demographic Rate Estimation

Throughout Phases 1 and 2, survey and capture/recapture data will be analyzed to estimate abundance, distribution, and key vital rates (as per Table 2). Where estimation is not yet possible due to insufficient data, data collection should continue until such estimations can be carried out to a sufficient level to support the needed power analysis, until the methodological/analytical design is reconsidered, or the site is abandoned.

3.2.2 Sample Size and Sampling Design Evaluation

Once initial data analyses are completed, and where estimation of abundance, distribution, and vital rates are possible, this information should be used to conduct a power analysis or likelihood-based approach to evaluate data and sampling designs at each site. This evaluation should include the number of sites overall; spatial distribution of species sampled and surveyed; and sampling frequency needed to enable detection of management-guided change of trends in abundance and survivorship within reasonable confidence bounds.

3.2.3 Refined Monitoring Program Design

Based on the insights gained from the power analysis or likelihood-based approach, the sampling regime should be adapted (where necessary) into a comprehensive, statistically robust, US GoM-wide, long-term, index site sea turtle in-water monitoring program. This would include specifying survey and sampling locations, sampling frequency, geographical range, species coverage, and life history stage coverage, as well as an evaluation of employed methodologies and their alternatives.

Questions to be considered in evaluating adequacy of a Phase 2 Index Site include:

- Does the site fill a gap in regional-zone representation?
- Does the survey facilitate spatial extrapolation from spatially restricted sites?
- Does the site fill a gap in habitat representation?
- What has been the degree of human impact since the start of Phase 1?
- Does the site fill a gap in species or life stage representation?
- What are the required, individual site case studies observations, recaptures, and time series to estimate annual survival rates within reasonable confidence limits and detect significant trends in abundance?
- What is the required frequency and spatial extent of surveys?
- Which analyses are now possible with any previously collected genetic samples?
- Does the site or survey area provide information useful for inference at other sites (e.g., movements, availability, and spatial distribution that reveal emigration, behavior, and spatiotemporal representation)?

3.2.4 Integrated Population Models

As US Gulf-wide sea turtle population metrics (Table 2) and trend data become available through Phase 1, an approach to integrate different types of data will be needed. Hierarchical statistical modeling procedures developed over the past 15 years have advanced the ability to test for drivers of variation in abundance and occurrence (Royle and Dorazio 2008), estimate species occurrence from presence-absence data even under imperfect detection scenarios (MacKenzie et al. 2006), and estimate abundance from imperfect count surveys (Royle and Dorazio 2006; Royle et al. 2007; Kery et al. 2009). Other analytical methods not detailed within this Plan (e.g., neritic survival equivalent scoring [Arendt et al. 2022]) may also provide supplemental information within Phase 2 once additional data are available.

Analytical techniques used will depend on which method answers specific objectives most effectively, given the structure, cost, and assumptions associated with data as well as the expertise of researchers. For example, Pagel et al. (2014) used hierarchical observation modeling to integrate different types of commonly available data sources, thereby improving the estimates of variation in species abundances across space and time. Although this approach centered on a butterfly species in Great Britain, data spanned 20 years and a broad spatial scale, and simulations based on data helped to determine regional trends in the population dataset. In other populations where repeated counts of closed populations or CMR data are available in addition to simple count surveys, the integration of these data allows for a more direct estimation of observation errors (Royle and Dorazio 2008), and better information about absolute population sizes.

Species distribution models (Elith and Leathwick 2009) have also evolved to include integrated approaches whereby data from different sources are combined. For example, a recent study merged telemetry data for 114 leatherback sea turtles with point source data from fishery bycatch and observation records from 2001-2019 in the Pacific to develop a better understanding of high-risk areas at sea for management concern (Liang et al. 2022). This example of integrated a species distribution model may be used for GoM leatherbacks in the future.

Eventual combination of survey and demographic data to understand sea turtle population dynamics can be accomplished through an integrated population modeling approach. In an example of a coupled integrated population model-Bayesian population viability analysis, Saunders et al. (2018) assessed impact of demographic rates on past population dynamics, population viability into the future, and efficacy of management strategies for an endangered bird (piping plover [*Charadrius melodus*]). Their model fused survey and CMR data while accounting for sources of uncertainty. Such an approach would be useful in Phase 2 of this Plan, which will be overseen by the LCE.

3.3 Implementation and Program Management

The sampling efforts outlined in this Plan will occur as part of an organized and coordinated network of individuals. During Phase 1 and Phase 2 sampling efforts, data must be collected in a consistent manner to facilitate comparisons across multiple study sites and collaborators. The SC recommends that the implementation of this Plan be coordinated by a single entity (referred to as the LCE), to oversee data collection, annual evaluation, data warehousing, and analyses.

The SC recommends that the LCE will be responsible for the following:

- Collaboration with partners to develop an Implementation Plan that includes, but is not limited to, staff responsibilities and accountabilities, budget considerations, recruitment of partners, communication strategies, and data management.
- Maintaining communications with collaborating partners to ensure all parties understand the methods and assumptions necessary to implement this Plan.
- Committing to frequent and effective communication and data sharing between data collection leads and state and federal agencies, permitting entities and contracted analytical groups.
- Recruiting data holders to participate in Plan implementation, including incentives for cooperation, data-sharing diplomacy, sharing of analytical results, and cooperative publication.
- Committing to periodic scientific and administrative review of Plan implementation and results.
- Seeking collaborations with international partners to expand monitoring within the GoM outside of US waters, to include Mexico.

Similarly, each collaborating partner would be responsible for:

- Providing information on study sites and frequency of sampling.
- Sharing resulting data for the purposes of completing abundance and trends analyses.

Additional details on the implementation of this Plan will be developed by the LCE.

4.0 Supplemental Data Collection

In addition to the recommended core data collection described to establish population trends, the SC suggests supplemental data collection if/when practical. Collecting additional satellite telemetry and aerial survey data may provide complementary information to the primary in-water monitoring program previously recommended in Section 3.0. Each of these potential supplemental data collection methods are briefly detailed below.

There are also several additional metrics that may be gathered during survey efforts that could provide useful supplementary information. Supplemental information could include diet, health, and/or age to potentially assist in interpreting sea turtle abundance and distribution trends. It could also include behavioral data, which may provide corrections for sea turtle presence and for estimating availability biases from sea turtle depths (and surface times), movement (flushing out and avoidance), and sheltering/conspicuity. Commonly, behavioral data come from telemetered sea turtles that represent the species, life stages, and habitat sampled in the accompanying distance sampling transects. Finer scale data can come from direct observations of sea turtles and biologging tags such as accelerometers, time-depth recorders, and animal-borne imaging. This level of information is beyond the scope of this Plan and its recommended data collection but could be helpful information for the future when facilitating interpretation of trends, to add qualitative insights where data gaps exist and guide the transition from Phase 1 to Phase 2 refinement.

4.1 Satellite Telemetry Data

Satellite tracking of sea turtle movements is a valuable complementary methodology to aerial surveys (Schroeder et al. 2020; Roberts et al. 2022). Satellite telemetry studies can assist aerial surveys by providing data on sea turtle surface time (i.e., availability windows to be counted by aerial surveyors and identifying areas of use not covered by aerial surveys or existing in-water projects due to spatial limitations of those studies). These data can be used to derive species-specific aerial correction factors for density and abundance estimates in areas surveyed by aerial flights.

Movement and connectivity data derived from satellite tracking sea turtles can also inform where new sampling sites may be located for Phase 2, and whether currently sampled sites are spatially separate/independent for trends analyses.

4.2 Aerial Survey Data

The primary source of publicly available aerial survey data for the GoM stems from the GoM Marine Assessment Program for Protected Species (GoMMAPPS). GoMMAPPS was a multi-agency partnership program that conducted broad-scale surveys to assess species distribution and abundance for sea turtles, marine mammals, and seabirds in the northern GoM, from nearshore waters to the US Exclusive Economic Zone, since 2017. Key tasks for GoMMAPPS were as follows:

1. Conduct aerial surveys over continental shelf waters
2. Conduct ship-board surveys on the shelf and out to the US Exclusive Economic Zone
3. Conduct satellite tracking of tagged animals
4. Perform genetic analyses for composition and connectivity
5. Develop spatially- and temporally explicit species density models

GoMMAPPS was a partnership between the Bureau of Ocean Energy Management Environmental Studies Program, NOAA Southeast Fisheries Science Center, US Fish and Wildlife Service Southeast Region, and US Geological Survey Wetland and Aquatic Research Center. GoMMAPPS was key in combining all existing aerial survey information together into one program.

GoMMAPPS ended in 2020, but data collected under this program are useful supplemental information to the data collection the SC has recommended in this Plan. For example, aerial surveys can identify the location of sea turtles and this information can be used to select sampling sites for tagging or capturing in areas that have greater sea turtle densities (Schroeder et al. 2020).

As of early 2023, the SC is unaware of long-term financial support for continuation of these surveys and no other Gulf-wide aerial survey data is available. Additional information on supplemental use of uncrewed aerial vehicle (UAV) technology is further discussed in Section 6.3.1.

5.0 Data Management

Data management and data analysis will be a critical element in the implementation of this Plan. Collecting sufficient data for abundance and population trends analyses will require collaborations across numerous agencies, universities, and private entities. Collaborators to this Plan will be responsible for providing relevant data and metadata from their studies to allow for appropriate analyses, such as the synthesis of Phase 1 efforts.

It is the SC's expectation that the LCE would provide resources such as datasheets, spreadsheets, relational database templates, analytical advice, and may provide sampling equipment or other resources that collaborators may use to facilitate data collection, submission, and their own publishing efforts. The SC suggests that the LCE hold annual meetings in which methods, data analyses, and results are shared and discussed. The LCE should be available for continual communications for problem-solving and other advice.

At the time this Plan was completed, the SC was unaware of a single centralized database consistently used for sea turtle in-water data. While there are several existing data repositories such as Sciencebase, MoveBank, Dryad, and GRIIDC, none are consistently used for sea turtle in-water capture data.

Understanding the need for a sea turtle data repository, the OO TIG has funded the development and maintenance of the Sea Turtle Atlas Project, which will be a centralized data platform for sea turtle data in the GoM (with the potential for expanding to all US waters in the future). While still in the early stages of development, the Sea Turtle Atlas will integrate and display available datasets including nesting data, aerial survey, in-water capture, telemetry, and strandings data, and would be an ideal platform and repository for data collected pursuant to this Plan. The Sea Turtle Atlas Project is currently funded for a 15-year duration, including four years of development and data integration and 11 years of operation (i.e., tracking usage, updating data). The Sea Turtle Atlas is envisioned as meeting multiple needs, and could hold raw data where needed, but otherwise would serve as a central platform to view data summaries or data products contributed by several sources. Maintenance of the Sea Turtle Atlas[1] would include troubleshooting technical issues, continued incorporation of new datasets, updating existing datasets, and supporting external uses of datasets available through the Sea Turtle Atlas.

The SC suggests that the LCE provide specific participation and data management requirements to all data contributors and recommends that the Sea Turtle Atlas be considered for the central repository. The Sea Turtle Atlas Project is managed by NOAA Fisheries and the DOI and is expected to be operational within the next 2 to 3 years (by mid-2025).

[1] https://www.gulfspillrestoration.noaa.gov/project?id=223

6.0 Future In-Water Plan Considerations

In preparation of the Phase 2 implementation described in Section 3.2, several additional efforts should be considered, including international partnerships, emerging technologies, and program expansion and application. These efforts are detailed in the following sections. As large-scale research in the GoM is steadily increasing, Greening et al. (2022) noted that emerging technologies along with advances in assessments, synthesis with other research, and use of refined methodologies will provide a unique opportunity to “demonstrate large-scale environmental recovery.”

6.1 International and Regional Partnerships

It is anticipated that partnerships between government agencies and academic institutions will be key to the success of this Plan, as a means of uniting diverse expertise, resources, and funding opportunities, and to more fully understand sea turtle abundance and population trends in the GoM. Likewise, achieving restoration goals for certain sea turtle species will require collaboration beyond US borders into Mexican waters to fully represent the entire GoM. For example, Shamblin et al. (2017, 2023) highlighted the significance of US waters as nursery habitat for green turtles originating in Mexico. Samples collected during these studies in the GoM yielded haplotypes originating from the Caribbean in addition to the US and Mexico. Similarly, Phillips et al. (2022) found that the GoM is an important nursery area for rookeries located outside the US. As another example, recovery of the critically endangered Kemp’s ridley depends on bi-national collaboration between the US and Mexico to protect nesting females and their hatchlings in the western GoM (Shaver and Caillouet 2015). To fully implement the broader goals of this Plan, it is anticipated that the LCE would seek collaborations with international partners as the SC recognizes the important connections among the GoM, the Caribbean Sea, and the wider Atlantic Ocean.

6.2 Program Expansion and Applications

Fully understanding sea turtle population dynamics in the GoM will require the eventual integration of data collected via this Plan with data acquired through other large spatial-scale programs and surveys, including ongoing research and restoration projects, the sea turtle nesting site monitoring program, and aerial survey programs. Data collected through this in-water program, or the more fully integrated combination with the programs detailed below, will support important management applications, such as evaluating the effectiveness of restoration programs or environmental impact assessments.

6.2.1 Integration with Ongoing Research and Restoration Projects

The SC recognizes that there are ongoing sea turtle projects occurring in the GoM that may be using methodologies that are different from those recommended in this Plan’s Phase 1 approach. If and where feasible without jeopardizing the objectives of existing projects, the SC suggests that applicable ongoing research and restoration be adapted to follow the approaches outlined in this Plan so that integration of those data are compatible with the data collected pursuant to this Plan. This will require continual communication between the LCE and researchers throughout the GoM, as well as continual diplomacy, communication, and facilitation to ensure data collection protocols are consistent and data can be combined to achieve the collective goal of understanding sea turtle abundance and population trends in the GoM.

6.2.2 Integration with Nesting Site Monitoring

Results of suggested data collection for Phase 1 would benefit from integration with future nesting site monitoring programs. Historically, as well as currently, time-series counts of crawls, nests, and/or adult females encountered on nesting beaches have provided the basis for evaluating trends in demography and abundance in sea turtle populations. However, relying solely on these data can introduce biases in population estimates (Bjorndal et al. 1993, 2005; Bell et al. 2012; Lopez-Castro et al. 2022).

In 2010, the NRC evaluated the methods by which the status and trends of sea turtle populations were assessed. Focusing on the integration of demography and abundance, the NRC (2010) concluded that population assessments in the US have been too heavily based on adult female abundance on nesting beaches and need to shift to apply knowledge of “accompanying changes in demographic rates at all life stages”. The most pressing demographic data gaps identified included: in-water abundance, hatching-cohort production, survival of “immature sea turtles” and nesting females, age at sexual maturity, breeding rates, and clutch frequency. As such, the NRC recommended that NOAA Fisheries and the US Fish and Wildlife Service ensure that all life stages are assessed to estimate sea turtle population abundance and not just adult female estimates of abundance. Similarly, McDonald et al. (2017) noted that additional monitoring of nesting sites in the future and additional abundance measures could provide insight into population-level effects of the DWH spill and/or similar future events.

6.2.3 Integration with Aerial Survey Monitoring

Data collection as recommended in this Plan could be expanded in the future to include integration with aerial survey monitoring, such as those conducted during past programs like GoMMAPPS (as detailed in Section 4.2). This integration could provide density and abundance estimate improvements for sea turtles using surface interval/diving behavior, which could mitigate availability bias (Roberts et al. 2022). Roberts et al. (2022) concluded that the analyzed dive and spatial data they collected from satellite tags for understanding surface times could be used to create correction factors for detection availability during aerial surveys. In addition, future efforts should consider funding aerial surveys specifically designed for sea turtles rather than relying on data collected during marine mammal surveys, which reduce sea turtle detectability due to their different study design (especially speed and altitude).

6.2.4 Restoration Planning and Evaluation

The DWH NRDA sea turtle restoration relies on the best available science to determine appropriate restoration actions, appropriate geographic and temporal locations to implement those restoration actions, and to conduct both project-level and resource-level restoration evaluations. Information exists on sea turtle population structure, spatiotemporal distribution, life history parameters, migration patterns, and habitat use, but there are temporal and spatial gaps in these data sets (National Marine Fisheries Service and USFWS 2008; Greening et al. 2022; Guilbeau et al. 2022).

Existing sea turtle population data were used in the development of the PDARP and the Region-wide OO TIG *Strategic Framework for Sea Turtle Restoration Activities*, while also acknowledging data gaps related to status, trends, and spatiotemporal distributions (DWH NRDA Trustees 2016, 2017). The DWH NRDA sea turtle restoration planning and evaluation efforts will significantly benefit from the data collected and analyses completed through this Plan. The coordinated network and sampling structure established in this Plan will provide new data to aid in future restoration planning and implementation. Additionally, DWH sea turtle restoration managers are actively looking at available data and tools to determine the long-term benefits derived from sea turtle restoration activities in the landscape of other sea turtle recovery efforts and ongoing threats. New and coordinated data sets on sea turtle abundance will assist in the evaluation of DWH NRDA restoration efforts, as well as providing support for a comparison between abundance and key sea turtle threats in select areas of the GoM.

6.3 Emerging Technologies

Emerging technologies are those that have shown potential to collect relevant demographic data in locations other than the GoM or for wildlife other than sea turtles, but are either still in a developmental stage, or are too costly or not widely available in their current form. For the purpose of this Plan, such emerging technologies include the use of UAVs, environmental DNA (eDNA), and tag technology. Each of these is further detailed below.

Other emerging technologies not discussed below include satellite developments and autonomous underwater vehicles (AUVs). Lower-orbiting satellites and other National Aeronautics and Space Administration (NASA) satellite sensor developments may be useful for future Gulf-wide sea turtle or sea turtle habitat monitoring. This field is extensive and quickly evolving so the reader is referred to the NASA earth missions website for its latest developments.[2] Similarly, AUVs may be utilized in the future as technology advances to cover larger distances in relatively clear water and could potentially cover greater depth ranges than other methods. However, as of now, the initial investment in equipment for this method is high and outweighs the benefits.

[2] https://science.nasa.gov/earth-science/earth-missions-future

6.3.1 Uncrewed Aerial Vehicles

Use of UAV technology (also referred to as drone technology) has been used increasingly over the last decade in wildlife surveys (Jones et al. 2006; Rees et al. 2018) to estimate abundance, distribution, and density (Schofield et al. 2019). Other information such as behavior, habitat use, climate change, and complementary biologging techniques can also be gathered from UAV surveys (Schofield et al. 2019).

One of the key benefits of using UAVs is that they can be an effective tool for surveying relatively large areas of inshore bays and estuaries (Rees et al. 2018). Surveying large areas was historically costly, but with UAV technology large areas can be surveyed without as many resources or time required. Sites that may be difficult or dangerous to access from land may also be more easily accessible via UAV (Chabot and Bird 2015).

High-definition video and photo imagery can be collected by UAVs that can be launched from a variety of locations (Ballorain et al. 2016). Visual data for sea turtle observations can be georeferenced from time-synced GPS records and video footage, which can then be used for abundance estimations (Fuentes et al. 2015; Sykora-Bodie et al. 2017). This method is already being used for nearshore sea turtle density estimations (Sykora-Bodie et al. 2017). Habitat use can also be assessed using georeferenced records and video footage. These high-definition videos can also aid in public outreach and engagement (Rees et al. 2018) as previously used satellite imagery often has comparatively coarser resolution (Kuenzer et al. 2014) and visually appealing images can more easily capture the interest of stakeholders (Rees et al. 2018).

Technological advances in UAV software and hardware capabilities are ongoing and expected to improve in the future (Rees et al. 2018). Although the use of UAVs can provide high resolution viewpoints for in-water surveys, it should be noted that UAV use is most effective in clear water. Use of UAVs for sea turtle monitoring is not as effective in turbid waters that reduce visibility in recorded footage. Other potential complications with UAV technology include potential local airspace restrictions, battery life restricts flight times and distances, and significant file storage is required to maintain high-resolution imagery (Rees et al. 2018). As such, UAV surveys are not a suggested primary sampling method at this time. As the technology continues to advance, UAV use may become a more valuable method of sea turtle data collection in the future. The SC suggests potentially using this methodology in the future for small-scale sampling and for sampling in bodies of water close to shore to capture areas not easily viewed via traditional aerial surveys. Additionally, UAV surveys could be useful along with other observation methods such as side-scan sonar (Maki et al. 2020).

For additional information on different designs of UAVs and their potential use in sea turtle surveys, refer to the following peer-reviewed literature: Rees et al. (2018), Bevan et al. (2018), Hensel et al. (2018), Schofield et al. (2019), and Dickson et al. (2022).

6.3.2 Environmental DNA

DNA that can be found in the environment (water, soil, sediment, snow), originating from organismal cellular material such as skin, saliva, urine, or feces is referred to as eDNA

(Farrell et al. 2022). This emerging methodology is increasingly being used to sample for the presence of aquatic organisms as DNA rapidly diffuses from its source in the environment allowing for detection of aquatic organisms' presence anywhere in a traversed waterbody even when the actual animal is not visible or present at the time of survey (Rees et al. 2014). This survey methodology is rapid and allows for non-invasive sampling.

Currently, the use of eDNA to sample sea turtles is hampered by numerous practical challenges. Although this methodology has been applied in recent years to detect freshwater turtles (Davy et al. 2015; Adams et al. 2019), freshwater turtle eDNA sampling often involves relatively enclosed or non-tidally influenced small bodies of water whereas sea turtles in the GoM are traversing a much larger body of water subject to regular flushing via currents and tides. Further, eDNA may suffer from high false negatives (i.e., failing to detect a sea turtle when it is present). For example, Rees et al. (2014) were unable to detect green sea turtle eDNA in a controlled tank of water regardless of the confirmed presence of the turtle. Recognizing the complexities and limitations in sea turtle eDNA research, Harper et al. (2020) tested for green sea turtle presence in both an aquarium and natural habitat setting. Results showed that methods must be adapted for different species' biological considerations; researchers suggested collecting samples from deeper depths to improve detection frequency for green sea turtles to be consistent with habitat preferences and typical behavior. Harper et al. (2020) concluded that eDNA could be a useful tool to monitor green sea turtles with more refinement of the methodology.

In the future, this methodology is likely to become more widely used and could be complementary to other survey methods. For example, when sea turtles are not visually observed during transect surveys, eDNA sampling could enhance understanding of a sampling location and its potential for sea turtle presence (Farrell et al. 2022). Sampling via eDNA techniques is expected to continue developing rapidly and may be a useful tool for Gulf-wide surveys in the future. However, as the technology currently exists, eDNA research largely focuses on presence/absence as opposed to abundance.

6.3.3 Satellite Tag Size

Satellite tags that provide appropriate dive and behavior data can inform in-water survival through known-fate survival methods. Pop-up satellite archival tags (PSATs) have been used to estimate survival of pelagic juveniles greater than 40 cm SCL (Sasso and Epperly 2007; Swimmer et al. 2014); however, using these methods to collect the data necessary to assess mortality events of surface pelagic or neritic juveniles most common in the GoM (15–27 cm SCL; Witherington et al. 2012) would require development of smaller towable archival tags than are currently available. The primary limitation of using current towable tags (such as a mini PSAT or SPLASH™ tag) on sea turtles is that satellite tag size restricts them to use on sea turtles approximately 30 cm SCL or greater.

Small location and temperature recording tags directly attached to the carapace have been used to track movements of small pelagic juvenile turtles. Mansfield et al. (2012) were able to successfully identify an appropriate method for satellite tag attachment to neonate sea turtles, and researchers in 2014 provided the first successful long-term satellite tracking data for neonate loggerhead turtles (from 11–18 cm SCL) in the Atlantic Ocean using 0.5-gram solar-powered satellite transmitters (Mansfield et al. 2014). These small solar-powered satellite transmitters were used in subsequent studies in 2017 and 2021 (Mansfield et al. 2017, 2021).

Historically, data collected in offshore environments for early sea turtle life stage have been limited due to associated logistics and cost, and no satellite tagging efforts for early life stage turtles have been published within the GoM to date. However, smaller tags are likely to continue being developed and are expected to be more widely used, which would allow for additional tracking data collection and allowance for survival estimate data to be collected for small sea turtles in the GoM.

7.0 Conclusions

This Plan addresses information gaps identified after DWH, with objectives set forth by the DWH NRDA Trustees. As such, this Plan is a guide for collecting biologically and statistically robust, in-water sea turtle data in a comprehensive, coordinated, and standardized fashion within the US GoM. The four main objectives of this Plan, as outlined in Section 1, are as follows:

- Identify and characterize biologically and statistically appropriate in-water sea turtle data collection and analyses to measure population change, including vital rates, abundance, distribution, and other demographic data.
- Provide a roadmap for the collection of data to inform sea turtle management and assess restoration efforts in the GoM.
- Recommend a comprehensive, coordinated, and standardized evaluation of the status and trends of sea turtle populations in the GoM.
- Identify processes needed for successful implementation of this Plan, including protocols for in-water sea turtle data management, and partnerships.

Successful implementation of this Plan will be reflected by an increased understanding of changes in populations of sea turtles inhabiting the GoM. Depending on magnitude of change, spatiotemporal variation, and the life stage measured, these changes may require decades of monitoring to reach biologically and statistically measurable significance. If guidance in this Plan is followed, these efforts will aid in designing restoration projects, assessing long-term effectiveness of restoration activities, and producing abundance and distribution baselines for sea turtles across the GoM.

Although there is considerable published information on sea turtle presence and distribution within the GoM, there are important spatial gaps, gaps in data detail, and likely biases for a regional sampling effort. Because long time-series are often needed to detect sea turtle population change, much of the historical monitoring in the GoM will be critical to understanding changes in GoM populations. However, this record is not complete and detailed enough to guide a statistically robust, Gulf-wide, in-water monitoring study design.

The SC proposes that an effective, Gulf-wide, in-water monitoring study design will require a long-term, phased, and adaptive approach to the collection of in-water sea turtle data. Phases would include:

- Phase 1: Exploration and identification of a limited number of prioritized sites in neritic waters in the US GoM.

- Phase 2: Continued monitoring of effective Phase 1 index sites and site refinement, based on initial results and sampling considerations per Phase 1, in the US GoM.
- Future In-Water Plan Considerations to include Monitoring non-US GoM waters.

7.1 Next Steps

For the Plan to be successful, the LCE will need to collaborate with partners to develop an Implementation Plan, commit to frequent and effective communication and data sharing (with securities in place for holders of the data), recruit data holders to participate, and commit to periodic scientific and administrative review of progress and results. Partners critical to this success will include holders of historical data sets; researchers with active monitoring projects willing to collect data in a manner as outlined in this plan; researchers willing to commit to long-term monitoring; permitting agencies; and administration of project-network monitoring, data management, data analyses, communication, and facilitation.

The SC acknowledges that this effort is a large undertaking, that funding will be a major component of future studies, and that overall goals will need to be prioritized accordingly. After the LCE has been identified, funding has been secured, and researchers are recruited, the SC recommends reviewing this Plan to flesh out Phase 1 methods. This discussion should include identifying specific locations for sampling, data to be collected, and anticipated modeling to be completed. A discussion of how results will then be used to plan and implement Phase 2 should follow.

Proper analysis of data collected is another key step in the implementation of the methods outlined in this Plan. Some of the suggested statistical methods are more advanced and require specific skills and expertise, which may necessitate collaborations with statistical consultants or academic groups.

The implementation of this Plan is expected to aid in filling the existing data gap; however, the SC recognizes that there may be unpublished literature that addresses some of the recommendations included within this Plan. The sharing (i.e., publication) of data collected is key to assist the scientific community in furthering knowledge of sea turtles in the GoM as a whole.

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9.0 Literature Cited

Adams, C.I.M., L.A. Hoekstra, M.R. Muell, and F.J. Janzen. 2019. A Brief Review of Non-Avian Reptile Environmental DNA (eDNA), with a Case Study of Painted Turtle (*Chrysemys picta*) eDNA Under Field Conditions. Diversity 11: 50. https://doi.org/10.3390/d11040050.

Aleksa, K.T., R.W. Nero, J.D. Wiggert, and W.M. Graham. 2018. Descriptive Density Models of Scyphozoan Jellyfish in the Northern Gulf of Mexico. Marine Ecology Progress Series 591: 71-85. https://doi.org/10.3354/meps12327.

Arendt, M.D., J.A. Schwenter, A.L. Segars, J.I. Byrd, P.P. Maier, J.D. Whitaker, D.W. Owens, G. Blanvillain, J.M. Quattro, and M.A. Roberts. 2012. Catch Rates and Demographics of Loggerhead Sea Turtles (*Caretta caretta*) Captured from the Charleston, South Carolina, Shipping Channel During the Period of Mandatory Use of Turtle Excluder Devices (TEDs). Fisheries Bulletin 110: 98-109.

Arendt, M.D., J.A. Schwenter, D.W. Owens, and R.A. Valverde. 2021. Theoretical Modeling and Neritic Monitoring of Loggerhead *Caretta caretta* [Linnaeus, 1758] Sea Turtle Sex Ratio in the Southeast United States Do Not Substantiate Fears of a Male-Limited Population. Global Change Biology 27(19): 4849-4859. https://doi.org/10.1111/gcb.15808.

Arendt, M.D., R.P. Webster, and J.A. Schwenter. 2022. High Annual Survival Suggested by Size Structure of Kemp's Ridley Sea Turtles Captured by Coastal Research Trawling in the Northwest Atlantic Ocean since 1990. Endangered Species Research 48: 107-121. https://doi.org/10.3354/esr01190.

Ashford, M., J.I. Watling, and K. Hart. 2022. One Shell of a Problem: Cumulative Threat Analysis of Male Sea Turtles Indicates High Anthropogenic Threat for Migratory Individuals and Gulf of Mexico Residents. Remote Sensing 14(16): 3887. https://doi.org/10.3390/rs14163887.

Ballorain, K., J. Wagner, and S. Ciccione. 2016. Drone Technology Used for Foraging Sea Turtle Surveys. In: L. Belskis, A. Frey, M. Jensen, R. LeRoux, and K. Stewart (compilers), Proc 34th Annual Symposium Sea Turtle Biology and Conservation. NOAA Tech Memo NMFS-SEFSC-701.

Bell, I., L. Schwarzkopf, and C. Manicom. 2012. High Survivorship of an Annually Decreasing Aggregation of Hawksbill Turtles, *Eretmochelys imbricata*, Found Foraging in the Northern Great Barrier Reef. Aquatic Conservation: Marine and Freshwater Ecosystems 22:673-682. https://doi.org/10.1002/aqc.2245.

Bevan, E., S. Whiting, T. Tucker, M. Guinea, A. Raith, and R. Douglas. 2018. Measuring Behavioral Responses of Sea Turtles, Saltwater Crocodiles, and Crested Terns to Drone Disturbance to Define Ethical Operating Thresholds. PLOS ONE 13(3). https://doi.org/10.1371/journal.pone.0194460.

Bjorndal, K.A., A.B. Bolten, and C.J. Lagueux. 1993. Decline of the Nesting Population of Hawksbill Turtles at Tortuguero, Costa Rica. Conservation Biology 7(4): 925-927. https://doi.org/10.1046/j.1523-1739.1993.740925.

Bjorndal, K.A., and A.B. Bolten. 2000. Proceedings of a Workshop on Assessing Abundance and Trends for In-Water Sea Turtle Populations. U.S. Department of Commerce NOAA Technical Memorandum NMFS-SEFSC-445, 83 p.

Bjorndal, K.A., A.B. Bolten, and M.Y. Chaloupka. 2003. Survival Probability Estimates for Immature Green Turtles *Chelonia mydas* in the Bahamas. Marine Ecology Progress Series 252: 273-281. https://doi.org/10.3354/meps252273.

Bjorndal, K.A., A.B. Bolten, and M.Y. Chaloupka. 2005. Evaluating Trends in Abundance of Immature Green Turtles, *Chelonia mydas,* in the Greater Caribbean. Ecological Applications 15(1): 304-314. https://doi.org/10.1890/04-0059.

Bjorndal, K.A., and A.B. Bolten. 2010. Hawksbill Sea Turtles in Seagrass Pastures: Success in a Peripheral Habitat. Marine Biology 157: 135-145. https://doi.org/10.1007/s00227-009-1304-0.

Bjorndal, K.A., B.W. Bowen, M. Chaloupka, L.B. Crowder, S.S. Heppell, C.M. Jones, M.E. Lutcavage, D. Policansky, A.R. Solow, and B.E. Witherington. 2011. Better Science Needed for Restoration in the Gulf of Mexico. Science 331(6017): 537-538. https://doi.org/10.1126/science.1199935.

Bolten, A.B. 2003. Variation in Sea Turtle Life History Patterns: Neritic vs. Oceanic Life History Stages. In: The Biology of Sea Turtles, Vol. II, P.L. Lutz, J.A. Musick, and J. Wyneken (eds.). CRC Press, Boca Raton, Florida. Pp.243-257.

Bravington, M.V., H.J. Skaug, and E.C. Anderson. 2016. Close-Kin Mark-Recapture. Statistical Science 31(2): 259-274.

Bresette, M.J., B.E. Witherington, R.M. Herren, D.A. Bagley, J.C. Gorham, S.L. Traxler, C.K. Crady, and R. Hardy. 2010. Size-Class Partitioning and Herding in a Foraging Group of Green Turtles *Chelonia mydas*. Endangered Species Research 9: 105-116. https://doi.org/10.1214/16-STS552.

Brost, B., B. Witherington, A. Meylan, E. Leone, L. Ehrhart, and D. Bagley. 2015. Sea Turtle Hatchling Production from Florida (USA) Beaches, 2002-2012, with Recommendations for Analyzing Hatching Success. Endangered Species Research 27(1): 53-68. https://doi.org/10.3354/esr00653.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, Oxford, UK.

Buckland, S.T., E.A. Rexstad, T.A. Marques, and C.S. Osedekoven. 2015. Exchanging Assumptions for Data. Distance Sampling: Methods and Applications Chapter 3279: 231-252. https://doi.org/10.1007/978-3-319-19219-2_11.

Budescu, D.V., and E. Chen. 2015. Identifying Expertise to Extract the Wisdom of Crowds. Management Science 61(2): 249-486. https://doi.org/10.1287/mnsc.2014.1909.

Burnham, K.P., D.R. Anderson, and J.L. Laake. 1980. Estimation of Density from Line Transect Sampling of Biological Populations. Wildlife Monographs 72: 3-202. https://doi.org/10.2307/2530429

Campbell, C.L., and C.J. Lagueux. 2005. Survival Probability Estimates for Large Juvenile and Adult Green Turtles (*Chelonia mydas*) Exposed to an Artisanal Marine Turtle Fisheries in the Western Caribbean. Herpetologica 61(2): 91-103. https://doi.org/10.1655/04-26.

Casale, P., A.D. Mazaris, D. Freggi, C. Vallini, and R. Argano. 2009. Growth Rates and Age at Adult Size of Loggerhead Sea Turtles (*Caretta caretta*) in the Mediterranean Sea, Estimated through Capture-Mark-Recapture Records. Scientia Marina 73(3): 589-595. https://doi.org/10.3989/scimar.2009.73n3589.

Chabot, D., and D.M. Bird. 2015. Wildlife Research and Management Methods in the 21st Century: Where Do Unmanned Aircraft Fit In? Journal of Unmanned Vehicle Systems 3: 137-155. https://doi.org/10.1139/juvs-2015-0021@juvs-vi.2016.01.issue-1.

Chabot, R.M., R.C. Welsh, C.R. Mott, J.R. Guertin, B.M. Shamblin, and B.E. Witherington. 2021. A Sea Turtle Population Assessment for Florida's Big Bend, Northeastern Gulf of Mexico. Gulf and Caribbean Research 32(1): 19-33. https://doi.org/10.18785/gcr.3201.05.

Chaloupka, M., and C. Limpus. 2001. Trends in the Abundance of Sea Turtles Resident in Southern Great Barrier Reef Waters. Biological Conservation 102(3): 235–249. https://doi.org/10.1016/S0006-3207(01)00106-9.

Chaloupka, M., and C. Limpus. 2002. Survival Probability Estimates for the Endangered Loggerhead Sea Turtle Resident in Southern Great Barrier Reef Waters. Marine Biology 140(2): 267-277. https://doi.org/10.1007/s002270100697.

Chaloupka, M., and C. Limpus. 2005. Estimates of Sex- and Age-Class-Specific Survival Probabilities for a Southern Great Barrier Reef Green Sea Turtle Population. Marine Biology 146(6): 1251–1261. https://doi.org/10.1007/s00227-004-1512-6.

Commission for Environmental Cooperation. 2022. Marine Ecoregions Level III. Available at: http://www.cec.org/north-american-environmental-atlas/marine-ecoregions/. Accessed January 2023.

Cooch, E. 2017. Program MARK - 'A Gentle Introduction'. Volume 1 – core concepts + models. Colorado State University, Fort Collins, Colorado. Available at: http://www.phidot.org/software/mark/docs/book/. Accessed January 2023.

Crouse, D.T., L.B. Crowder, and H. Caswell. 1987. A Stage-Based Population Model for Loggerhead Sea Turtles and Implications for Conservation. Ecology 68(5): 1412-1423. https://doi.org/10.2307/1939225.

Cuevas, E., N.F. Putman, A. Uribe-Martinez, M.C. Lopez-Castro, V. Guzman-Hernandez, S.A. Gallegos-Fernandez, M.A. Liceaga-Correa, J.A. Trujillo-Cordova, R.J. Gonzalez-Diaz-Miron, A. Negrete-Phillipe, H.H. Acosta-Sanchez, R.C. Martinez-Portugal, M. Lopez-Hernandez, P. Huerta-Rodriguez, and J. Silver. 2020. First Spatial Distribution Analysis of Male Sea Turtles in the Southern Gulf of Mexico. Frontiers in Marine Science 7. https://doi.org/10.3389/fmars.2020.561846.

Davis, G.E., and M.C. Whiting. 1977. Loggerhead Sea Turtle Nesting in Everglades National Park, Florida, USA. Herpetologica 33(1): 18-28.

Davy, C.M., A.G. Kidd, and C.C. Wilson. 2015. Development and Validation of Environmental DNA (eDNA) Markers for Detection of Freshwater Turtles. PLOS ONE 10(7): e0130965. https://doi.org/10.1371/journal.pone.0130965.

Dickson, L.C.D., S.R.B. Negus, C. Eizaguirre, K.A. Katselidis, and G. Schofield. 2022. Aerial Drone Surveys Reveal the Efficacy of a Protected Area Network for Marine Megafauna and the Value of Sea Turtles as Umbrella Species. Drones 6: 291. https://doi.org/10.3390/drones6100291.

Deepwater Horizon (DWH) Natural Resource Damage Assessment (NRDA) Trustees. 2016. Deepwater Horizon Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Available at: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan. Accessed January 2023.

DWH NRDA Trustees. 2017. *Deepwater Horizon* Oil Spill Natural Resource Damage Assessment: Strategic Framework for Sea Turtle Restoration Activities. June. Available at: https://www.gulfspillrestoration.noaa.gov/sites/default/files/wp-content/uploads/Sea_Turtle_Strategic_Framework_6.23.17.pdf. Accessed January 2023.

Eaton, C., E. McMichael, B. Witherington, A. Foley, R. Hardy, and A. Meylan. 2008. In-Water Sea Turtle Monitoring and Research in Florida: Review and Recommendations. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-OPR 38, 233 p.

Ehrhart, L.M., and L.H. Ogren. 1999. Studies in Foraging Habitats: Capturing and Handling Turtles, p. 61-64. In: Eckert, K.L., K.A. Bjorndal, F.A. Abreu-Grobois, and M. Donnelly (Editors). Research and Management Techniques for the Conservation of Sea Turtles. IUCN/SSC Marine Turtle Specialist Group Publication No. 4.

Ehrhart, L.M., W. E. Redfoot, and D.A. Bagley. 2007. Marine Turtles of the Central Region of the Indian River Lagoon System, Florida. Biological Sciences 70(4): 415-434.

Elith, J., and J.R. Leathwick. 2009. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annual Review of Ecology, Evolution, and Systematics 40:677-97. https://doi.org/10.1146/annurev.ecolsys.110308.120159.

Evans, D.R., R.A. Valverde, C. Ordonez, and R.R. Carthy. 2021. Identification of the Gulf of Mexico as an Important High-Use Habitat for Leatherback Turtles from Central America. Coastal and Marine Ecology 12(8): 1-14. https://doi.org/10.1002/ecs2.3722.

Farrell, J.A., L. Whitmore, N. Mashkour, D.R.R. Ramia, R.S. Thomas, C.B. Eastman, B. Burkhalter, K. Yetsko, C. Mott, L. Wood, B. Zirkelbach, L. Meers, P. Kleinsasser, S. Stock, E. Libert, R. Herren, S. Eastman, W. Crowder, C. Bovery, D. Anderson, D. Godfrey, N. Condron, and D.J. Duffy. 2022. Detection and Population Genomics of Sea Turtle Species via Noninvasive Environmental DNA Analysis of Nesting Beach Sand Track Sand Oceanic Water. Molecular Ecology Resources 22(7): 2471-2493. https://doi.org/10.1111/1755-0998.13617.

Fuentes, M.M.P.B., I. Bell, R. Hagihara, M. Hamann, J. Hazel, A. Huth, J.A. Seminoff, S. Sobtzick, and H. Marsh. 2015. Improving In-Water Estimates of Marine Turtle Abundance by Adjusting Aerial Survey Counts for Perception and Availability Biases. Journal of Experimental Marine Biology and Ecology 47: 77-83. https://doi.org/10.1016/j.jembe.2015.05.003.

Fujisaki I., K.M. Hart, D. Bucklin, A.R. Iverson, C. Rubio, M.M. Lamont, R.J.G.D. Miron, P.M. Burchfield, J. Pena, D.J. Shaver. 2020. Predicting Multi-Species Foraging Hotspots for Marine Turtles in the Gulf of Mexico. Endangered Species Research 43:253-266. https://doi.org/10.3354/esr01059.

Galloway, K.R., Z. Malakpa, and S.L. Bretz. 2016. Investigating Affective Experiences in the Undergraduate Chemistry Laboratory: Students' Perceptions of Control and Responsibility. Journal of Chemical Education 93: 227-238. https://doi.org/10.1021/acs.jchemed.Sb00737.

Girard, C., A.D. Tucker, and B. Calmettes. 2009. Post-nesting migrations of loggerhead sea turtles in the Gulf of Mexico: dispersal in highly dynamic conditions. Marine Biology, 156, pp.1827-1839. https://doi.org/10.1007/s00227-009-1216-z.

Goodwin, D.J., D.A. Kane, K. Dhakal, K.R. Covey, C.Bettigole, J. Hanle, J.A. Ortega-S, H.L. Perotto-Baldivieso, W.E. Fox, and D.R. Tolleson. 2022. Can Low-Cost, Handheld Spectroscopy Tools Coupled with Remote Sensing Accurately Estimate Soil Organic Carbon in Semi-Arid Grazing Lands? Soil Systems 6(2): 38. https://doi.org/10.3390/soilsystems6020038.

Gorham, J.C., D.R. Clark, M.J. Bresette, D.A. Bagley, C.L. Keske, S.L. Traxler, B.E. Witherington, B.M. Shamblin, C.J. Nairn. 2014. Characterization of a Subtropical Hawksbill Sea Turtle (*Eretmochelys imbricata*) Assemblage Utilizing Shallow Water Natural and Artificial Habitats in the Florida Keys. PLOS ONE 9(12): e114171. https://doi.org/10.1371/journal.pone.0114171.

Gray, S., P. Aminpour, C. Reza, S. Scyphers, J. Grabowski, R. Murphy, A. Singer, D. Baltaxe, R. Jordan, A. Jetter, and J. Introne. 2020. Harnessing the Collective Intelligence of Stakeholders for Conservation. Frontiers in Ecology and the Environment 18(8): 465-472. https://doi.org/10.1002/fee.2232.

Gredzens, C., and D.J. Shaver. 2020. Satellite Tracking Can Inform Population-Level Dispersal to Foraging Grounds of Post-Nesting Kemp's Ridley Sea Turtles. Frontiers in Marine Science 7: 559. https://doi.org/10.3389/fmars.2020.00559.

Greening, H.S., K.L. Heck, L.D. McKinney, H.L. Diefenderfer, W.R. Boynton, B.A. Kleiss, D.R. Mishra, A.A. George II, B.A. Carl Kraft, C.A. Kling, and L.A. Widecker. 2022. Assessing the Effectiveness of Large-Scale Environmental Restoration: Challenges and Opportunities. Estuaries and Coasts 46: 293-301. http://doi.org/10.1007/s12237-022-01149-8.

Grossman, A., F.G. Daura-Jorge, M. de Brito Silva, and G.O. Longo. 2019. Population Parameters of Green Turtle Adult Males in the Mixed Ground of Atol das Rocas, Brazil. Marine Ecology Progress Series 609: 197-207. http://doi.org/10.3354/meps12821.

Guilbeau, K.G., A.C. Hijuelos, S.S. Romanach, and G.D. Steyer. 2022. Identifying Shared Priorities for a Bioregional Approach to Restoration in the Northern Gulf of Mexico. Frontiers in Ecology and Evolution 10: 958684. https://doi.org/10.3389/fevo.2022.958684.

Hardy, R.F., C. Hu, B. Witherington, B. Lapointe, A. Meylan, E. Peebles, L. Meirose, and S. Hirama. 2018. Characterizing a Sea Turtle Developmental Habitat Using Landsat Observations of Surface-Pelagic Drift Communities in the Eastern Gulf of Mexico. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 11(10): 3646-3659. https://doi.org/10.1109/JSTARS.2018.2863194.

Harper, K.J., K.D. Goodwin, L.R. Harper, E.L. LaCasella, A. Frey, and P.H. Dutton. 2020. Finding Crush: Environmental DNA Analysis as a Tool for Tracking the Green Sea Turtle *Chelonia mydas* in a Marine Estuary. Frontiers in Marine Science 6: 810. https://doi.org/10.3389/fmars.2019.00810.

Hart, K.M., D.G. Zawada, I. Fujisaki, and B.H. Lidz. 2013. Habitat Use of Breeding Green Turtles *Chelonia mydas* Tagged in Dry Tortugas National Park: Making Use of Local and Regional MPAs. Biological Conservation 161: 142-154. https://doi.org/10.1016/j.biocon.2013.03.019.

Hart, K.M., M.M. Lamont, A.R. Sartain, and I. Fujisaki. 2014. Migration, Foraging, and Residency Patterns for Northern Gulf Loggerheads: Implications of Local Threats and International Movements. PLOS ONE 9(7): e103453. https://doi.org/10.1371/journal.pone.0103453.

Hart, K.M., A.R. Sartain, and I. Fujisaki. 2015. Bahamas Connection: Residence Areas Selected by Breeding Female Loggerheads Tagged in Dry Tortugas National Park, USA. Animal Biotelemetry 3:3. https://doi.org/10.1186/s40317-014-0019-2.

Hart, K.M., A.R. Iverson, I. Fujisaki, M.M. Lamont, D. Bucklin, and D.J. Shaver. 2018. Sympatry or syntopy? Investigating drivers of distribution and co-occurrence for two imperiled sea turtle species in Gulf of Mexico neritic waters. Ecology and Evolution. https://doi.org/10.1002/ece3.4691.

Hatase, H., Y. Matsuzawa, K. Sato, T. Bando, and K. Goto. 2004. Remigration and Growth of Loggerhead Turtles (*Caretta caretta*) Nesting on Senri Beach in Minabe, Japan: Life-history Polymorphism in a Sea Turtle Population. Marine Biology 144: 807-811. https://doi.org/10.1007/s00227-003-1232-3.

Hensel, E., S. Wenclawski, and C.A. Layman. 2018. Using a Small, Consumer-Grade Drone to Identify and Count Marine Megafauna in Shallow Habitats. Latin American Journal of Aquatic Resources 46(5): 1025-1033. https://doi.org/10.3856/vol46-issue5-fulltext-15.

Heppell, S.S., C.J. Limpus, D.T. Crouse, N.B. Fraer, and L.B. Crowder. 1996. Population Model Analysis for the Loggerhead Sea Turtle, *Caretta caretta*, in Queensland. Wildlife Research 23:143-159. https://doi.org/10.1071/WR9960143.

Heppell, S.S., M.L. Snover, and L.B. Crowder. 2003. Sea Turtle Population Ecology. In: Biology of Sea Turtles, Vol. II, P.L. Lutz, and J.A. Musick (eds). CRC Press, Boca Raton, FL. pp. 275-306.

Heppell, S.S. 2005. Development of Alternative Quantitative Tools to Assist in Jeopardy Evaluation for Sea Turtles. Final Report for the Southeast Fisheries Science Center. Available at: https://www.researchgate.net/profile/Selina-Heppell/publication/278406829_Alternative_models_for_Jeopardy_Analysis_for_Sea_Turtles_2005/links/558058af08aea3d7096e4837/Alternative-models-for-Jeopardy-Analysis-for-Sea-Turtles-2005.pdf. Accessed December 2022.

Jones, G.R., L.G. Pearlstine, and H.F. Percival. 2006. An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research. Wildlife Society Bulletin 34(3): 750-758. https://doi.org/10.2193/0091-7648(2006)34[750:AAOSUA]2.0.CO;2.

Kery, M., R.M. Dorazio, L. Soldaat, A. van Strien, A. Zuiderwijk, and J.A. Royle. 2009. Trend Estimation in Populations with Imperfect Detection. Journal of Applied Ecology 46: 1163–1172. https://doi.org/10.1111/j.1365-2664.2009.01724.x.

Koch, V., L.B. Brooks, and W.J. Nichols. 2007. Population Ecology of the Green/Black Turtle (*Chelonia mydas*) in Bahia Magdalena, Mexico. Marine Biology 153: 35-46. https://doi.org/10.1007/s00227-007-0782-1.

Kuenzer, C., M. Ottinger, M. Wegmann, H. Guo, C. Wang, J. Zhang, S. Dech, and M. Wikelski. 2014. Earth Observation Satellite Sensors for Biodiversity Monitoring: Potentials and Bottlenecks. International Journal of Remote Sensing 35: 3599-3347. https://doi.org/10.1080/01431161.2014.964349.

Laake, J.L., D.S. Johnson, and P.B. Conn. 2013. Marked: An R Package for Maximum-Likelihood and MCMC Analysis of Capture-Recapture Data. Methods Ecology and Evolution 4(9): 885–890. https://doi.org/10.1111/2041-210X.12065.

Lamont, M.M., I. Fujisaki, and R.R. Carthy. 2014. Estimates of Vital Rates for a Declining Loggerhead Turtle (*Caretta caretta*) Subpopulation: Implications for Management. Marine Biology 161: 2659-2668. https://doi.org/10.1007/s00227-014-2537-0.

Lapointe, B.E. 1995. A Comparison of Nutrient-Limited Productivity in *Sargassum natans* from Neritic vs. Oceanic Waters of the Western North Atlantic Ocean. Limnology and Oceanography 40(3): 625-633. https://doi.org/10.4319/lo.1995.40.3.0625.

Liang, D., H. Bailey, A.L. Hoover, S. Eckert, P. Zarate, J. Alfaro-Shigueto, J.C. Mangel, N. de Paz Campos, J.Q. Davila, D.S. Barturen, J.M. Rguez-Baron, C. Fahy, A. Rocafuerte, C. Veelenturf, M. Abrego, and G.L. Shillinger. 2022. Integrating Telemetry and Point Observations to Inform Management and Conservation of Migratory Marine Species. Ecosphere 14: e4375. https://doi.org/10.1002/ecs2.4375.

Limpus C., and M. Chaloupka. 1997. Nonparametric Regression Modelling of Green Sea Turtle Growth Rates (Southern Great Barrier Reef). Marine Ecology Progress Series 149: 23-34. https://doi.org/10.3354/meps149023.

Lopez-Castro, M., E. Cuevas, V.G. Hernandez, A.R. Sanchez, R.C. Martinez-Portugal, D.J.L. Reyes, and J.A.B. Chio. 2022. Trends in Reproductive Indicators of Green and Hawksbill Sea Turtles Over a 30-Year Monitoring Period in the Southern Gulf of Mexico and Their Conservation Implications. Animals 12(23): 3280. https://doi.org/10.3390/ani12233280.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. In: Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Academic Press, San Diego, CA.

Maki, T., H. Horimoto, T. Ishihara, and K. Kofuji. 2020. Tracking a Sea Turtle by an AUV with a Multibeam Imaging Sonar: Toward Robotic Observation of Marine Life. International Journal of Control, Automation and Systems 18: 597-604. https://doi.org/10.1007/s12555-019-0690-4.

Mansfield, K.L., J. Wyneken, D. Rittschof, M. Walsh, C.W. Lim, P.M. Richards. 2012. Satellite tag attachment methods for tracking neonate sea turtles. Marine Ecology Progress Series 457: 181-192. https://doi.org/10.3354/meps09485.

Mansfield, K.L., J. Wyneken, W.P. Porter, and J. Luo. 2014. First satellite tracks of neonate sea turtles redefine the ‘lost years’ oceanic niche. Proceedings of the Royal Society 281: 20133039. https://doi.org/10.1098/rspb.2013.3039.

Mansfield, K.L., M.L. Mendilaharsu, N.F. Putman, M.A.G. dei Marcovaldi, A.E. Sacco, G. Lopez, T. Piers, and Y. Swimmer. 2017. First satellite tracks of South Atlantic Sea Turtle ‘Lost Years’: Seasonal Variation in Trans-Equatorial Movement. Proceedings of the Royal Society B: Biological Sciences 284(1868). https://doi.org/10.1098/rspb.2017.1730.

Mansfield, K.L., J. Wyneken, and J. Luo. 2021. First Atlantic Satellite Tracks of ‘Lost Years’ Green Turtles Support the Importance of the Sargasso Sea as a Sea Turtle Nursery. Proceedings of the Royal Society B 288(1950): 20210057. https://doi.org/10.1098/rspb.2021.0057.

McDonald, T.L., B.A. Schroeder, B.A. Stacy, B.P. Wallace, L.A. Starcevich, J. Gorham, M.C. Tumlin, D. Cacela, M. Rissing, D.B. McLamb, E. Ruder, and B.E. Witherington. 2017. Density and Exposure of Surface-Pelagic Juvenile Sea Turtles to Deepwater Horizon Oil. Endangered Species Research 33: 69-82. https://doi.org/10.3354/esr00771.

Metz, T.L., and A.M. Landry Jr. 2013. An Assessment of Green Turtle (*Chelonia mydas*) Stocks Along the Texas Coast, with Emphasis on the Lower Laguna Madre. Chelonian Conservation and Biology 23(2): 293-302. https://doi.org/10.2744/CCB-1046.1.

Metz, T.L., and A.M. Landry Jr. 2016. Trends in Kemp’s Ridley Sea Turtle (*Lepidochelys kempii*) Relative Abundance, Distribution, and Size Composition in Nearshore Waters of the Northwestern Gulf of Mexico. Gulf of Mexico Science 33(2): 5. https://doi.org/10.18785/goms.3302.05.

Meylan, A. 1988. Spongivory in Hawksbill Turtles: A Diet of Glass. Science 239(4838): 393-395. https://doi.org/10.1126/science.239.4838.39.

Meylan, P.A., A.B. Meylan, and J.A. Gray. 2011. The Ecology and Migrations of Sea Turtles. 8 Tests of the Developmental Habitat Hypothesis. Bulletin of the American Museum of Natural History 2011(357): 1-70. https://doi.org/10.1206/357.1.

Miller, D.L., E. Rexstad, L. Thomas, L. Marshall, and J.L. Laake. 2019. Distance Sampling in R. Journal of Statistical Software 99(1): 1-28. https://doi.org/10.18637/jss.v089.i01.

Naro-Maciel, E., A.N. Mihnovets, M. Martin, Durham, and T. Lii. 2011. Mysteries of an Ancient Mariner: The Endangered Kemp's Ridley Sea Turtle Case Study. Center for Biodiversity and Conservation of the American Museum of Natural History. Available at: https://ncep.amnh.org/index.php/Detail/objects/204.Accessed March 2023.

National Academy of Sciences, Engineering, and Medicine. 2017. In: Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico. The National Academies Press.

National Marine Fisheries Service and United States Fish and Wildlife Service (USFWS). 2008. Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtles (*Caretta caretta*), 2nd revision. National Marine Fisheries Service, Silver Spring, MD, and U.S. Fish and Wildlife Service, Atlanta, GA.

National Research Council (NRC). 2010. In: Assessment of Sea-Turtle Status and Trends: Integrating Demography and Abundance. The National Academies of Sciences Press. 174 pgs.

Pagel, J., B.A. Anderson, R.B. O'Hara, W. Cramer, R. Fox, F. Jeltsch, D.B. Roy, C.D. Thomas, and F.M. Schurr. 2014. Quantifying Range-Wide Variation in Population Trends form Local Abundance Surveys and Widespread Opportunistic Occurrence Records. Methods in Ecology and Evolution 2014(5): 751-760. https://doi.org/10.1111/2041-210X.12221.

Patricio, A.R., X. Velez-Zuazo, C.E. Diez, R. Van Dam, and A.M. Sabat. 2011. Survival Probability of Immature Green Turtles in Two Foraging Grounds at Culebra, Puerto Rico. Marine Ecology Progress Series 440: 217-227. https://doi.org/10.3354/meps09337.

Phillips, K.F., K.L. Mansfield, D.J. Die, and D.S. Addison. 2014. Survival and Remigration Probabilities for Loggerhead Turtles (*Caretta caretta*) Nesting in the Eastern Gulf of Mexico. Marine Biology 161: 863-870. https://doi.org/10.1007/s00227-013-2386-2.

Phillips, K.F., D.S. Addison, C.R. Sasso, and K.L. Mansfield. 2021. Postnesting Migration Routes and Fidelity to Foraging Sites Among Loggerhead Turtles in the Western North Atlantic. Bulletin of Marine Science 97(1): 1-18. https://doi.org/10.5343/bms.2019.0099.

Phillips, K.F., K.R. Martin, G.D. Stahelin, A.E. Savage, and K.L Mansfield. 2022. Genetic Variation Among Sea Turtle Life Stages and Species Suggests Connectivity Among Ocean Basins. Ecology and Evolution 12(11): e9426. https://doi.org/10.1002/ece3.9426.

Putman, N.F., and K.L. Mansfield. 2015. Direct Evidence of Swimming Demonstrates Active Dispersal in the Sea Turtle “Lost Years”. Current Biology 25(9): 1221-1227. https://doi.org/10.1016/j.cub.2015.03.014.

Qi, L., M. Wang, C. Hu, and B. Holt. 2022. On the Capacity of Sentinel-1 Synthetic Aperture Radar in Detecting Floating Macroalgae and Other Floating Matters. Remote Sensing of Environment 280: 113188. https://doi.org/10.1016/j.rse.2022.113188.

Redfoot, W., and L. Ehrhart. 2013. Trends in Size Class Distribution, Recaptures, and Abundance of Juvenile Green Turtles (*Chelonia mydas*) Utilizing a Rock Riprap Lined Embayment at Port Canaveral, Florida, USA, as Developmental Habitat. Chelonian Conservation and Biology 12(2): 252-261. http://doi.org/10.2744/CCB-0952.1.

Rees, H., B.C. Maddison, D.J. Middleditch, J.R.M. Patmore, and K.C. Gough. 2014. The Detection of Aquatic Animal Species Using Environmental DNA – A Review of eDNA as a Survey Tool in Ecology. Journal of Applied Ecology 51: 1450-1459. https://doi.org/10.1111/1365-2664.12306.

Rees, A.F., L. Avens, K. Ballorain, E. Bevan, A.C. Broderick, R.R. Carthy, M.J.A. Christianen, G. Duclos, M.R. Heithaus, D.W. Johnston, J.C. Mangel, F. Paladino, K. Pendoley, R.D. Reina, N.J. Robinson, R. Ryan, S.T. Skykora-Bodie, D. Tilley, M.R. Varela, E.R. Whitman, P.A. Whittock, T. Wibbels, B.J. Godley. 2018. The Potential of Unmanned Aerial Systems for Sea Turtle Research and Conservation: A Review and Future Directions. Endangered Species Research 35: 81-100. https://doi.org/10.3354/esr00877.

Roberts, K.E., L.P. Garrison, J. Ortega-Ortiz, C. Hu, Y. Zhang, C.R. Sasso, M. Lamont, and K.M. Hart. 2022. The Influence of Satellite-Derived Environmental and Oceanographic Parameters on Marine Turtle Time at Surface in the Gulf of Mexico. Remote Sensing 14: 4534. https:// doi.org/10.3390/rs14184534.

Rooker, J.R., M.S. Dance, R.J. Wells, M.J. Ajemian, B.A. Block, M.R. Castleton, J.M. Drymon, B.J. Falterman, J.S. Franks, N. Hammerschlag, and J.M. Hendon. 2019. Population Connectivity of Pelagic Megafauna in the Cuba-Mexico-United States Triangle. Scientific Reports 9(1): 1-13. https://doi.org/10.1038/s41598-018-38144-8.

Royle, J.A., and R.M. Dorazio. 2006. Hierarchical Models of Animal Abundance and Occurrence. Journal of Agricultural, Biological, and Environmental Statistics 11: 249-263. https://doi.org/10.1198/108571106X129153.

Royle, J.A., M. Kery, R. Gautier, and H. Schmid. 2007. Hierarchical Spatial Models of Abundance and Occurrence from Imperfect Survey Data. Ecological Monographs 77: 465-481. https://doi.org/10.1890/06-0912.1.

Royle, J.A., and R.M. Dorazio. 2008. Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities. Academic Press, San Diego, CA.

Sasso, C.R., J. Braun-McNeill, L. Avens, and S.P. Epperly. 2006. Effects of Transients on Estimating Survival and Population Growth in Juvenile Loggerhead Turtles. Marine Ecology Progress Series 324:287-292. https://doi.org/10.3354/meps324287.

Sasso, C.R., and S.P. Epperly. 2007. Survival of Pelagic Juvenile Loggerhead Turtles in the Open Ocean. Journal of Wildlife Management 71(6): 1830-1835. https://doi.org/10.2193/2006-448.

Sasso, C.R., P.M. Richards, S.R. Benson, M. Judge, N.F. Putman, D. Snodgrass, and B.A. Stacy. 2021. Leatherback Turtles in the Eastern Gulf of Mexico: Foraging and Migration during Autumn and Winter. Frontiers in Marine Science 8: 660798. https://doi.org/10.3389/fmars.2021.660798.

Saunders, S.P., F.J. Cuthbert, and E.F. Zipkin. 2018. Evaluating Population Viability and Efficacy of Conservation Management Using Integrated Population Models. Journal of Applied Ecology 2018(55): 1380-1392. https://doi.org/10.1111/1365-2664.13080.

Schofield, G., N. Esteban, K. Katselidis, and G. Hays. 2019. Drones for Research on Sea Turtles and Other Marine Vertebrates – A Review. Biological Conservation 238: 108214. https://doi.org/10.1016/j.biocon.2019.108214.

Schroeder, B.A., A.B. Bolten, R.F. Hardy, J.L. Keene, W.L. Kendall, A.M. Lauritsen, T.L. McDonald, C.R. Sasso, and J.A. Seminoff. 2020. Developing and Evaluating Methods to Determine Abundance and Trends of Northwest Atlantic Loggerhead Turtles. NOAA Technical Memorandum NMFS-OPR-67, 28 p.

Seminoff, J.A., T. Todd Jones, A. Resendiz, W.J. Nichols, and M.Y. Chaloupka. 2003. Monitoring Green Turtles (*Chelonia mydas*) at a Coastal Foraging Area in Baja California, Mexico: Multiple Indices to Describe Population Status. Journal of the Marine Biological Association of the United Kingdom 83(6): 1355–1362. https://doi.org/10.1017/S0025315403008816.

Shamblin, B.M., A.B. Bolten, K.A. Bjorndal, P.H. Dutton, J.T. Nielsen, F.A. Abreu-Grobois, K.J. Reich, B.E. Witherington, D.A. Bagley, L.M. Ehrhart, and A.D. Tucker. 2012. Expanded mitochondrial control region sequences increase resolution of stock structure among North Atlantic loggerhead turtle rookeries. Marine Ecology Progress Series, 469, pp.145-160. https://doi.org/10.3354/meps09980

Shamblin, B.M., P.H. Dutton, D.J. Shaver, D.A. Bagley, N.F. Putman, K.L. Mansfield, L.M. Ehrhart, L.J. Pena, and C.J. Nairn. 2017. Mexican Origins for the Texas Green Turtle Foraging Aggregation: A Cautionary Tale of Incomplete Baselines and Poor Marker Resolution. Journal of Experimental Marine Biology and Ecology 488: 111–120. https://dx.doi.org/10.1016/j.jembe.2016.11.009.

Shamblin, B.M., B.E. Witherington, S. Hirama, R.F. Hardy, and C.J. Nairn. 2018. Mixed Stock Analyses Indicate Population-Scale Connectivity Effects of Active Dispersal by Surface-Pelagic Green Turtles. Marine Ecology Progress Series 601: 215-226. https://doi.org/10.3354/meps12693.

Shamblin, B.M., K.M. Hart, M.M. Lamont, D.J. Shaver, P.H. Dutton, E.L. LaCasella, and C.J. Nairn. 2023. United States Gulf of Mexico Waters Provide Important Nursery Habitat for Mexico's Green Turtle Nesting Populations. Frontiers in Marine Science 9: 1035834. https://doi.org/10.3389/fmars.2022.1035834.

Shaver, D.J., B.A. Schroeder, R.A. Byles, P.M. Burchfield, J. Pena, R. Marquez, and H.J. Martinez. 2005. Movements and home ranges of adult male Kemp's ridley sea turtles (Lepidochelys kempii) in the Gulf of Mexico investigated by satellite telemetry. Chelonian Conservation and Biology 4(4):817-827.

Shaver, D.J., K.M. Hart, I. Fujisaki, C. Rubio, A.R. Sartain, J. Pena, P.M. Burchfield, D. Gomez, and J. Ortiz. 2013. Foraging Area Fidelity for Kemp's Ridleys in the Gulf of Mexico. Ecology and Evolution 3(7): 2002-2012. https://doi.org/10.1002/ece3.594.

Shaver, D.J. and C.W. Caillouet. 2015. Reintroduction of Kemp's Ridley (*Lepidochelys Kempii*) Sea Turtle to Padre Island National Seashore and its Connection to Head-starting. Herpetological Conservation and Biology 10(Symposium):378–435.

Shaver, D.J., K.M. Hart, I. Fujisaki, C. Rubio, A.R. Sartain-Iverson, J. Pena, D. Gomez Gamez, R. de Jesus Gonzales Diaz Miron, P.M. Burchfield, H.J. Martinez, and J. Ortiz. 2016. Migratory corridors of adult female Kemp's ridley turtles in the Gulf of Mexico. Biological Conservation 194(2016):158-167.

Shaver, D.J., K.M. Hart, I. Fujisaki, D. Bucklin, A.R. Iverson, C. Rubio, T.F. Backof, P.M. Burchfield, R. de Jesus Gonzales Diaz Miron, P.H. Dutton, A. Frey, J. Pena, D. Gomez Gamez, H.J. Martinez, and J. Ortiz. 2017. Inter-nesting movements and habitat use of adult female Kemp's ridley turtles in the Gulf of Mexico. PLOS ONE 12(3): e0174248. https://doi.org/10.1371/journal.pone.0174248.

Simoiu, C., C. Sumanth, A. Mysore, and S. Goel. 2019. Studying the "Wisdom of Crowds" at Scale. In Proceedings of the AAAI Conference on Human Computation and Crowdsourcing 7: 171-179. https://doi.org/10.1609/hcomp.v7i1.5271.

Starcevich, L.A.H., K.M. Irvine, and A.M. Heard. 2018. Impacts of Temporal Revisit Designs on the Power to Detect Trend with a Linear Mixed Model: An Application to Long-Term Monitoring of Sierra Nevada Lakes. Ecological Indicators 93: 847-855. https://doi.org/10.1016/j.ecolind.2018.05.087.

Stewart, K.R., E.L. LaCasella, S.E. Roden, M.P. Jensen, L.W. Stokes, S.P. Epperly, and P.H. Dutton. 2016. Nesting Population Origins of Leatherback Turtles Caught as Bycatch in the U.S. Pelagic Longline Fishery. Ecosphere 7(3): e01272. https://doi.org/10.1002/ecs2.1272.

Strindberg, S., R.A. Coleman, V.R. Burns Perez, C.L. Campbell, I. Majil, and J. Gibson. 2016. In-Water Assessments of Sea Turtles at Glover's Reef Atoll, Belize. Endangered Species Research 31: 211-225. https://doi.org/10.3354/esr00765.

Swimmer, Y., C. Empey Campora, L. McNaughton, M. Musyl, and M. Parga. 2014. Post-release Mortality Estimates of Loggerhead Sea Turtles (*Caretta caretta*) Caught in Pelagic Longline Fisheries Based on Satellite Data and Hooking Location. Aquatic Conservation: Marine and Freshwater Ecosystems 24(4): 498-510. https://doi.org/10.1002/aqc.2396.

Sykora-Bodie, S.T., V. Bezy, D.W. Johnston, E. Newton, and K.J. Lohmann. 2017. Quantifying Nearshore Sea Turtle Densities: Applications of Unmanned Aerial Systems for Population Assessments. Scientific Reports 7:17690. https://doi.org/10.1038/s41598-017-17719-x.

Tezak, B., I. Sifuentes-Romero, S. Milton, and J. Wyneken. 2020. Identifying Sex of Neonate Turtles with Temperature-Dependent Sex Determination Via Small Blood Samples. Scientific Reports 10(1): 1-8. https://doi.org/10.1038/s41598-020-61984-2.

Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques, and K.P. Burnham. 2010. Distance Software: Design and Analysis of Distance Sampling Surveys for Estimating Population Size. Journal of Applied Ecology 47: 5-14. https://doi.org/10.1111/j.1365-2664.2009.01737.x.

Thompson, N. 1989. Research on Sea Turtles in the Water Needed for Management, In: Ogren, L. (ed), Proceedings of the Second Western Atlantic Turtle Symposium, October 12-16, 1987, Mayaguez, Puerto Rico.

Turtle Expert Working Group. 2009. An Assessment of the Loggerhead Turtle Population in the Western North Atlantic. US Department of Commerce, NOAA Technical Memorandum NMFS-SEFSC-575, Miami, Florida.

Valverde, R.A., and K.R. Holzwart. 2017. Sea Turtles of the Gulf of Mexico. Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill: Volume 2: Fish Resources, Fisheries, Sea Turtles, Avian Resources, Marine Mammals, Diseases and Mortalities, pp.1189-1351. https://doi.org/10.1007/978-1-4939-3456-0_3.

Vander Zanden, H.B, K.A. Bjorndal, K.J. Reich, and A.B. Bolten. 2010. Individual Specialists in a Generalist Population: Results from a Long-Term Stable Isotope Series. Biology Letters 6(5): 711-714. https://doi.org/10.1098/rsbl.2010.0124.

Wallace, B.P., B.A. Stacy, M. Rissing, D. Cacela, L.P. Garrison, G.D. Graettinger, J.V. Holmes, T. McDonald, D. McLamb, and B. Schroeder. 2017. Estimating Sea Turtle Exposures to Deepwater Horizon Oil. Endangered Species Research 33: 51-67. https://doi.org/10.3354/esr00728.

White, G.C., and K.P. Burnham. 1999. Program MARK: Survival Estimation from Populations of Marked Animals. Bird Study 46 Supplement 120-138. https://doi.org/10.1080/00063659909477239.

Williams, B.K., J.D. Nichols, and M.J. Conroy. 2002. In: Analysis and Management of Animal Populations: Modeling, Estimation and Decision Making. Academic Press. San Diego, California. ISBN: 13: 978-0-754406-9.

Witherington, B.E., P. Kubilis, B. Brost, and A.B. Meylan. 2009. Decreasing Annual Nest Counts in a Globally Important Loggerhead Sea Turtle Population. Ecological Applications 19(1): 30-54. https://doi.org/10.1890/08-0434.1.

Witherington, B., S. Hirama, and R. Hardy. 2012. Young Sea Turtles of the Pelagic Sargassum-dominated Drift Community: Habitat Use, Population Density, and Threats. Marine Ecology Progress Series 463: 1-22. https://doi.org/10.3354/meps09970.

Witzell, W.N. 1983. In: Synopsis of Biological Data on the Hawksbill Turtle, *Eretmochelys imbricata* (Linnaeus, 1766). FAO Fisheries Synopsis 137: 1-78.