Evaluating the Threats of Disease, Contaminants, and Environmental Hazards on Louisiana Dolphin Health:

A Literature Review, Conceptual Model, and Health Assessment Plan

Executive Summary

Deliverable 12 in support of Monitoring Approaches
for Bottlenose Dolphin Restoration in Louisiana

Draft 1 – June 2025

As part of the *Deepwater Horizon* (DWH) natural resource damage assessment (NRDA) settlement, the Louisiana Trustee Implementation Group (TIG) is collecting and analyzing data to inform the planning of restoration activities and to help quantify the effectiveness of future restoration projects. To understand what restoration activities may benefit common bottlenose dolphin (*Tursiops truncatus*; hereafter "dolphins") populations in Louisiana, it is necessary to understand what threats they face. This report focuses on three categories of stressors: 1) infectious diseases, 2) chemical contaminants and other pollutants, and 3) environmental hazards and adverse environmental conditions. In the following report, we refer to these categories generally as disease, contaminant, and environmental (DCE) stressors.

The document contains three chapters: 1) a literature review, data synthesis, and risk assessment for DCE stressors and Louisiana dolphins, 2) a conceptual model to summarize the highest priority stressors, parameters to monitor them, and key data gaps, and 3) a health assessment monitoring framework, health assessment monitoring plan, and sampling plans/protocols to support future Louisiana dolphin health monitoring efforts, with a particular focus on key DCE stressors. It is a living document and should be updated/revised periodically based on new information and research. Chapter 1 provides summary tables for risk assessments of each stressor in each Louisiana dolphin stock; the written literature review, with relevant in-line citations, is provided as Appendix A.

Based on our literature review and scoring system, the MSS, BBES, NCS, and WCS were the stocks with the highest overall risk from all threats combined, likely driven by the availability of data on both threats and especially dolphins in those populations in the wake of the *Deepwater Horizon* NRDA. Across all stocks, the top three threats were, in order, oil and gas pollution, extreme weather (and the associated risk of entrapment), and infectious diseases. The risk assessment scores align closely with the priority threats identified in the National Marine Mammal Health Monitoring and Surveillance Plan (MMC 2024):

- **Viruses:** flaviviruses, morbilliviruses, and influenza
- **Bacteria/fungi:** *Erysipelothrix rhusiopathiae, Vibrio* spp., *Paracoccidioides* spp.*, and Brucella*

- **Protozoa/parasites:** *Toxoplasma gondii* and *Sarcocystis neurona*
- **Biotoxins:** Brevetoxin, saxitoxin, and domoic acid
- **Contaminants:** polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs)
- **Environmental hazards:** fresh water.

Thus, to organize the key elements of a Louisiana health assessment monitoring framework, we developed a conceptual model organized in three categories:

- **DCE stressor sources:** Where do the stressors originate?
- **Exposure pathways:** What is the route of exposure by which the stressors come into contact with a dolphin?
- **Dolphin systems, tissues, and fluids:** What are the primary physiological systems, tissues, and fluids first impacted by the stressors and what other systems, tissues, and fluids may eventually be affected and/or sampled for evidence of exposure/effect?

Fully evaluating the threats from disease, contaminants, and environmental hazards often requires many years and entire working groups (e.g., unusual mortality event working groups, natural resource damage assessments, and environmental impact statements). However, similar to the considerations discussed in the Freshwater Strategy Report, the fundamental question driving health assessment activities is: “What is the relationship between the exposure to a given stressor and the resulting adverse health effects?” To generate the sample sizes needed for robust and reliable analyses, it will be critical to integrate and synthesize data across as many opportunistic and directed sampling efforts as possible (from Louisiana, the Southeast U.S., and potentially internationally), including: 1) past efforts, 2) future studies under programs outside of this LA marine mammal monitoring and adaptive management effort, 3) opportunistic studies that arise and offer important chances to collect relevant data, and 4) studies designed and conducted specifically to support this effort. Combining the results from live strandings, necropsies, out-of-habitat interventions, remote sampling research efforts, and temporary catch-and-release sampling efforts will help overcome limitations or biases associated with singular individual approaches (e.g., logistics, cost, sample size, sample design, types of data/samples that can be collected).

The LA BND Monitoring Plan, Freshwater Strategy Report, and this Health Assessment Plan should ideally all be considered as one unified effort, saving time and resources, and ensuring that decision makers get the best-available information as soon as possible. Briefly, the key components of a unified approach from the three documents includes:

1. Establish infrastructure for overarching planning needs in the LA BND Monitoring Plan.
2. Collect/aggregate baseline dolphin and environmental data as early as possible, to facilitate the detection and investigation of future changes in health from DCE stressors.
3. Identify, as early as possible, known or predictable future environmental threats (e.g., large freshwater inputs into Louisiana basins) and deploy field crews for monitoring environmental conditions and dolphin distributions/health status before, during, and after the events.

4. Integrate the protocols/tools from the Freshwater Strategy Report and this Health Assessment Plan into any future dolphin studies in Louisiana or, if possible, nearby states–whether as part of Louisiana marine mammal monitoring and adaptive management activities (e.g., the field activities recommended in the LA BND Monitoring Plan) or by collaborating with scientists with other programs/funding.
5. Ensure that Stranding Network Partners in Louisiana have the training and resources they need to: 1) fully integrate the protocols/tools into their routine activities and 2) respond to as many cases as possible across Louisiana.
6. Convene subject matter expert groups to regularly review and further develop the plans and recommendations, including the specific protocols/tools.

It is important to note that, at least as of the writing of this report, the current structure of NMFS coordination of the National Marine Mammal Stranding Network (via the NOAA Regional Offices and Regional Stranding Coordinators and the Marine Mammal Health and Stranding Response Program [MMHSRP]), in combination with close coordination among marine mammal researchers, the NOAA Protected Resources Permits review process, and other relevant NOAA offices (e.g., Office of Response and Restoration, Office of Habitat Conservation and their Restoration Center) provides a strong foundation for the proposed activities herein.

This document is one in a series of deliverables to support decision-makers setting monitoring and adaptive management objectives for bottlenose dolphin restoration planning and monitoring restoration effectiveness in Louisiana waters. Please visit the Louisiana MAM Monitoring Approaches for Bottlenose Dolphin Restoration project website, which hosts all of these documents and serves as a user manual/data dictionary for the deliverables. For convenience, all of the documents, we reference each product by the following shorthand:

- LA BND Monitoring Plan, short for the: “Monitoring Plan for Common Bottlenose Dolphin Stocks across Louisiana Basins and Nearshore Coastal Waters”
- Human-caused Threats Review, short for the: “Characterization of Human-Caused Threats to Bottlenose Dolphins in Louisiana”
- Freshwater Strategy Report, short for the: “Freshwater Response, Scientific/Impact Assessment, and Decision-making Strategy Report”
- DCE Report and Assessment Plan, short for the: “Evaluating the Threats of Disease, Contaminants, and Environmental Hazards on Louisiana Dolphin Health: A Literature Review, Conceptual Model, and Health Assessment Plan”.

The citations for all of these documents can be found in a spreadsheet: the LA BND Citation Inventory.

Chapter 1:
A Data Synthesis of Threats to Bottlenose Dolphins in Louisiana from Disease, Contaminants, and Environmental Hazards

Part 1 of Deliverable 9 in support of Monitoring Approaches
for Bottlenose Dolphin Restoration in Louisiana

Draft 1 – June 2025

1 Introduction

1.1 Purpose & Goals

This chapter gathers and synthesizes existing literature, reports, data, and other information to better understand how infectious and non-infectious diseases, contaminants, and environmental hazards are impacting the health of Louisiana dolphins. In this comprehensive, coast-wide characterization of these hazards, we document (where possible) their impacts to dolphin health and populations, prioritize the stressors by stock, and assess potential future risk.

1.2 Scope

Worldwide, dolphins have been identified as the marine mammal species affected by the largest range of threats (Avila et al. 2018). The situation is no different in the Southeast U.S., where the threats to dolphin health are wide-ranging and can be difficult to place into distinct categories without overlap or redundancy. The hazards covered in this report consist of those impacting dolphin health via disease, contaminants, and environmental hazards, and include the following:

- Infectious disease
- Oil & gas pollution
- Chemical pollution
- Heavy metal pollution
- Harmful algal blooms
- Hypoxia
- Extreme weather events
- Habitat loss
- Climate change

Some threats that could result from the stressors listed above (e.g., out-of-habitat animals resulting from extreme weather events) are covered within the primary threat. In general, these hazards are those that we loosely characterize as not being caused by direct contact with a “point-source” anthropogenic activity but are of a more diffuse nature. Freshwater exposure is discussed in the Freshwater Strategy Report. Threats primarily deriving from direct interaction with human activities (e.g., fisheries, dredging and construction) are discussed as part of the Human-caused Threats Review. In Appendix A, we provide evidence (with supporting citations) for how each stressor impacts dolphins in general, then discuss what is known about its prevalence within each Louisiana dolphin stock. When multiple stocks have similar information and findings available, we grouped them together in the narratives, and when no information is available about individual stocks, we discuss Louisiana dolphins in general.

The NOAA-defined bay, sound, and estuary (BSE) stocks and coastal stocks that fall within Louisiana waters and are assessed in this document include:

- Mississippi Sound/Lake Borgne/Bay Boudreau stock (MSS stock)
- Mississippi River Delta stock (MRD stock)
- Barataria Bay Estuarine System stock (BBES stock)
- Terrebonne-Timbalier Bay Estuarine System stock (TTBES stock)
- Vermilion Bay/West Cote Blanche Bay/Atchafalaya Bay stock (Vermilion stock)
- Calcasieu Lake stock
- Sabine Lake stock
- Northern Coastal stock (NCS)
- Western Coastal stock (WCS)

For more information on each stock, please reference NOAA's Stock Assessment Reports. All references throughout this report can be found in the LA BND Citation Inventory.

1.3 Approach

To characterize each threat within Louisiana waters, we reviewed NOAA Stock Assessment Reports (SARs), NRDA injury assessments, peer-reviewed publications, and unpublished datasets. We also consulted subject matter experts, publicly available state and federal reports and internet resources. For on-line access to a wide variety of data related to the Louisiana coastal environment and many of the stressors discussed in this report, we recommend the Environmental Data Gateway hosted by the Louisiana Oil Spill Coordinator's Office.

To summarize our findings and compare the relative risk for each threat across stocks, we considered several structured approaches, including those described by Phillips and Rosel (2014), Murawski et al. (2021), Lettrich et al. (2023), and Wade et al. (2021). Ultimately, we chose to adapt the approach developed by Phillips & Rosel (2014) based on its ease of application, dolphin-specific focus, and assimilation of data availability into the risk assessment. Their method was originally used to prioritize research time and money for the dolphin stocks of Texas based on the level of threats faced by each stock in combination with the level of demographic data available about the stock. Since our focus here is primarily on threats (we focus on population monitoring and demographic rates in the LA BND Monitoring Plan), we only use the threat assessment portion of the Phillips & Rosel (2014) approach with some modifications to best serve the present effort.

We use the information we gathered about each threat for each stock to generate a threat prevalence score and a dolphin impact score based on the following criteria:

Threat prevalence score: what is the prevalence of the threat to the stock in question?

0. The threat is not present
1. The threat is present, but insufficient data are available to characterize the prevalence of the threat. For example, if dolphins from a particular stock have not been sampled for chemical pollutants.
3. The threat is present and some characterization of its prevalence exists

Dolphin impact score: what is the impact (sub-lethal effects or mortalities) of the threat on the dolphins in the stock in question ("here")?

2. No mortality or sub-lethal effects on dolphins are documented here, but impacts have been documented elsewhere
4. Mortalities, serious injuries, or sub-lethal effects linked to the threat have been documented here
6. Mortalities, serious injuries, or sub-lethal effects are expected to have population-level impacts here

The final risk assessment score for a given threat in a given Louisiana dolphin stock (e.g., harmful algal blooms in the Sabine Lake Stock) is the sum of the two scores (Table 1). This metric is intended to provide a relative number to compare risk across stressors on each stock within this document or the Human-caused Threats Review. It should not be used to compare risk assessments outside of these documents/analyses.

		Threats		
		0 Threat not present	**1** Threat present but insufficient data to characterize prevalence	**3** Threat present and some characterization of prevalence
Dolphin Impacts	**2** No mortality or sub-lethal effects documented here, but impacts documented elsewhere	2	3	5
	4 Mortalities and/or sub-lethal effects documented here	NA	5	7
	6 Mortalities and/or sub-lethal effects are expected to have population-level impacts here	NA	7	9

Table 1. Risk assessment scoring rubric adapted from Phillips & Rosel (2014).

In general, the final scores can be interpreted using the following descriptions:

Scores	Description of Risk
2-3	This stressor is a potential future risk to this stock but is not currently a significant concern because either: ● it has been documented to affect dolphins elsewhere but the threat is not currently present in the stock, or ● the threat is present at some unknown level but no impacts to dolphins have been detected here.
5	This stressor is of medium concern but is data deficient because either: ● impacts to dolphins have been documented from this threat in this stock, but data are lacking about the prevalence of the threat, or ● the threat is of known concern, but data are lacking on the level of impact to dolphins.
7	This stressor is of high concern because either: ● this threat is expected to have population level impacts to dolphins even though the prevalence of the threat is unquantified, or ● the prevalence of the threat is known and mortalities or sub-lethal effects have been documented for dolphins.
9	This stressor is of critical concern given documented prevalence of the threat, and mortalities and sublethal effects due to the threat are expected to have population-level impacts.

2 Threat Summaries

In this section we provide a summary of our findings for each threat that includes the following components:

- What is Included: within each category, what are the specific types of stressors that make up the threat?
- Possible Impacts: what immediate possible impacts might be incurred by dolphins from the threat?
- Known Sources/Risk Factors: what are the specific known sources of the threat to Louisiana dolphins, or in some cases, what are the risk factors that make Louisiana dolphins more susceptible to this threat?
- State of Our Knowledge: A brief statement summarizing the risk of the threat to Louisiana dolphins based on a synthesis of data availability and the level of threat.
- Areas of Increasing Concern: Identifies any noteworthy specific aspects of the threat that may become more severe in the near future.
- Sample of Documented Cases: Are there any noteworthy specific cases documented for how the threat has impacted dolphins in general and in Louisiana specifically?
- Stock-by-Stock Risk Assessment Summary: A table summarizing the threat prevalence, dolphin impact, and total risk assessment scores (described above) for each stock from the threat.

2.1 Infectious Disease

What is included	Possible Impacts	Known Sources
Morbillivirus *Brucella* *Other bacteria, viruses, fungi, and parasites*	*Mortality* *Abortions/neonatal loss* *Immunosuppression* *Severe chronic infection* *Pneumonia*	*Endemic delphinid reservoirs (e.g., morbillivirus)* *Contaminated runoff & wastewater discharge (e.g., Brucella, Toxoplasma gondii)* *Birds & insects (e.g., influenza)*

State of our Knowledge	Areas of increasing concern
We know most about morbillivirus and brucella, which have both been linked to unusual mortality events (UMEs) in the northern Gulf including some impacting Louisiana dolphins. However, information is relatively limited about Louisiana-specific rates of infection. We do not have Louisiana-specific data on rates of infection from other causative agents.	

Sample of Documented Cases

General

- *Multiple dolphin UMEs on the US Atlantic coast and in Texas were caused by morbillivirus*[1,2]
- *Brucella was detected in 18.4% of dolphins stranded in Alabama from 2007 to 2008*[3]

Louisiana

- *Seroprevalence of morbillivirus antibodies in dolphins sampled in Calcasieu, BBES, and MSS have ranged from 7% to 44%*[4]
- *Morbillivirus may be endemic in the coastal stocks (NCS & WCS)*[5]
- *Brucella may have played a role in the 2007 and 2008 UMEs that impacted dolphins from the WCS* [2]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*4*	*7*
Mississippi River Delta	*1*	*2*	*3*
Barataria Bay	*3*	*4*	*7*
Terrebonne-Timbalier Bays	*1*	*2*	*3*
Vermilion Bay	*1*	*2*	*3*
Calcasieu Lake	*3*	*2*	*7*
Sabine Lake	*3*	*2*	*7*
Northern Coastal	*3*	*4*	*7*
Western Coastal	*3*	*6*	*9*

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[1] Duignan et al. 1996

[2] Litz et al. 2014

[3] Bloodgood et al 2023

[4] Fauquier et al. 2017; Cloyed et al. 2021

[5] Rowles et al 2011; Cloyed et al. 2021

Scoring: ***Threat Prevalence***: *0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts: *2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere, 4=impacts documented in this stock, 6=mortalities and sub-lethal impacts expected to have population level effects*

See Section A.1 for the complete literature review

2.2 Oil & Gas

What is included	Possible Impacts	Known Sources
● *Direct effects of exposure to oil* ● *Effects of oil and gas infrastructure and exploration (e.g., seismic activity)* ● *Platform removal (often using explosives)*	● *Mortality* ● *Immune dysfunction leading to secondary infections* ● *Adrenal gland disease* ● *Lung disease* ● *Body mass loss* ● *Reproductive failure* ● *Hearing loss*	● *Deepwater Horizon and other oil spills* ● *Oil and gas exploration and drilling activities* ● *~4,000 active oil and gas structures in the northern Gulf* ● *Orphaned/derelict infrastructure/wells*

State of our Knowledge	Areas of increasing concern
Much of our considerable knowledge about the effects of an acute oiling event on dolphin individuals and populations comes from the DWH oil spill. Population-level impacts from DWH were estimated for five of the nine Louisiana stocks (BBSE, MRD, MSS, WCS, NCS) most affected by the spill. Little is known about how much oil and gas is released and encountered by dolphins during smaller spills or regular exploration and drilling operations along the Louisiana coast, or how those background levels of oil impact dolphins.	

Sample of Documented Cases

Louisiana

- *Reproductive rates in BBES following DWH were less than 1/3 that of populations in non-oiled areas*[6]
- *DWH resulted in an estimated loss of over 30,000 cetacean years for BBES dolphins, with a projected time to recovery of 35-39 years*[7]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*6*	*9*
Mississippi River Delta	*3*	*6*	*9*
Barataria Bay	*3*	*6*	*9*
Terrebonne-Timbalier Bays	*3*	*6*	*9*
Vermilion Bay	*3*	*2*	*5*
Calcasieu Lake	*3*	*2*	*5*
Sabine Lake	*3*	*2*	*5*

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[6] Kellar et al. 2017

[7] Schwacke et al. 2017, 2022

Northern Coastal	*3*	*6*	*9*
Western Coastal	*3*	*6*	*9*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere, 4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects*

See Section A.2 for the complete literature review

2.3 Chemical Pollution

What is included	Possible Impacts	Known Sources
• *Persistent organic pollutants (POPs; e.g., PCBs, PBDEs, DDTs, dioxins)* • *Polyfluorinated compounds (PFCs)* • *Other emerging contaminants (plasticizers, pharmaceuticals, antiseptics, microplastics)*	• *Mortality* • *Immunosuppression* • *Endocrine disruption* • *Reproductive failure* • *Inflammation* • *Oxidative stress*	• *Legacy contaminants from pesticides, paints, lubricants, hydraulic fluid, etc.)* • *Industrial processes* • *Freshwater runoff* • *Microplastic pollution* • *Waste treatment plants*

State of our Knowledge	Areas of increasing concern
POPs are the most widely studied of the pollutants that affect dolphins and we know the most about their impacts on dolphins. Of these, PCB, DDT, and CHL concentrations have been measured in BBES, MSS, and NCS.	*Contaminants of emerging concern (e.g., microplastics, phthalates)*

Sample of Documented Cases

General
- *PCBs are one of the pollutants found in the highest concentrations in dolphin tissue and have been linked to a wide range of health issues including reproductive failure and dysfunction, endocrine disruption, immune dysfunction, and liver toxicity*[8]
- *Microplastics are a contaminant of emerging concern and in one study of wild dolphins in Sarasota Bay, FL, were found in the gastric samples of every dolphin examined*[9]

Louisiana
- *BBES, MSS, and NCS dolphins have similar levels of total POPs in their blubber compared to other sites in the northern Gulf but BBES had lower DDT and CHLs than Sarasota Bay*[10]
- *MSS had higher levels of plasma PCBs than in BBES, but in general, BBES, MSS, and NCS dolphins had PCB levels comparable to, or lower than, other coastal dolphins outside the Gulf, but still within the range associated with health impacts*[10, 11]

Stock by Stock Risk Assessment Summary

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[8] Kucklick et al. 2011; Schwacke et al. 2002, 2009; Desforges et al. 2016; Fair et al. 2013

[9] Hart et al. 2022

[10] Schwacke et al. 2014a; Balmer et al. 2015

[11] Balmer et al. 2018

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*4*	7
Mississippi River Delta	*1*	*2*	*3*
Barataria Bay	*3*	*4*	*7*
Terrebonne-Timbalier Bays	*1*	*2*	*3*
Vermilion Bay	*1*	*2*	*3*
Calcasieu Lake	*1*	*2*	*3*
Sabine Lake	*1*	*2*	*3*
Northern Coastal	*3*	*4*	*7*
Western Coastal	*1*	*2*	*3*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere,*
4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects

See Section A.3 for the complete literature review

2.4 Heavy Metal Pollution

What is included	Possible Impacts	Known Sources
- *Mercury* - *Lead* - *Cadmium* - *Arsenic* - *Other heavy metals (barium, zinc, copper, manganese, iron)*	- *Endocrine disruption* - *Immune disfunction* - *Neurological effects* - *Increased susceptibility to infectious disease*	- *Coal-fired power plants* - *Oil & gas operations* - *Atmospheric and river deposition* - *Ocean currents* - *Prey*

State of our Knowledge	Areas of increasing concern
One study has measured the levels of mercury and selenium in Louisiana dolphins (from coast-wide strandings during the 2010-2014 UME) and found them to be lower than levels from Florida dolphins. Little other information is available beyond these two heavy metals	

Sample of Documented Cases

General

- *Evidence of immunological suppression was found in two populations of dolphins with high mercury levels along the southern US Atlantic coast*[12]
- *Levels of lead have been found to be lower in dolphins in the Gulf than those from the US Atlantic coast*[13]*, but mercury levels have been found to be higher in Gulf dolphins*

Louisiana

- *Total mercury levels were lower in sampled stranded dolphins in Louisiana than those sampled from the Florida panhandle and Sarasota Bay*[14]

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[12] Schaefer et al. 2011

[13] Kuehl and Haebler 1995; Meador et al. 1998

[14] McCormack et al. 2020a, 2020b, 2022

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*2*	*5*
Mississippi River Delta	*3*	*2*	*5*
Barataria Bay	*3*	*2*	*5*
Terrebonne-Timbalier Bays	*3*	*2*	*5*
Vermilion Bay	*3*	*2*	*5*
Calcasieu Lake	*3*	*2*	*5*
Sabine Lake	*3*	*2*	*5*
Northern Coastal	*3*	*2*	*5*
Western Coastal	*3*	*2*	*5*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere, 4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects*

See Section A.4 for the complete literature review

2.5 Algal Blooms

What is included	Possible Impacts	Known Sources/Risk Factors
Harmful algal blooms (HABs) *HAB toxins (e.g., domoic acid, saxitoxin, brevetoxin, okadaic acid)* *Freshwater algae & associated neurotoxins (e.g., microcystins, nodularines, and BMAA[15])*	*Mortality* *Immune dysfunction* *Neurological effects* *Respiratory symptoms* *Increased susceptibility to infectious disease*	*80 species of phytoplankton* *Nutrient pollution (i.e., from agriculture, sewage, aquaculture, industrial discharge)* *Warming ocean temperatures* *Freshwater discharge*

State of our Knowledge	Areas of increasing concern
Definitively linking HABs with large-scale mortality events in dolphins is challenging, but several UMEs have been linked to HABs in the northern Gulf. However, in Louisiana specifically, dolphins have not historically been exposed to HABs.	*Emergence of toxins produced by freshwater cyanobacteria species in estuarine systems*

Sample of Documented Cases

General
- *During a concurrent HAB and dolphin UME in Indian River Lagoon, FL, 80% of stranded dolphins tested positive for brevetoxin and 57% tested positive for saxitoxin[16]*

Louisiana
- *A review of UMEs in the northern Gulf prior to 2010 found the Louisiana dolphins are not particularly*

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[15] BMAA: beta-N-methylamino-L-alanine–a neurotoxin produced by some cyanobacteria

[16] Fire et al. 2020a

prone to HAB-related mortality[17]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*1*	*2*	*3*
Mississippi River Delta	*1*	*2*	*3*
Barataria Bay	*1*	*2*	*3*
Terrebonne-Timbalier Bays	*1*	*2*	*3*
Vermilion Bay	*1*	*2*	*3*
Calcasieu Lake	*1*	*2*	*3*
Sabine Lake	*1*	*2*	*3*
Northern Coastal	*1*	*2*	*3*
Western Coastal	*1*	*2*	*3*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere,*
4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects

See Section A.5 for the complete literature review

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[17] Litz et al. 2014

2.6 Hypoxia

What is included	**Possible Impacts**	**Known Sources**
- *Water containing <2 mg/l of dissolved oxygen* - *Prey mortality and redistribution that results from hypoxic waters*	- *Reduced prey availability/habitat loss* - *Displacement* - *Increased competition* - *Increased fisheries interactions*	- *Nutrient pollution (e.g., nitrogen and phosphorous)* - *Warming ocean temperatures* - *Freshwater inputs that create stratification*

State of our Knowledge	**Areas of increasing concern**
Substantial data are available on the size, duration, and seasonality of the hypoxic zone that includes some of the continental shelf waters of Louisiana; however, data are limited on the effects of these hypoxic conditions on coastal and BSE dolphins, but it is thought to be intermittent in shallow bays where mixing regularly occurs	*Increases in freshwater inputs due to both the effect on stratification and the additional input of nutrient pollution*

Sample of Documented Cases

General

- *Dolphins appeared to reduce their use of an hypoxic area at a faster rate than an adjacent non-hypoxic area in the face of other habitat loss/degradation*[18]

Louisiana

- *MSS, NCS and WCS dolphins use waters within the largest human-caused seasonal hypoxic zone in the US and the western Atlantic Ocean*[19]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*1*	*2*	*3*
Mississippi River Delta	*3*	*4*	*7*
Barataria Bay	*3*	*2*	*5*
Terrebonne-Timbalier Bays	*3*	*2*	*5*
Vermilion Bay	*3*	*2*	*5*
Calcasieu Lake	*3*	*2*	*5*
Sabine Lake	*3*	*2*	*5*
Northern Coastal	*3*	*4*	*7*
Western Coastal	*3*	*4*	*7*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere, 4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects*

See Section A.6 for the complete literature review

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[18] Guo et al. 2022

[19] Rabalais and Turner 2001, 2019; Rabalais et al. 2009

2.7 Extreme Weather Events

What is included	Possible Impacts	Known Sources
● *Seasonal tropical storms* ● *Large storms resulting in storm surge* ● *Severe winter weather/cold snaps* ● *Heatwaves*	● *Injury and mortality* ● *Lower survival* ● *Displacement* ● *Altered foraging patterns* ● *Entrapment & increased strandings* ● *Increase exposure to freshwater and other altered physical properties*	● *Tropical storms, hurricanes, unnamed storms* ● *Severe weather (e.g., cold snaps or heat wave)*

State of our Knowledge	Areas of increasing concern
The vast majority of documented impacts of extreme weather in Louisiana come from records of entrapment resulting from storm surge, but one coast-wide (and beyond) UME was partially attributed to a cold snap and freshet event.	*Increased number and severity of hurricanes and tropical storms from climate change*

Sample of Documented Cases

General

- *Permanent or temporary displacement and changes in habitat use and foraging patterns are commonly documented dolphin responses to large storms*[20]
- *Extreme weather events have been shown to lower survival of dolphins and other marine mammals*[21]

Louisiana

- *Storm surges from Hurricanes Katrina, Rita, Gustav, Barry, Ida, and Laura are all thought to have resulted in some of the many documented cases of out-of-habitat dolphins in Louisiana.*

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*6*	*9*
Mississippi River Delta	*3*	*4*	*7*
Barataria Bay	*3*	*4*	*7*
Terrebonne-Timbalier Bays	*3*	*4*	*7*
Vermilion Bay	*3*	*4*	*7*
Calcasieu Lake	*3*	*4*	*7*
Sabine Lake	*3*	*4*	*7*
Northern Coastal	*3*	*4*	*7*
Western Coastal	*3*	*4*	*7*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere, 4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects*

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[20] Fury and Harrison 2011; Ortega-Ortiz et al. 2019; Fandel et al. 2020; Fazioli and Mintzer 2020

[21] Miller 1992; Langtimm & Beck 2003; Wild et al. 2019; Mann et al. 2021; Coxon et al. 2022

See Section A.7 for the complete literature review

2.8 Habitat Loss

What is included	Possible Impacts	Known Sources
• *Wetland loss/degradation* • *Loss of foraging areas* • *Loss of areas with no/minimal human disturbance* • *Degradation or loss of prey habitat*	• *Decreased prey availability* • *Increased risk of predation* • *Lower survival* • *Lower reproductive rates* • *Decreased population viability* • *Increased overlap with human-caused stressors*	• *Coastal development* • *Land reclamation for industry* • *Agricultural development* • *Sea-level rise* • *Subsidence* • *Shoreline erosion* • *Water diversion/impoundment projects*

State of our Knowledge	Areas of increasing concern
Loss of dolphin habitat within wetlands and coastal and estuarine waters is a well-documented phenomenon in Louisiana, however, the impact of these losses on dolphin populations has not been well-studied	*An estimated 1,000 mi^2 of land could be lost to development and natural processes by 2050 (citation).*

Sample of Documented Cases

General
- *Loss of coastal and estuarine waters can threaten dolphin population viability*[22]

Louisiana
- *>2,000 mi^2 of wetland and barrier shoreline lost since 1900 due to natural processes and human activities*[23]
- *>1,500 mi^2 coastal Louisiana lost in the past 50 years*
- *Coastal wetland degradation in Louisiana now exceeds 100 km^2/year*[24]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*2*	*5*
Mississippi River Delta	*3*	*2*	*5*
Barataria Bay	*3*	*2*	*5*
Terrebonne-Timbalier Bays	*3*	*2*	*5*
Vermilion Bay	*3*	*2*	*5*
Calcasieu Lake	*3*	*2*	*5*
Sabine Lake	*3*	*2*	*5*
Northern Coastal	*1*	*2*	*3*

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[22] Wu et al. 2017

[23] Couvillion et al. 2017

[24] Walking et al. 1987

Western Coastal	*1*	*2*	*3*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere,*
4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects

See Section A.8 for the complete literature review

2.9 Climate Change

What is included	Possible Impacts	Known Sources
• *Rising ocean and bay temperatures* • *Changes in circulation patterns* • *Decreases in ocean pH* • *Changes in salinity and oxygen levels*	• *Changes in habitat and prey availability* • *Increase in HABs and infectious disease outbreaks* • *Subsequent impacts on survival, reproduction, and health* • *Heat stress as water temperatures approach dolphin body temperature, with attendant health impacts*	• *Greenhouse gas emissions*

State of our Knowledge	Areas of increasing concern
A lot is known about the direct effects of climate change on the waters of the northern Gulf, but much less has been documented or is known about how those changes will impact marine mammals, including dolphins. Assessments of dolphin habitat requirements and projected climate-induced changes suggest that Louisiana stocks are particularly vulnerable.	

Sample of Documented Cases

General

- *One model projection estimated that in the northern Gulf, the number of species (including small odontocetes) is expected to decline*[25]

Louisiana

- *Based on the level of exposure to climate change risks and their sensitivity, all Louisiana stocks were estimated to have a high overall vulnerability (WCS) to climate impacts, or a "very high" level of vulnerability (all other stocks)*[26]

Stock by Stock Risk Assessment Summary

	Threat Prevalence	Dolphin Impacts	Sum
Mississippi Sound	*3*	*2*	*5*
Mississippi River Delta	*3*	*2*	*5*
Barataria Bay	*3*	*2*	*5*
Terrebonne-Timbalier Bays	*3*	*2*	*5*

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[25] Kaschner et al. 2011

[26] Lettrich et al. 2023

Vermilion Bay	*3*	*2*	*5*
Calcasieu Lake	*3*	*2*	*5*
Sabine Lake	*3*	*2*	*5*
Northern Coastal	*3*	*2*	*5*
Western Coastal	*3*	*2*	*5*

Scoring: ***Threat Prevalence****: 0=threat not present, 1=threat is present but data deficient, 3=threat is present and some characterization*
Dolphin Impacts*: 2=no mortality or sub-lethal impacts documented in this stock, but impacts documented elsewhere,*
4=impacts documented in this stock, 6= mortalities and sub-lethal impacts expected to have population level effects

See Section A.9 for the complete literature review

2.10 Synthesis

[Adding discussion around this figure. Use it to help set up priority DCE stressors discussed below.]

Figure 1 provides a comparison of the final risk assessment scores stratified by stock and threat. Although the summary tables in Section 2 and the literature review in Appendix A mainly focus on the immediate threats to individual dolphins in each stock, we can also evaluate a given stressor's threat to the stock/population as a whole. To do so, it is helpful to understand the stock abundance, which is provided on the x-axis of Figure 1 based on the latest Stock Assessment Reports (Hayes et al. 2023). A more detailed analysis of how some of these stressors contribute to the potential biological removal (PBR) in each stock is given in the respective Stock Assessment Reports, and we do not aim to recapitulate those determinations here.

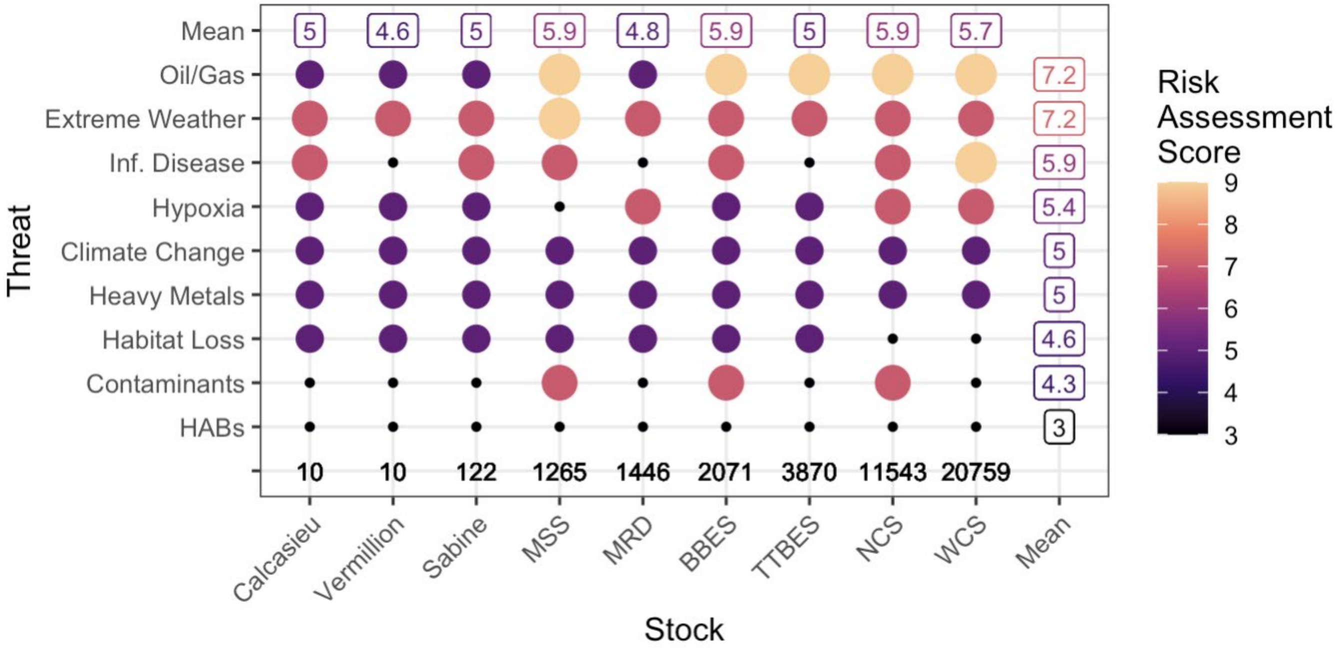

Figure 1: A summary of the risk assessment scores as sums of both known threat prevalence and known dolphin impacts. Means for the scores by threat and by basin are given at the right and top (respectively). The best available abundance estimates are provided (black numbers at bottom) to provide context for interpreting the risk to the stocks. Inf. Disease= Infectious disease; Oil/Gas= Oil &

gas pollution; Extreme Weather= Extreme weather events; Contaminants= Chemical pollution; HABs= Harmful algal blooms; Heavy Metals= Heavy metal pollution.

The MSS, BBES, NCS, and WCS were the stocks with the highest scores, likely partially driven by the availability of data on both threats and especially dolphins in those populations in the wake of the *Deepwater Horizon* Natural Resource Damage Assessment (NRDA). Across all stocks, the top three threats were, in order, oil and gas pollution, extreme weather (and the associated risk of entrapment), and infectious diseases. At least some effort has gone into quantifying the threats in most of the basins–e.g., strandings responses and out-of-habitat interventions providing more specific numbers towards characterizing the prevalence of extreme weather and infectious disease across the basins.

None of the scores for a specific threat/stock pairing reached the highest score possible (9). However, seven pairings reached the threshold for “high concern” (a score of 7):

1. Oil and gas pollution and BBES dolphins
2. Oil and gas pollution and TTBES dolphins
3. Oil and gas pollution and MSS dolphins
4. Oil and gas pollution and WCS dolphins
5. Oil and gas pollution and NCS dolphins
6. Extreme weather and MSS dolphins
7. Infectious diseases and WCS dolphins.

Based on the scoring system used here, restoration projects targeting these pairings would likely have 1) sufficient data for reasonable planning, scaling, and scoping efforts and/or 2) the highest likelihood of benefits for restoration activities.

Chapter 2:
A Conceptual Model for Disease, Contaminant, and Environmental Hazards to Louisiana Dolphins

Deliverable 10 in support of Monitoring Approaches
for Bottlenose Dolphin Restoration in Louisiana

Draft 1 – June 2025

1 Purpose & Goals

The goal of this chapter is to provide a conceptual model that will facilitate discussion on the priority disease, contaminant, and environmental (DCE) stressors for Louisiana dolphins, including their likely exposure pathways, what physiological systems they affect, and any priority data gaps to address in the near future. The focus is on chemicals/pollutants, infectious diseases, and harmful algal blooms. The conceptual model is meant to be used in concert with the references in the data synthesis (Chapter 1 and Appendix A) and the sampling plan in the health assessment framework (Chapter 3).

2 The Conceptual Model

Chapter 1 presents an extensive synthesis about the many DCE stressors threatening Louisiana dolphins, including a variety of infectious diseases, contaminants, and environmental hazards. We focus on the stressors and threats for dolphins in the Southeast U.S. (Figure 2, black boxes)–as identified in the National Marine Mammal Health Monitoring and Surveillance Plan (MMC 2024) and from our data synthesis and literature review (Chapter 1)–including:

- **Viruses:** flaviviruses, morbilliviruses, and influenza
- **Bacteria/fungi:** *Erysipelothrix rhusiopathiae, Vibrio* spp., *Paracoccidioides* spp.*, and Brucella* spp.
- **Protozoa/parasites:** *Toxoplasma gondii* and *Sarcocystis neurona*
- **Biotoxins:** Brevetoxin, saxitoxin, and domoic acid
- **Contaminants:** polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs)
- **Environmental hazards:** fresh water.

The model (Figure 2) is organized in three categories, from left to right:
- **DCE stressor sources (green boxes):** Where do the stressors (black boxes) originate?
- **Exposure pathways (blue boxes):** What is the route of exposure by which the stressors come into contact with a dolphin?

- **Dolphin systems, tissues, and fluids (orange boxes):** What are the primary physiological systems, tissues, and fluids first impacted by the stressors (light orange boxes) and what other systems, tissues, and fluids may eventually be affected and/or sampled for evidence of exposure/effect (dark orange boxes)?

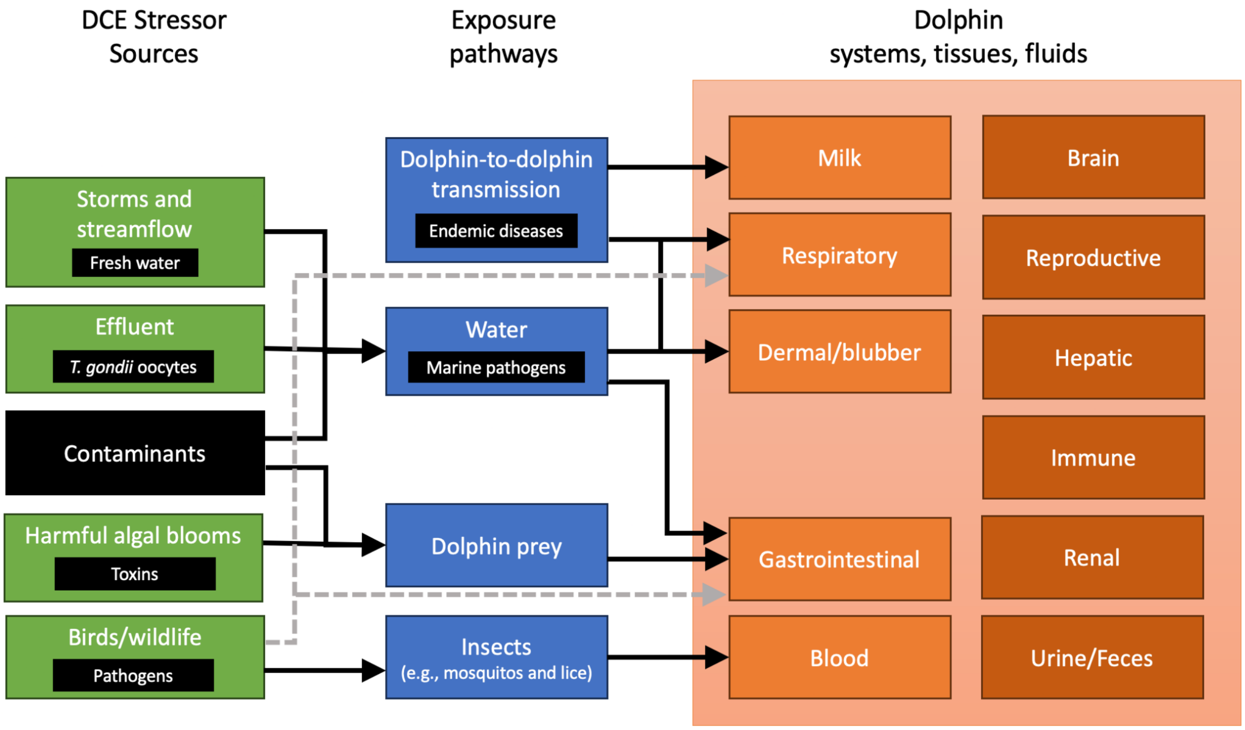

Figure 2: A conceptual model for the priority DCE stressors. See Table 3 in Chapter 3 for specific samples to collect for each priority stressor. Solid black lines/arrows represent connections with support in the literature, while dashed gray lines/arrows represent connections that are reasonable and assumed based on conserved mechanisms with other species, but for which there is little information in the literature specifically with regard to dolphin exposure pathways and effects. See the text above for more information.

2.1 Viruses

2.1.1 Flaviviruses

Dolphins in the Indian River Lagoon, FL showed evidence of exposure to flaviviruses, such as West Nile Virus (Schaefer et al. 2009). The authors suggest that dolphins were exposed via mosquitos or lice that passed on the infection from coastal birds, into the dolphin bloodstream, and ultimately into the neurological system and the brain. Tissue samples of the brain for histology and molecular typing can help identify a flavivirus infection. Abnormal behavior in free-swimming dolphins can be a sign of infection. Few cases have been seen to date, but the ranges of insects and birds are changing as temperature patterns shift, potentially increasing the risk of infections in cetaceans.

2.1.2 Influenza

Birds are also likely the vector by which dolphins are exposed to highly pathogenic avian influenza (HPAI), perhaps by inhalation of aerosolized virus from avian saliva, mucus, or feces, when in proximity, or potentially if dolphins mouth/bite birds in the water (Murawski et al. 2024). Abnormal behavior in free-swimming dolphins can be a sign of infection, but molecular typing with swabs and tissues from nares, blowhole, lung, and brain can be diagnostic. However, the exact route of transmission from bird to dolphin is still uncertain.

2.1.3 Morbilliviruses

Cetacean morbillivirus is transmitted from dolphin to dolphin, typically via inhalation of aerosolized virus. Migratory dolphins in coastal and oceanic stocks are likely the reservoir for the virus, with bay, sound, and estuarine stock dolphins infected by transient coastal stock dolphins. Diagnostic molecular typing can be done with nares, brain, rectum, lung, and lymph node tissues.

2.2 Bacteria and Fungi

2.2.1 *Erysipelothrix rhusiopathiae*

Erysipelothrix rhusiopathiae is ubiquitous in the marine environment, and a serious threat to cetaceans. Infection typically results in skin lesions and ulcerations and can progress into acute septicemia (Lee et al. 2022). Culturing swabs of the lesions/abscesses or molecular typing and histology of lung, spleen, and liver can be diagnostic of Erysipelas.

2.2.2 *Vibrio* spp.

A group of bacteria prevalent in marine habitats, *Vibrio* spp. typically infiltrate dolphin wounds in the skin. Cultures with rectal swabs or molecular typing of fecal samples can both be diagnostic. In the absence of wounds, species of *Vibrio* likely are a normal part of cetacean skin microbiomes (Gallego et al. 2025).

2.2.3 *Paracoccidioides* spp.

Paracoccidioides is ubiquitous in the marine environment, and can lead to skin infections in cetaceans (Garcia-Bustos et al. 2024). The formerly named lacaziosis and lobomycosis belong to this taxon of fungus, driving skin lesions and abscesses. Swabs of lesioned skin and/or lung, spleen, and liver tissues for molecular typing and histology can be used for diagnostic testing.

2.2.4 *Brucella* spp.

It is unclear how dolphins are exposed to *Brucella* spp., but in other animals it is from contact with tissues and fluids after delivery of a fetus, inhalation, through a wound, or via milk while nursing. The bacterium can rapidly spread throughout the body and into the brain, cerebrospinal fluid, lung, lymph node, uterus, testis, and spleen. Culturing cerebrospinal fluid for conducting molecular typing and histology can confirm *Brucella* infection.

2.3 Protozoa/Parasites

2.3.1 *Toxoplasma gondii*

A parasite in cats, oocytes are passed into the feces and then can enter marine ecosystems through effluent. The oocytes are then eaten by fish, which in turn are prey for dolphins. Once consumed, the parasites can move throughout the body, including the lymph nodes, lungs, and liver, but brain tissue/swabs are preferred for diagnostic tests, including histology, molecular typing, and culture.

2.3.2 *Sarcocystis* spp.

A protozoa with a complicated, multi-host life cycle, sarcocystis leave oocytes in dolphin prey. Similar to *Toxoplasma gondii*, the parasites can move throughout the body, including the lymph nodes, lungs, and liver, but brain tissue/swabs are preferred for diagnostic tests, including histology, molecular typing, and culture.

2.4 Toxins

Brevetoxin, domoic acid, and saxitoxin are three toxins associated with harmful algal blooms. In the wake of a HAB event, these toxins bioaccumulate up the food chain, and dolphins can be exposed through their prey, as well as through inhalation of volatilized toxins from lysed cells. For brevetoxin and saxitoxin, the preferred sample submission for ELISA or chromatography is stomach contents, while for domoic acid, the preferred sample is urine. Otherwise, serum, urine, liver, kidney, lung, and amniotic fluid could also be used for diagnostic testing.

2.5 Contaminants

Oil, gas, and chemical infrastructure is pervasive throughout most of Louisiana’s bay, sounds, and estuaries. The DWH marine mammal NRDA provides a proven template for how to evaluate the effects of polycyclic aromatic hydrocarbons (PAHs), which tend to be inhaled or aspirated by dolphins at the sea surface. Currently, the best way to evaluate exposure is to evaluate the suite of adverse health effects that result from petroleum exposure, including hypoadrenocorticism, lung disease, reproductive failure, and immune dysfunction, among others. Diagnostic tests for persistent organic pollutants (POPs) are widespread, typically by using blubber for analytical chemistry. Adverse health effects from PCBs include reproductive failure, immune dysfunction, and endocrine disruption.

2.6 Cross-stressor data gaps

Knowledge of quantitative relationships between exposure and effects is lacking for nearly all stressors except for freshwater (discussed more in the Freshwater Strategy Report) and for mortality associated with oil exposure. Dose-response relationships would be extremely helpful for making predictions about individual animals and extrapolating the effects from many individuals into population trajectories. This is especially true for exposure pathways that rely on inhalation or aspiration. There are projects currently underway to quantify dolphin inhalation/aspiration rates using 3-D holographic imagery, which will help address oil exposures and may inform infectious disease exposure characterizations.

Chapter 3:

A Common Framework for Health Assessments with Louisiana Dolphins

1 Introduction

1.1 Purpose & Goals

The goal of this living document is to support NOAA's marine mammal monitoring and adaptive management efforts to develop a common framework for assessing the health of dolphins across Louisiana, with a particular focus on the risks from disease, contaminants, and environmental (DCE) hazards. It is especially meant to promote state-wide consistency in collecting data about health and threats to dolphins across Louisiana. Such consistency will facilitate comparisons between stocks and enable reliable, robust longitudinal analyses of population trends in support of restoration planning and, once restoration projects are implemented, monitoring their effectiveness.

1.2 Scope

This document complements, and relies upon, the summaries and recommendations in the other documents produced under this Louisiana Marine Mammal Monitoring and Adaptive Management effort, including:

- LA BND Monitoring Plan
- Human-caused Threats Review
- Freshwater Strategy Report, and
- the literature review (Chapter 1) and conceptual model (Chapter 2) in this report.

To avoid redundancy, we make liberal references to content throughout those documents. These reports, and their associated materials, are available at the project's website and data repository.

A note on naming conventions for these documents: although this document might be more accurately described as the combination of a Louisiana dolphin 1) health assessment monitoring framework, 2) health assessment monitoring plan, and 3) health assessment monitoring sampling plans/protocols, to avoid confusion with the aforementioned LA BND Monitoring Plan, we shorten the respective references in this document to 1) health assessment framework, 2) health assessment plan, and 3) health assessment sampling plans/protocols.

Given the breadth of disease agents, contaminants, and environmental hazards that affect Louisiana dolphins, we focus on a subset of the highest priority stressors for Louisiana dolphins, including those identified by the experts who participated in the Marine Mammal Health Surveillance Workshop (MMC 2024). Although the workshop explicitly developed the plan for threats that are likely to be influenced by a changing climate, the priorities they identified are important threats to Louisiana dolphins even without considering a changing climate. Given the significant concerns about freshwater exposure, we recommend that all health assessment activities be built on top of the suggested activities in the LA BND Monitoring Plan and Freshwater Strategy Report. Then, based on the literature review in Chapter 1 (and associated Appendix A), we also include priority contaminants. Specific data/sample collection can be added to those activities to inform the highest priority DCE stressors, including:

- Viruses: flaviviruses, morbilliviruses, and influenza
- Bacteria/fungi: *Erysipelothrix rhusiopathiae, Vibrio* spp., and *Paracoccidioides* spp.
- Protozoa/parasites: *Toxoplasma gondii* and *Sarcocystis neurona*
- Biotoxins: Brevetoxin, saxitoxin, and domoic acid
- Contaminants: polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs).

This document provides a brief framework on how the LA BND Monitoring Plan, Freshwater Strategy Report, and the priority DCE stressor sample collection should be integrated, then provides specific plans/protocols for sample collection relevant to the priority DCE stressors. Future efforts by the Louisiana Marine Mammal Monitoring and Adaptive Management project could be spent to combine all of these reports and plans into one, unified plan for Louisiana dolphins.

2 Louisiana Dolphin Health Assessment Framework

In 2024, the U.S. Marine Mammal Commission convened a workshop to develop a National Marine Mammal Health Monitoring and Surveillance Plan (MMC 2024). It forms the basis for this Louisiana dolphin health assessment framework, facilitating the ability to integrate the results of any Louisiana activities (e.g., monitoring, data collection, and analyses) into the larger national efforts for marine mammal health surveillance. The four objectives of the MMC Plan should guide Louisiana dolphin health monitoring:

1. **Establish health status of populations, including prevalence of endemic disease** to understand effects on populations and aid in the planning and interpretation of mortality and morbidity investigations;
2. **Establish baseline toxin exposures** to allow interpretation of levels reported during harmful algal blooms;
3. **Improve knowledge of infectious disease ecology** to inform recovery plans and future mitigation actions;
4. **Detect changes in population health early** to facilitate effective response and mitigation for animals and humans.

Fully evaluating the threats from disease, contaminants, and environmental hazards often requires many years and entire working groups (e.g., unusual mortality event working groups, natural resource damage assessments, and environmental impact statements). However, similar to the considerations discussed in the [Freshwater Strategy Report](), the fundamental question driving health assessment activities is: “What is the relationship between the exposure to a given stressor and the resulting adverse health effects?” In some cases, just the presence of both a threat and an adverse response may be enough, if there is a reasonable causative mechanism and no other plausible explanations. In other cases, a more developed exposure-effect/dose-response relationship may be required for decision-makers to plan appropriate actions. In either case, addressing the many data gaps among exposure, individual impacts, and population effects will require significant data collection efforts by research and response organizations across years to generate reliable and robust sample sizes.

Studies with marine mammals can be logistically challenging, and often result in low sample sizes. To generate the sample sizes needed for robust and reliable analyses, it will be critical to integrate and synthesize data across as many opportunistic and directed sampling efforts as possible (from Louisiana, the Southeast U.S., and potentially internationally), including: 1) past efforts, 2) future studies under programs outside of this LA marine mammal monitoring and adaptive management effort, 3) opportunistic studies that arise and offer important chances to collect relevant data, and 4) studies designed and conducted specifically to support this effort. Combining the results from live strandings, necropsies, out-of-habitat interventions, remote sampling research efforts, and temporary catch-and-release sampling efforts will help overcome limitations or biases associated with singular individual approaches (e.g., logistics, cost, sample size, sample design, types of data/samples that can be collected).

The LA BND Monitoring Plan provides recommendations for coordinated field efforts to monitor the dolphin populations across Louisiana, but it also offers a solid framework integrating both the freshwater-specific tools discussed in the Freshwater Strategy Report and the recommendations in this Health Assessment Plan. Specifically, the overarching planning needs described in Section 2 of the LA BND Monitoring Plan, as well as the specific monitoring activities recommended can be the base upon which freshwater and stressor assessment and monitoring can be added. In other words, the LA BND Monitoring Plan, Freshwater Strategy Report, and this Health Assessment Plan should ideally all be considered as one unified effort, saving time and resources, and ensuring that decision makers get the best-available information as soon as possible. Briefly, the key components of a unified approach from the three documents includes:

7. Establish the infrastructure for the overarching planning needs in Section 2 of the LA BND Monitoring Plan including: integrated population modeling; a centralized group of scientists to coordinate across studies, analyses, and modeling (including for all stressors); centralized dorsal fin photo-identification matching; population structure analyses using genetic markers; and standardized stranding response and data collection.

8. Collect/aggregate baseline dolphin and environmental data as early as possible, to facilitate the detection and investigation of future changes in health from DCE stressors.
9. Identify, as early as possible, known or predictable future environmental threats (e.g., large freshwater inputs into Louisiana basins) and deploy field crews for monitoring environmental conditions and dolphin distributions/health status before, during, and after the events.
10. Integrate the protocols/tools from Section 4 of the Freshwater Strategy Report and Section 4 of this Health Assessment Plan into any future dolphin studies in Louisiana or, if possible, nearby states–whether as part of Louisiana marine mammal monitoring and adaptive management activities (e.g., the field activities recommended in the LA BND Monitoring Plan) or by collaborating with scientists with other programs/funding.
11. Ensure that Stranding Network Partners in Louisiana have the training and resources they need to: 1) fully integrate the protocols/tools into their routine activities and 2) respond to as many cases as possible across Louisiana.
12. Convene subject matter expert groups to regularly review and further develop the plans and recommendations, including the specific protocols/tools.

It is important to note that, at least as of 2025, the current structure of NMFS coordination of the National Marine Mammal Stranding Network (via the NOAA Regional Offices, Regional Stranding Coordinators, and the MMHSRP), in combination with close coordination among marine mammal researchers, the NOAA Protected Resources Permits review process, and other relevant NOAA offices (e.g., Office of Response and Restoration, Office of Habitat Conservation and their Restoration Center) provides a strong foundation for the proposed activities herein. MMHSRP actively maintains protocols, datasheets, and sampling/analysis plans for response and interventions with small cetaceans and offers guidelines and best practices for permit applications for directed research studies on free-swimming dolphins. These protocols typically include data/sample collection that covers the majority of data needs for evaluating health and DCE stressors, and MMHSRP works closely with subject matter experts including pathologists, veterinarians, epidemiologists, and biologists to ascertain whether certain stressors are impacting dolphins of concern (e.g., determining cause of death for strandings cases and UMEs, conducting expert elicitations). Where possible, we have aggregated those materials in the data repository. This framework (in combination with the Freshwater Strategy Report) attempts to catalog those already available resources/tools, and then offers recommendations for any unique needs identified for DCE stressors and Louisiana dolphins in particular.

3 Louisiana Dolphin Health Assessment Plan

3.1 Synthesizing recommendations in the Monitoring Plan, Freshwater Strategy, and MMC Report

A Louisiana Dolphin Health Assessment Plan cannot proceed in isolation; it must be an integrated effort built on more than just addressing DCE stressors and threats. Therefore, we use this first section of the plan to aggregate the key elements of relevant Louisiana dolphin activities into a coherent base upon which to add the specific DCE-related recommendations further below.

3.1.1 Overarching planning needs

Section 2 of the LA BND Monitoring Plan discusses the infrastructure needed to best monitor dolphin populations across Louisiana and, in turn, provide decision-makers with the best-available information. All of the recommendations therein should be integrated into this plan, including:

- A coordinated set of population models
- A centralized group of scientists to coordinate across studies, analyses, and modeling for all stressors (for ease of communication, hereafter referred to as the MAM Science Coordination Group: MAM SCG)
- Centralized dorsal fin photo-identification matching
- Using genetic markers to define population structure, and
- Standardized stranding response and data collection.

An accurate understanding of the abundance, distribution, population structure, and habitat use patterns for dolphins across Louisiana (as laid out in the LA BND Monitoring Plan) is critical to planning for and interpretation of health assessment activities. As such, the MAM SCG should integrate health assessment considerations into those ecological data collection activities from the start of their planning. To achieve this, the SCG should serve as a conduit among the many entities necessary for the proposed work, including response and intervention teams in the stranding network; researchers in the field; subject matter experts; MMHSRP, NMFS, and other State and Federal offices; and any other relevant stakeholders/decision-makers. As this conduit, the SCG will be facilitating clear communication and coordination about: 1) what data the models require and how to collect them, 2) the interpretations of various analyses, and 3) how the data and analyses could inform restoration planning and other decision-making. Some important tasks for the group would include:

- Coordinating all activities and information with the LA TIG.
- Identifying and promoting the best data repositories and protocols for efficient input, processing, and sharing for the Louisiana Marine Mammal Monitoring and Adaptive Management efforts and across other marine mammal efforts (e.g., HealthMap).

- Coordinating with national marine mammal and One Health efforts for wildlife health monitoring and surveillance efforts and best practices.
- Helping introduce and remind collaborators, partners, and diagnostic/analytical laboratories about shared tools, materials, and protocols to ensure standardized and consistent data collection.
- Performing quantitative analyses to guide study designs and response/intervention data collection, debriefs, and decision-making, including selecting individual dolphins for assessments, setting sample size targets, and informing triggers for surveillance or other decisions and what specific actions those triggers should elicit.
- Setting a schedule for transparent updates to stakeholders and the public, as well as for periodic review and update of the monitoring and health assessment plans.
- Integrating health, demographic, and environmental data (e.g., via the Integrated Ocean Observing System [IOOS]).

Coordination led by a centralized group of scientists (i.e., the SCG) would be especially helpful for bringing together data from opportunistic efforts (e.g., response, interventions, and necropsies) with targeted research studies. The primary stranding network partner in the state of Louisiana is Audubon Aquarium Rescue (AAR; coordinated by Audubon Nature Institute), who are typically the first responders on scene after a sick, injured, or stranded dolphin is found/reported. We recommend that all stranding network activities begin implementing the protocols recommended in the Freshwater Strategy Report and the Freshwater Data Repository, to begin collecting data on both freshwater-related cases and non-freshwater-related cases (for considering baseline/reference conditions in analyses), as well as the priority DCE stressor data/samples recommended below (Section 4). For responding to larger groups of dolphins during/after disasters (natural or human-caused), we recommend integrating any appropriate findings from the "Reducing Impacts to Cetaceans during Disasters by Improving Response Activities" restoration project that is currently in progress.

AAR and MMHSRP (and any other appropriate subject matter experts) should debrief about the updated protocols after each case, and when appropriate (but no later than after ten cases with the updated protocols), they should summarize their results, outcomes, processes, and recommendations for updates/adjustments for discussion with the SCG. If other stranding network partners (e.g., in Alabama and Mississippi) are also implementing the new protocols, a broader workshop could be conducted, either facilitated by the SCG or MMHSRP.

For both response/intervention/necropsy efforts and targeted research efforts, if time and resources allow, we recommend that any sample collection efforts be conducted in collaboration with the NIST National Marine Mammal Tissue Bank. At the least, they can provide valuable guidance and advice about sample management. If funding is available, they can also provide access to sample collection/storage materials, trained sample collection personnel for field efforts, the FreezerWorks barcode labeling and database software, and a facility for sample storage.

3.1.2 Stock-specific activities

As discussed above, ideally, the data and sample collection for evaluating freshwater and DCE stressors (e.g., water samples) and dolphin health can be collected in parallel with the activities recommended in the LA BND Monitoring Plan; Table 1 provides a summary of the stock-specific recommendations.

Integration of sample collection for freshwater and DCE stressors into these activities could include, for example, collecting water/environmental samples during photo-ID, remote biopsy, and telemetry tagging surveys from small vessels, or coordinating data/sample collection from stranding activities, which would provide baseline water quality data for harmful algal blooms, salinity and infectious disease stressor analyses.

However, if any of those monitoring efforts are not conducted, we recommend collaborating with field biologists (e.g., from academia, marine mammal research groups, or from State agencies) to begin collecting baseline water quality data for harmful algal blooms, salinity, and pathogens. The centralized group of scientists should assist with determining how to coordinate any potential new efforts with ongoing studies by State agencies or independent researchers, depending on what monitoring efforts are planned for implementation and the stressors of priority in those basins.

3.2 Integrating priorities for DCE stressors

3.2.1 Diseases

The Marine Mammal Health Surveillance Workshop Report makes recommendations for the highest priority pathogens, toxins, and non-infectious disease samples to be included in health assessments for bottlenose dolphins in the Southeast U.S. (Tables 1E and 3 in MMC 2024), with a particular focus on the threats that are most likely to be exacerbated by climate change. The literature search and risk assessment in Chapter 1 of this document is consistent with their findings. For non-infectious disease, they recommend collecting samples to monitor health conditions in general, including skin lesions (focused on freshwater exposure), inflammation markers in blood, and hormone levels in blood and blubber. For infectious diseases and biotoxins from harmful algal blooms, they recommend collecting samples to assess for:

- **Viruses:** flaviviruses, influenza, and morbilliviruses
- **Bacteria/fungi:** *Brucella* spp., *Erysipelothrix rhusiopathiae*, *Paracoccidioides* spp., and *Vibrio* spp.
- **Protozoa/parasites:** *Sarcocystis* spp. and *Toxoplasma gondii*
- **Biotoxins:** brevetoxin, domoic acid, and saxitoxin.

Table 1. A summary of the activities recommended in the LA BND Monitoring Plan. See that document for more information and for definitions of acronyms.

	Stranding network	**Photo-ID**	**Aerial Surveys**	**Remote Biopsies for Genetics**	**Satellite-linked Telemetry Tags**	**Notes**
All stocks associated with the Northwest Inner Shelf DIP*	Support ongoing efforts	Targeted surveys	Supplement GoMMAPPS II	Coordinated effort across NWIS DIP	Determine geographic extent of NWIS DIP	
Mississippi Sound	Ongoing	Exploratory surveys near Lake Catherine area	Add Lake Borgne and Bay Boudreau transects	Focus on Bay Boudreau and Lake Borgne	Include	
Mississippi River Delta	Develop resources to support dedicated surveillance here	Supplement aerial surveys, if needed	Add to GoMMAPPS II	Use telemetry data to inform sampling design	Identify potential overlap with MS and Chandeleur Sounds	
Northern Coastal	Ongoing	NA	Covered by GoMMAPPS II	Focus on Chandeleur Sound	Focus on Chandeleur Sound	
Western Coastal	Ongoing	NA	Covered by GoMMAPPS II	Coordinate with nearby BSE photo-ID efforts	Include	
Western Louisiana BSE Stocks						
Barataria Bay Estuarine System	Ongoing	Conduct if delays in MBSD monitoring	Not a priority	Conduct if delays in MBSD monitoring	Not a priority at this time	Collect data in SW MS River Delta
Terrebonne-Timbalier Bay Estuarine	Ongoing	Priority to update with new primary sessions	Not a priority	Pair BSE and coastal efforts	Focus on Port Fourchon and western half of stock area	
Vermilion Bay/West Cote Blanche Bay/Atchafalaya Bay	Ongoing	Exploratory surveys designed around salinity	Not a priority	Exploratory surveys designed around salinity	Not a priority at this time	
Calcasieu Lake	Ongoing	One primary survey	Not a priority	Compare to NWIS DIP/other BSEs	Not a priority at this time	
Sabine Lake	Ongoing	One primary survey	Not a priority	Compare to NWIS DIP/other BSEs	Not a priority at this time	

3.2.2 Contaminants

Based on the literature search and risk assessment in Chapter 1 of this document, the highest priority contaminant threats for Louisiana dolphins are polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and other persistent organic pollutants (POPs), and microplastics (and the chemicals that bind to them). PCB levels in Louisiana dolphin blubber are only available in the Barataria Bay Estuarine System, Mississippi Sound, and Northern Coastal stocks. Collecting samples and data from other stocks is a critical data gap, especially for establishing baseline of POPs prior to any future spills/releases. Blubber for those analyses could be taken from the remote biopsy efforts suggested in the Monitoring Plan (for genetic analyses with skin).

The efforts to measure the effects from oil, gas, and petroleum products (usually in the form of PAHs) for the DWH oil spill are well documented and integrated into the example sampling plan given in Table 2. Generally, it is difficult to measure PAHs from tissues without collecting samples soon after exposure, but measuring adverse health effects (e.g., lung disease, abnormal hormone levels, and immune dysfunction), in combination with ruling out other stressors, can provide a strong case for oil exposure.

Techniques for measuring dioxin levels using the amount of blubber from a typical remote biopsy sample are underway as part of a NOAA RESTORE research project, and may be a contaminant to consider for future versions of this plan. Other emerging contaminants (e.g., polybrominated diethyl ethers [PBDEs] and per- and polyfluoroalkyl substances [PFAS]) should also be considered as more information about their presence in Louisiana coastal waters and their relationship with dolphins in the Southeast U.S. becomes available. Microplastics, and chemicals associated with them (e.g., phthalates) should also be considered.

3.2.3 Environmental hazards

While Louisiana dolphins are at risk from a variety of environmental hazards, the resulting adverse effects are likely to fall under one of two categories: 1) freshwater exposure (discussed in the Freshwater Strategy Report), e.g., extreme weather events leading to out-of-habitat dolphins or 2) stress and poor health potentially leading to non-infectious diseases. For the latter, we recommend continuing to evaluate the standard panel of data/sample collection efforts associated with health assessments to date. Climate change falls under the latter category as well, but also either increases the level of other stressors (e.g., freshwater exposure, habitat loss, algal blooms) or exacerbates the threat posed by other stressors (e.g., contaminants). Given its interactive and potentially non-linear impacts on other stressors, addressing climate change as a threat means taking into account cumulative impacts, changing environments, and the potential for different exposure pathways in the future, emphasizing the need for periodic review and update of sampling protocols.

4 Sampling plans and protocols

The MMHSRP developed Live and Dead Animal Freshwater Disease Sampling protocol documents for Stranding Network Partners, and we discuss potential updates to those protocols in the Freshwater Strategy Report (Section 4). Similarly, sampling and analysis plans for temporary catch-and-release health assessments are available from various research groups. We provide one example list of the sample-types collected from a 2023 health assessment in Barataria Bay, LA (Table 2). In addition to the samples listed in Table 2, for both stranded and research efforts, we recommend adding the sample-types prioritized by the National Marine Mammal Health Surveillance Plan (MMC 2024) for bottlenose dolphins in the Southeast U.S., which we summarize in Table 3.

When starting any new sampling plan, and gathering the requisite protocols, we highly recommend reaching out to the diagnostic laboratories that you hope to work with. They will provide critical information about sample collection, storage, and shipment protocols, and they can send specific materials and containers for the analytes of interest. Some examples of laboratories with marine mammal expertise include (but are not limited to):

Wide range of veterinary diagnostic services:

- The Zoological Pathology Program at the University of Illinois Urbana-Champaign
- The Animal Health Diagnostic Center at Cornell University
- The Veterinary Diagnostic Laboratories at the University of Georgia
- Zooquatic Laboratory

Contaminants

- NOAA's Environmental Chemistry Program at the Northwest Fisheries Science Center

Genetic species identification, omics, and eDNA

- NOAA's Marine Mammal Molecular Genetics Laboratory at the Southeast Fisheries Science Center

Table 2. An example sampling plan from a temporary catch-and-release health assessment in Barataria Bay, LA.

Tissue Type	**Container Type**	**Analysis**	**Storage/Shipment Plan**	**Temp**
Blood				
Heparin Whole blood	Heparinized syringe	i-STAT	Used in field	NA
	Hematocrit tube	Hematocrit	Used in field	NA
	10 mL blood tube	Lymphocyte proliferation	Daily shipments	4°C
	10 mL blood tube	Treg cell counts	Daily shipments	4°C
	2 mL cryovial	Archive: infectious diseases	Archived	-70°C
EDTA Whole blood	3 mL blood tube and slides	Lab hematology	Daily shipments	4°C
	Microscope slide	On-site hematology	Used in field; slide box	RT
PAXgene Whole blood	3 mL blood tube	Archive: transcriptomics	Archived	-70°C
Serum	5 mL cryovial	Serum chemistry	Daily shipments	4°C
	2 mL cryovial	Serum osmolality	Daily shipments	4°C
	5 mL cryovial	Stress/thyroid hormones	Shipped in one batch	-70°C
	5 mL cryovial	Reproductive hormones	Shipped in one batch	-70°C
	2 mL cryovial	Cytokines	Archived	-70°C
	2 mL cryovial	Morbillivirus	Shipped in one batch	-70°C
	2 mL cryovial	SAA/haptoglobin	Archived	-70°C
	2 mL cryovial	SARS: serum	Archived	-70°C
	2 mL cryovial	Archive: serum	Archived	-70°C
Citrate Plasma	2 mL cryovial	Fibrinogen	Daily shipments	4°C
	2 mL cryovial	Archive: coagulated plasma	Archived	-70°C
EDTA Plasma	2 mL cryovial	rT3	Shipped in one batch	-70°C
Heparinized Plasma	2 mL cryovial	Archive: plasma	Archived	-70°C
	5 mL cryovial	Archive: PFCs	Archived	-70°C
	7 mL Teflon jar	Archive: OCs	Archived	-70°C
Buffy Coat (from Hep plasma)	2 mL cryovial	Archive: buffy coat	Archived	-70°C
Remaining cells (from Hep plasma)	5 mL cryovial	Archive: red blood cells	Archived	-70°C

Table 2 continued. An example sampling plan from a temporary catch-and-release health assessment in Barataria Bay, LA.

Tissue Type	**Container Type**	**Analysis**	**Storage/Shipment Plan**	**Temp**
		Skin/blubber biopsy		
Blubber	7 mL Teflon jar	Archive: blubber contaminants	Archived	-70°C
	2 mL cryovial	Archive: hormones	Archived	-70°C
Skin	2 mL cryovial	Archive: skin contaminants	Archived	-70°C
	5 mL cryovial (AllProtect)	Archive: omics	Archived	Step-freeze
	2 mL cryovial	Archive: skin	Archived	-70°C
Skin (tag biopsy)	2 mL cryovial	Genetics/epigenetics	Shipped in one batch	-70°C
		Blowhole		
Blowhole- catheter tube	2 mL cryovial	Archive: blowhole PCR	Archived	-70°C
	slide	Cytology blowhole	Used in field; slide box	RT
Blowhole- respiratory exudate	slide	Cytology respiratory exudate	Used in field; slide box	RT
Breath	30 mL Glass jar	Exhalate: microplastics	Shipped in one batch	4°C
		Urine, feces, and milk		
Urine	5 mL cryovial	Urinalysis	Daily shipments	4°C
	2 ml cryovial	Phthalates	Shipped in one batch	-70°C
	2 ml cryovial	Osmolality and chemistry	Daily shipments	4°C
	5 mL cryovial	Archive: urine	Archived	-70°C
Feces	slide	Cytology feces	Used in field; slide box	RT
	5 mL cryovial	Archive: feces	Archived	-70°C
Milk	7 mL Teflon jar	Archive: OCs	Archived	-70°C
	5 mL cryovial	Archive: milk	Archived	-70°C

Table 2 continued. An example sampling plan from a temporary catch-and-release health assessment in Barataria Bay, LA.

Tissue Type	**Container Type**	**Analysis**	**Storage/Shipment Plan**	**Temp**
Sick animal (veterinary discretion)				
Whole blood	40 mL VersaTrek aerobic	Aerobic bacteria culture	Daily shipments	RT
	40 mL VersaTrek anaerobic	Anaerobic bacteria culture	Daily shipments	RT
Blowhole- catheter tube	Amies Swab	Aerobic bacteria culture	Daily shipments	4°C
	Amies Swab	Anaerobic bacteria culture	Daily shipments	4°C
	VTM vial	Fungal/mycoplasma culture	Daily shipments	4°C
Blowhole- respiratory exudate	Amies Swab	Aerobic bacteria culture	Daily shipments	4°C
	Amies Swab	Anaerobic bacteria culture	Daily shipments	4°C
	VTM vial	Fungal/mycoplasma culture	Daily shipments	4°C
Skin- lesion	5 mL cryovial formalin	Histology	Shipped in one batch	RT
	2 mL cryovial	Lesion molecular typing	Shipped in one batch	-70°C
Aspirate- lesion	5 mL cryovial formalin	Histology	Shipped in one batch	RT
	Amies Swab	Aerobic bacteria culture	Daily shipments	4°C

Table 3. Sampling recommendations for infectious diseases and harmful algal bloom toxins. Adapted from MMC 2024.

Pathogen/Toxin	**Sample type**	**Analysis**	**Container/media**	**Temperature**
Flaviviruses	Tissue: brain	Histology	Jar with formalin	RT
		Molecular typing	Empty vial	-70°C
Influenza	Swabs: nares, blowhole, lung, and brain	Molecular typing	Empty vial or with RNA preservative	-20°C for < 1 week, then -70°C
	Tissues: brain, lung, and lymph node	Histology	Jar with formalin	RT
		Molecular typing	Empty vial	-70°C
Morbilliviruses	Swabs: nares, brain, and rectum	Molecular typing	Empty vial or with RNA preservative	-20°C for < 1 week, then -70°C
	Tissues: brain, lung, and lymph node	Molecular typing	Empty vial	-70°C
		Histology	Jar with formalin	RT
Erysipelothrix rhusiopathiae	Swabs: abscess/lesion	Culture	Specific culture media	4°C
	Tissues: lung, spleen and liver	Molecular typing	Empty vial	-70°C
		Histology	Jar with formalin	RT
Vibrio spp.	Swabs: rectum	Culture	Specific culture media	4°C
	Feces	Molecular typing	Empty vial	-70°C
Paracoccidioides spp.	Swabs: abscess/lesion (preferred)	Culture	Specific culture media	4°C
	Tissues: lung, spleen and liver	Molecular typing	Empty vial	-70°C
		Histology	Jar with formalin	RT
Brucella spp.	Cerebral spinal fluid	Culture	Specific culture media	4°C
	Tissues: brain, lung, lymph node, uterus, testis, and spleen	Molecular typing	Empty vial	-70°C
		Histology	Jar with formalin	RT
Toxoplasma gondii and *Sarcocystis* spp.	Tissues: brain (preferred), lymph node, lung and liver	Histology	Jar with formalin	RT
		Molecular typing	Empty vial	-70°C
	Swabs: same as above	Culture	Specific culture media	4°C
Brevetoxin	GI contents (preferred), serum, urine, liver, kidney, and lung	ELISA or chromatography	Empty vial	-20°C
Domoic acid	Urine (preferred), serum, feces, GI contents, and amniotic fluid	ELISA or chromatography	Empty vial	-20°C
Saxitoxin	GI contents (preferred), liver (preferred), and kidney	ELISA or chromatography	Empty vial	-20°C

Appendix A:

Review of Threats to Louisiana Dolphins from Disease, Contaminants, and Environmental Stressors

Part 2 of Deliverable 9 in support of Monitoring Approaches
for Bottlenose Dolphin Restoration in Louisiana

Draft for review – May 2025

A literature cited list can be found in the LA BND Citation Inventory; for this report in particular, please filter on the DCE column (Column E).

A.1 Infectious Disease

Infectious disease has been found to be one of the most frequent causes of mortality in stranded marine vertebrates (Bogomolni et al. 2008) and in dolphins in particular (McFee & Lipscomb 2009). Within dolphin populations, impacts from infectious diseases can range from subclinical infections to large die-offs. The infectious disease-causing agents that have been documented to impact Louisiana dolphin stocks or that are known to impact other dolphin stocks in the southeast US include:

- Morbillivirus
- *Brucella*
- Other bacteria
- Fungi
- Protozoan parasites
- Other viruses

Morbillivirus and *Brucella* infections pose the most significant threats to dolphin populations because of their potentially deadly outcomes and their potential to inflict both individual- and population-level impacts, including unusual mortality events (UMEs). Subsequently, they are the best-studied. Beyond these two notable infections, however, dolphins throughout the northern Gulf and the US Atlantic coast are affected by other fungal, bacterial, parasitic, and viral diseases that can negatively affect their health. And depending on the infection type, an individual that survives an acute stage of infection could be more likely to then suffer from other opportunistic infections due to the immunosuppression caused by the initial infection (Van Bressem et al. 2014).

Infectious disease literature specific to Louisiana dolphins and the nine Louisiana dolphin stocks is very limited. However, more research is available for diseases affecting northern Gulf dolphins more generally, which we assume is directly applicable to Louisiana dolphins. Additionally, infectious disease research along the US Atlantic Coast has produced some insights that can be applied to the Louisiana stocks.

In the paragraphs below, we characterize each causative agent that potentially impacts Louisiana dolphin stocks using published literature. We focus on describing the impacts they have had on dolphin populations primarily in the southeastern US, as well as risk factors that have been found more broadly to make infection and outbreaks more likely. Where available, we highlight any work done specifically on Louisiana dolphins, but because of the lack of Louisiana-specific research, we do not provide stock-by-stock information.

A.1.1 Morbillivirus

Morbillivirus is a highly contagious paramyxovirus. Cetacean morbillivirus strains of interest to bottlenose dolphins include dolphin morbillivirus (DMV) and porpoise morbillivirus (PMV). Inhalation seems to be the most likely form of transmission when it is shed by an infected individual and aerosolized (Van Bressem et al. 2014). Disease modeling showed that individuals with DMV during an outbreak along the US Atlantic coast were infectious for up to 24 days (Morris et al. 2015). Thus, large groups of dolphins can quickly become infected, and given the potential for wide-ranging movement in that timeframe, the footprint of an outbreak could be large. If a mother has been previously infected with morbillivirus, her newborn will typically have immunity for some months after birth, but eventually the immunity will fully fade, making them vulnerable to infection (Van Bressem et al. 2014).

Morbillivirus outbreaks are often associated with a high level of mortality. Infections can result in acute fatal pneumonia or chronic encephalitis (Van Bressem et al. 2014). An individual that is able to survive the acute phase of a morbillivirus is at higher risk for secondary, opportunistic infections, and may succumb to those (Van Bressem et al. 2014). Morbillivirus infections can lead to central nervous system infections, identifiable by lesions on the brain. Animals that develop this can die from central nervous system complications (Van Bressem et al. 2014). Given these fates, morbillivirus outbreaks pose significant population-level threats and have led to UMEs among cetaceans, with significant population declines observed in bottlenose dolphins (Lipscomb et al. 1994a; McLellan et al. 2002; Bossart et al. 2009).

Along the US Atlantic coast morbillivirus has been definitively connected to a number of UMEs. A morbillivirus outbreak led to the 1987-88 UME along the coasts of New Jersey, Virginia, and eastern Florida in which 742 dolphins died (representing more than 50% of that population) (Federal Register 1993; Lipscomb et al. 1994a). Another morbillivirus outbreak caused significant mortality between 2013 and 2015 where more than 1,600 dolphins died (Fauquier et al. 2017). Within the 1987-88 UME, morbilliviral antigen was detected in 53% of tested dolphins (Lipscomb et al. 1994a). Among antigen-positive dolphins, 52% showed evidence of secondary infections based on histopathology, thus, morbillivirus infection likely led to secondary fungal and bacterial infections due to immunosuppression (Lipscomb et al. 1994a).

In the northern Gulf, morbillivirus was first detected in the 1990s (Lipscomb et al. 1994b; Fauquier et al. 2017) and has since been identified as a significant pathogen impacting dolphin populations in multiple northern Gulf UMEs (Litz et al. 2014). Research on two UMEs in 1990 and 1992 that affected the entire Gulf and Texas coasts, respectively, suggested that morbillivirus was responsible for the large-scale strandings (Duignan et al. 1996; Litz et al. 2014). A 1994 UME in Texas was also found to be caused by morbillivirus (Duignan et al. 1996; Litz et al. 2014).

Despite its contagiousness and link to UMEs, evidence suggests that subclinical morbillivirus infections exist. A study in the Indian River Lagoon (IRL) on the Atlantic coast of Florida found morbillivirus antibodies in the population despite the absence of a mass die-off event, suggesting that morbillivirus infections can occur without fatal consequences (Bossart et al. 2009; Van Bressem et al. 2014). Another study examining the potential role of morbillivirus in the 2010-2014 UME that affected the Gulf coast from Louisiana to northwest Florida found that it was not the primary cause of the large-scale die-off but that 9.9% of stranded cetaceans and 1% of free-ranging live dolphins were positive for DMV (Fauquier et al. 2017). In the same study, around a quarter of live stranded and live free-ranging dolphins had titers for CMV indicating prior (but not necessarily recent) exposure to the virus, which may mean that morbillivirus is endemic in the northern Gulf (Fauquier et al. 2017). In contrast, molecular testing of stranded dolphins from Alabama, 2015-2020, did not detect any morbillivirus in the 66 animals tested (Bloodgood et al. 2023). Prior infection of 60% or more of a population has been suggested would confer herd immunity and offer protection from future outbreaks within a population (Morris et al. 2015).

A.1.1.1 Louisiana Stocks

As noted above, the 1990 UME that affected dolphins from Texas to Florida that was thought to be at least partially caused by morbillivirus (Litz et al. 2014) affected Louisiana dolphins, but which stocks were affected and to what extent is unclear from published accounts. The only research on morbillivirus we found related specifically to Louisiana dolphin stocks was the Fauquier et al. (2017) study just mentioned and a subsequent study focused on Barataria Bay and the eastern portion of Mississippi Sound in Mississippi and Alabama (Cloyed et al. 2021). Fauquier et al. (2017) sampled a total of 55 stranded dolphins from the Barataria Bay (BBES) and Calcasieu areas (no breakdown of how many per stock) and 82 live free-swimming dolphins from Barataria Bay. They found that 7% of the stranded Louisiana dolphins were positive for morbillivirus. Of the free-swimming BBES dolphins, 18.3% had positive antibody titers for CVM, indicating prior exposure. The BBES dolphins sampled by Cloyed et al. (2021) showed a higher overall prevalence of positive antibody titers at 37%. In dolphins from the eastern portion of Mississippi Sound (outside of Louisiana but nonetheless part of the MSS stock) they found a 44% seroprevalence. The authors noted that these seroprevalences were higher than have been found in most other catch-and-release health assessments in the southeastern US. They also found that BBES dolphins that used the interior waters of the Bay had 0% seroprevalence, while the island-associated BBES dolphins that primarily use the southern portion of the Bay had 45% seroprevalence, and that there was less variation in seroprevalence among the subsets of MSS dolphins, indicating that exposure of BSE dolphins is likely due to overlap with coastal stocks where morbillivirus could be endemic (Rowles et al. 2011; Cloyed et al. 2021).

No other information on the occurrence of morbillivirus in Louisiana dolphin stocks could be found.

A.1.2 Brucella

Infections from *Brucella* were first described in dolphins in California and other marine mammals in Italy in 1994 (Ewalt et al. 1994; Ross et al. 1994). Brucella infections in cetaceans pose significant individual health risks, with documented pathologic lesions in various organs leading to meningoencephalitis, arthritis, multi-organ abscessation, reproductive tract inflammation, placentitis, and in-utero pneumonia (González-Barrientos et al. 2010; Nymo et al. 2011; Colegrove et al. 2016a, 2016b; Buckle et al. 2017; Sánchez-Sarmiento et al. 2019; Curtiss et al. 2022; Granados-Zapata et al. 2022; Grattarola et al. 2023). *Brucella* infections in dolphins can manifest as pneumonia in perinates and reproductive tract infections in older animals (Bloodgood et al. 2023). It can cause severe chronic infections in multiple organ systems that can have long-term health impacts (de Figueiredo et al. 2015; Curtiss et al. 2022). *Brucella* can also cause late-term abortions or early neonatal loss as it is often transmitted through either the placenta or nursing (Phillips and Rosel 2014). Neurobrucellosis, when *Brucella* infects the central nervous system, is a common cause of cetacean strandings due to characteristic disorientation, uncoordinated lateral swimming, buoyancy issues, and death (Granados-Zapata et al. 2022; Grattarola et al. 2023). Secondary infections are also common; one study of striped dolphins found that more than 50% of studied individuals had co-infections, mostly with morbillivirus (Grattarola et al. 2023).

Brucella species replicate inside host macrophages and trophoblasts, but the full life cycle of *Brucella ceti,* the species most commonly found to infect cetaceans, is not yet well characterized (Grattarola et al. 2023). The transmission of *Brucella* in marine environments may occur through ingestion of feces-feeding fish and infestation with parasitic lungworms (Dawson et al. 2008; Scheafer et al. 2009). In other animals transmission occurs from contact with tissues and fluids after delivery of an aborted fetus, inhalation, or through a wound. Coastal water contamination, often from runoff and wastewater discharges, serves as an important vector for *Brucella* transmission, with water transport facilitating the spread of pathogens to areas where they are not indigenous (Stewart et al. 2008; Oates et al. 2012).

The presence and potential impact of *Brucella* infections in dolphin populations within the northern Gulf, and in the southeastern US more broadly, have certainly been a subject of interest, but with limited research compared to morbillivirus. While *Brucella* has been confirmed in various marine mammal species globally, its role in causing UMEs or large-scale die-offs in marine mammals, including dolphins, has not been conclusively established (Litz et al. 2014). However, because of its potential to cause late-term abortions and early neonatal death in marine mammals (McFee et al. 2020), *Brucella* has been hypothesized as a cause of some UMEs that are characterized by high numbers of stranded perinates (Litz et al. 2014). In a 2003-2007 study by Schaefer et al. (2009), 37% of dolphins in the Indian River Lagoon, on the Atlantic coast of Florida, were found to have high antibody titers against *Brucella*. In another study of dolphins stranded along the Alabama coast from 2015 to 2020, *Brucella* was detected in 18.4% of the 98 animals tested – potentially representing the baseline prevalence of this pathogen in the northern Gulf (Bloodgood et al. 2023).

A.1.2.1 Louisiana Stocks

Brucella was thought to play a role in the 2007 and 2008 UMEs that affected Texas and west Louisiana, including the Sabine and Calcasieu Lake stock regions, based on the high proportion of perinate strandings, but the definitive causes remain undetermined (Litz et al. 2014). All of the stranded dolphins analyzed for mitochondrial DNA in those UMEs were identified as being from the coastal ecotype, thus were likely from the Western Coastal Stock. This highlights a need for further investigation into *Brucella*'s role in disease outbreaks.

A.1.3 Other Causative Agents

A.1.3.1 Bacteria

Beyond *Brucella*, a number of other pathogenic bacteria have been found in wild dolphins. For example, *Erysipelothrix rhusiopathiae*, *Pasteurella multocida*, *Mannheimia haemolytica*, and *Staphylococcus aureus* are all bacterial species that have been documented to affect the health of bottlenose dolphins (Danil et al. 2023; Field 2024), but little information exists on the prevalence of these bacteria or their impact on dolphin populations in the northern Gulf or in Louisiana stocks specifically. None of these bacteria are thought to produce detrimental impacts to cetacean populations as severe as *Brucella*, but *Erysipelothrix rhusiopathiae*, for example can result in skin lesions and ulcerations that can result in acute septicemia (Lee et al. 2022).

Other bacteria that have been found to be associated with dolphins may cause subclinical health impacts, or may be non-pathogenic associates (i.e., part of their microbiome). A 2003–2007 study in Florida and South Carolina reported the first evidence of exposure to *Chlamydophila psittaci* in dolphins (Schaefer et al. 2009). While *C. psittaci* infections are generally subclinical, they can make dolphins more susceptible to other infections (Bossart et al. 2014, 2017). Taken together with the high seroprevalence (>80%) found in the Schaefer et al. (2009) study, *C. psittaci* has the potential to negatively impact dolphin populations but is unlikely to be the direct cause of large die-offs. Several studies have explored the bacteria species that are associated with presumably healthy dolphins, but that could pose risks to humans. Multiple studies of dolphins along the US Atlantic and Gulf coasts have found that species from the *Vibrio* genus (e.g., *V. alginolyticus*, *V. parahaemolyticus*, *V. vulnificus, and V. damsela*) are common, typically infiltrating through wounds in the skin, and some are associated with disease (Buck et al. 2006; Stewart et al. 2014). *Escherichia coli*, *Shewanella putrefaciens*, *Pseudomonas fluorescens/putida*, *Plesiomonas shigelloides, Aeromonas hydrophila*, *Clostridium perfringens, Bacillus* species, and *Staphylococcus* species are also common (Buck et al. 2006; Morris et al. 2011; Stewart et al. 2014).

Antibiotic resistance among bacteria, such as *E. coli*, commonly found in dolphins from various regions, poses additional challenges for disease management and treatment (Greig et al. 2007; Morris et al. 2011). Subsequent research by Schaefer in 2019 revealed that 88.2% of bacterial samples from dolphins in the Indian River Lagoon, Florida, from 2003–2015, showed resistance to at least one antibiotic, highlighting the challenge of treating dolphin bacterial infections as bacteria evolve.

Anthropogenic activities, such as sewage discharge, can introduce fecal coliforms into estuarine ecosystems, increasing the risk of *E. coli* (and other bacteria) colonization in dolphins (Schaefer et al. 2011).

A.1.3.2 Viruses

Dolphins have been found to be infected with a variety of papillomaviruses, herpesviruses, arboviruses, and poxviruses (Bossart et al. 2005; Schaefer et al. 2009; Van Bressem et al. 2009a; Bossart et al. 2017), but information is relatively limited about the prevalence and impact of most of these viruses in wild dolphin populations. Orogenital papillomatosis (OP) caused by a papillomavirus was found to be present in 12% of dolphins caught and released for health assessments between 2003 and 2007 in BSE populations along the US Atlantic coast (Bossart et al. 2017). Notably, however, several of the infected animals were re-examined between 2010 and 2015 and the infections had all resolved, leading researchers to conclude that OP is endemic to these populations and does not progress to carcinomas (Bossart et al. 2017). There were two cases of dolphins infected with a novel alphaherpesvirus–one in 1995 and one in 1999–in which both died as a result of the infection (Blanchard et al. 2001). Tattoo skin disease, caused by poxviruses, has been reported to affect from 0 to 71% of studied populations of bottlenose dolphins and its prevalence is speculated to be an indicator of aquatic conditions and/or overall dolphin health (Van Bressem et al. 2009a; Hart et al. 2012). In the northern Gulf, Hart et al. (2012) found tattoo-like skin lesions (likely indicative of poxvirus infections) to affect about 43% of photographed individuals in Sarasota Bay, FL, which was a significantly higher prevalence than in other populations from the southeastern US along the Atlantic coast. Whether the Sarasota population is representative of other populations in the Gulf with respect to the prevalence of poxviruses, is unknown. Similarly, little is known about the prevalence of the other viruses discussed above in the Louisiana dolphin stocks.

Schaefer et al. (2009) provided the first evidence of cetacean exposure to arboviruses (those transmitted via mosquitos, ticks, or other arthropods), which are responsible for several types of equine encephalitis and West Nile virus. West Nile Virus, from the genus *Flavivirus*, has been found in dolphins in the Indian River Lagoon, FL (Schaefer et al. 2009). The exposure pathway was likely via mosquitos or lice that passed on the infection from coastal birds, into the dolphin bloodstream, and ultimately into the neurological system and the brain. Abnormal behavior in free-swimming dolphins can be a sign of infection. Few cases have been seen to date, but the ranges of insects are changing as temperature patterns shift, potentially increasing the risk of infections in cetaceans.

Dolphins can also be infected with the highly pathogenic avian influenza (HPAI). They are likely exposed through inhalation of aerosolized virus from avian saliva, mucus, or feces, when in proximity to birds or bird colonies, or potentially if dolphins mouth/bite birds in the water (Murawski et al. 2024). Abnormal behavior in free-swimming dolphins can be a sign of infection, but molecular typing with swabs and tissues from nares, blowhole, lung, and brain can be diagnostic. However, the exact route of transmission from bird to dolphin is still uncertain.

A.1.3.3 Fungi

Paracoccidioidomycosis ceti and *Candida* species appear to be the most common fungal species impacting dolphins in the southeastern US. In a study spanning 2003 to 2013, multiple fungal species were isolated from wild dolphins in the Indian River Lagoon, Florida (IRL), and Charleston estuaries in South Carolina (CHS), with *Candida glabrata* and *Candida tropicalis* being the most prevalent (Morris et al. 2010; Reif et al. 2017). *Paracoccidioides ceti* was recently established as the etiologic agent of the fungal disease, *Paracoccidioidomycosis ceti* (PC), which affects the skin and subcutaneous tissues of dolphins (Bossart et al. 2019; Vilela et al. 2021). The condition was formerly thought to be a dolphin-variant of the human disease lacaziosis or lobomycosis which is caused by *Lacazia loboi*; older literature on dolphin diseases reference these conditions rather than PC (Migaki et al. 1971; Van Bressem et al. 2009a, 2009b; Murdoch et al. 2010; Bossart et al. 2015, 2017). *Paracoccidioidomycosis ceti* in dolphins is associated with compromised immunity, leading to opportunistic infections (Reif et al. 2009; Murdoch et al. 2010; Bossart et al. 2017), and severe infections have been associated with poor prognoses (Bossart et al. 2019). In the southeast US, PC has been identified in about 12% of the IRL population and was a substantial contributor to morbidity. Incidence was spatially concentrated within IRL, but was more rare in coastal dolphins (3.8%), and was not found in populations further north, suggesting it might be an emerging disease in this region and endemic in IRL (Murdoch et al. 2010; Bossart et al. 2017). *Paracoccidioidomycosis ceti* appears to be rare in the northern Gulf, with the only highlighted case in a free-ranging male bottlenose dolphin from a 1992 catch-and-release assessment in Matagorda Bay, Texas (under its former name, lobomycosis; Cowan 1993).

A.1.3.4 Protozoan Parasites

Compared to bacterial, viral, and fungal infections, research on parasitic infections is very rare in the literature for the southeastern US, but at least two parasites with potentially harmful impacts have been described in dolphins along the Atlantic coast of the US: *Toxoplasma gondii* and *Sarcocystis speeri*.

T. gondii is found worldwide, causing toxoplasmosis in humans, domestic animals, and wildlife, and is considered a threat to some at-risk marine mammals (Van Bressem et al. 2009a; Dubey et al. 2020). It was first described in dolphins in Florida in 1990 (Inskeep et al 1990). Clinical toxoplasmosis is often expressed following immunosuppression caused by morbillivirus infection and can result in lympho-adenitis, myocarditis, pneumonia, and encephalitis (Van Bressem et al. 2009a). No studies have been done on the prevalence of toxoplasmosis in Louisiana, but between 2003 and 2007, 9.3% and 15.2% of dolphins in IRL and CHS, respectively, were found to be positive for *T. gondii* (Schaefer et al. 2019). Despite the lack of published research on toxoplasmosis along the Louisiana coast, there is growing concern about the spread of this disease throughout coastal regions like Louisiana that are experiencing rapid development, flooding, and climate change (Van Wormer et al. 2016). Domestic and wild felids are the exclusive hosts of *Toxoplasma gondii* and they can shed hundreds of millions of oocysts following an infection, which can then be carried to local bays, sounds, and estuaries through freshwater runoff. Infection in dolphins and other marine mammals is an indication of environmental contamination and the risk to humans, other animals, and the ecosystem (Dubey et al. 2020).

Despite limited surveillance, studies have uncovered new infections in dolphins from *Sarcocystis speeri*, a protozoan parasite. Research in 2020 found *S. speeri* in a stranded adult male spotted dolphin on Pensacola Beach, Florida (Balik et al. 2023). The study concluded that *S. speeri* was the cause of death, likely after leading to immunosuppression and secondary fungal (*Aspergillus fumigatus*) pneumonia (Balik et al. 2023). This study hypothesized that dolphins might be aberrant intermediate hosts to the parasite, based on inflammation in the dolphin's central nervous system. Whether this parasite is a risk to dolphins in Louisiana is unclear, but surveillance for this parasite may be warranted.

A.1.3.5 Other

There are likely adverse health effects to dolphins as a result of exposure to a wide range of other diatoms, algae, and fungi that may not be strictly considered "infectious". For example, an orange film that has been documented on the skin of multiple dolphin species (including bottlenose dolphins) is thought to be from diatom species that infest the skin, and which has the potential to be a vector for pathogens or parasites (Maldini et al. 2010; Serres et al. 2023). Orange patches of skin have been documented on dolphins along the Florida Gulf coast, but at a very low prevalence (Hart et al. 2012). Evidence suggests that these films are less prevalent in warmer water (Maldini et al. 2010), which may suggest that Louisiana dolphins are less likely to be impacted. Other similar infections that are known to impact bottlenose dolphins have the potential to impact Louisiana stocks, but the paucity of information for these and other northern Gulf populations limits our ability to assess the risk from these other sources.

A.2 Oil & Gas Pollution

Dolphins can be exposed to oil and gas pollution from spills that occur during exploration and drilling, natural seeps, vessel leaks, and of course, catastrophic failures such as ships running aground (e.g., Exxon Valdez) or oil platform collapse (e.g., *Deepwater Horizon* [DWH]). Dolphins and other cetaceans do not actively avoid oil or other petroleum products (Smultea and Wursig 1995; Aichinger Dias et al. 2017), and when surface slicks are encountered, individuals can inhale, aspirate, ingest, and/or adsorb it (Takeshita et al. 2017). Given the toxicity of oil, these exposures can cause a variety of negative individual health effects that can lead to long-term population level impacts (Takeshita et al. 2017, 2021; Barron et al. 2020; Schwacke et al. 2022). Indirect effects from spills can also occur via impacts on the abundance, size, or nutritional value of their prey. Here we will focus primarily on the direct effects of oil exposure, and briefly, from oil and gas infrastructure.

The health effects of oil exposure on marine mammals can range from acute mortality to a wide range of sub-lethal (but often long-term) injuries. During the 1989 *Exxon Valdez* oil spill in Alaska, acute mortality of harbor seals and killer whales was thought to have been the result of inhalation of toxic fumes that caused brain lesions, stress, and disorientation (Peterson et al. 2003; Barron et al 2020). The two pods of killer whales affected by the Alaska spill suffered losses of 33 and 41% within the first year following the spill. One pod has experienced some recovery but has still not reached pre-spill numbers, and the other has experienced no recruitment since the spill and is expected to become extirpated (Matkin et al. 2008; Esler et al. 2018; Barron et al. 2020). Extensive research in the wake of the DWH oil spill significantly improved our understanding of the many sublethal effects that can arise from oil exposure in dolphins. From this work, we know that exposure to oil and dispersant can cause immune dysfunction, lung disease, impaired stress response, body mass loss, reproductive failure, and fetal distress (Schwacke et al. 2014a; Lane et al. 2015; White et al. 2016; Kellar et al 2017; Takeshita et al. 2021). Possible additional impacts include cardiac abnormalities and disease, liver damage, and dermal symptoms (Linnehan et al. 2021; Takeshita et al. 2021).

The DWH oil spill led to unprecedented oil contamination in the Gulf, with Barataria Bay facing extensive and sustained exposure. However, dolphins in other regions of the northern Gulf were also exposed and experienced negative impacts, albeit to a lesser extent than the BBES dolphins. Following the spill, similar adverse health impacts and an increase in stranding events were observed across the northern Gulf. Mississippi and Alabama had significantly higher stranding counts, especially in 2011, although Florida and Texas did not see an increase in stranding numbers (Venn-Watson 2015b; Carmichael et al. 2022). While not all strandings during the northern Gulf UME could be attributed to oil, the spatial and temporal overlap with the DWH spill suggests a substantial contribution from oil exposure (Venn-Watson et al. 2015b). Venn-Watson et al. (2015a) noted that non-perinatal carcasses examined during the UME exhibited a higher prevalence of bacterial pneumonia and thin adrenal cortices, consistent with oil exposure impacts. However, these pathological findings were less prevalent among dolphins in Mississippi and Alabama. Regarding perinatal strandings, the highest numbers were recorded in Mississippi and Alabama, particularly in 2011 and 2012 (Colegrove et al. 2016). These perinatal strandings were generally smaller in size compared to other areas in the northern Gulf, and *Brucella* infections were more common than in stranded perinates from Louisiana or other northern Gulf states (Colegrove et al. 2016). Although *Brucella* was not a primary cause of non-perinatal mortalities during this UME, the study suggests that immune impacts from oil exposure may have increased fetal susceptibility to infection, leading to reproductive losses (Colegrove et al. 2016). This hypothesis was supported by findings from Kellar et al. (2017), who estimated a reproductive success rate of 22.2% for dolphins in Mississippi. This rate, while slightly higher than that of BBES dolphins, was still 2-3 times lower than non-oiled populations. Furthermore, Mullin et al. (2017) noted that the annual survival rate for northern Gulf dolphins was low immediately following the DWH spill. Additionally, they documented a decrease in the abundance of MS dolphins between July 2011 and January 2012, aligning with the timing of the UME. Findings by Samuelson et al. (2021) also indicate a reduction in survival rate for MS dolphins following the DWH spill. While the population may be stable, returning to pre-spill abundance levels is expected to take considerable time (Samuelson et al. 2021).

With respect to the impact of oil and gas infrastructure, dolphins do not appear to avoid the physical structures and may be attracted to them when they serve as a type of artificial reef. Cremer et al. (2009) found that dolphins did not avoid oil platforms, and spent more time near platforms during night hours (compared to daylight). The authors also observed that dolphins near the platforms demonstrated territoriality/aggressive behavior when conspecifics approached at night. In another study, dolphins in the Adriatic Sea did not avoid oil and gas fields, and were more likely to be feeding (vs. traveling/socializing) when in proximity to platforms, likely a reflection of platforms acting as an attractant to prey (Triossi et al. 2012). Fish may aggregate around platforms as a result of the benthic organisms that attach themselves to platforms within days or weeks of installation (Sinclair 2011) or possibly from artificial lighting; these prey concentrations may, in turn, attract dolphins. Construction of oil and gas infrastructure has also not been found to impact short- or long-term abundance (Culloch et al. 2020). However, if dolphins are actively feeding near oil and gas platforms, their risk of exposure to small and large leaks increases.

There are approximately 4,000 active oil and gas structures in the northern Gulf (Vollmer & Rosel 2013). Beyond the DWH spill, routine leaks and smaller spills from these structures and associated operations are another risk factor for dolphins. Vollmer & Rosel (2013) report that according to a 2012 report (BOEM 2012), from 1996 to 2011 there were 190 reported spills larger than 2,100 gallons each in the Gulf. Increased failures associated with derelict/abandoned oil and gas infrastructure may pose an especially serious risk to dolphins. NOAA continues to evaluate/assess several cases of oil/gas releases in Louisiana waters and the potential impacts on dolphins, including the former Taylor Energy MC20 site off the coast of the Birdsfoot, the Lake Washington/Rattlesnake Bayou site in Barataria Bay, and the Lake Pelto site in Terrebonne Bay.

A.2.1 BBES Stock

Barataria Bay, home to nearly 2,000 bottlenose dolphins, experienced extensive and prolonged oiling as a result of the DWH oil spill (Garrison et al. 2020). Catch-and-release health assessments of live dolphins and necropsies of stranded animals in this region have illuminated acute and chronic impacts from exposure to oil. When compared with dolphin populations from non-oiled regions of the Gulf, or those stranded outside the oil spill impact zone, BBES dolphins exhibited a significantly higher prevalence of health issues. These included adrenal gland disease, lung disease, immune dysfunction, liver abnormalities, cardiac issues, and reproductive loss (Schwacke et al. 2014a; Smith et al. 2015, 2017, 2022; Linnehan et al. 2021; Takeshita et al. 2021).

Specifically, BBES dolphins experienced hypoadrenocorticism post-DWH spill, as evidenced by abnormally low cortisol and aldosterone levels during catch-and-release health assessments (Schwacke et al. 2014a; Smith et al. 2017). Additionally, those that died during the unusual mortality event immediately following the DWH spill displayed abnormally thin adrenal cortices (Venn-Watson et al. 2015a). Respiratory assessments revealed moderate to severe lung disease and alveolar interstitial syndrome (AIS) unique to BBES dolphins (Schwacke et al. 2014a; Smith et al. 2017, 2020, 2022). The prevalence of bacterial pneumonia and corresponding lung consolidation metabolites further confirmed these respiratory impacts (Venn-Watson et al. 2015a; Pasamontes et al. 2017). Sharp et al. (2023) found that dolphins with severe lung disease exhibited abnormal blood gas concentrations and capnographic results indicative of compromised oxygenation. Post-spill, increased T and B cell proliferation was observed and persisted up to seven years, without a link to infectious diseases, contaminants or biotoxins (DeGuise et al. 2017, 2021). Hepatobiliary disorders were also observed with several enzymes out of reference interval range (Schwacke et al. 2014a). Cardiovascular assessments by Linnehan et al. (2021) revealed atypical findings for bottlenose dolphins, such as thinner ventricular walls, smaller left atrial sizes, and valve abnormalities. These cardiovascular issues were likely linked to oil-related pulmonary impacts (Linnehan et al. 2021). Finally, reproductive challenges were pronounced, with only 20% of post-spill pregnancies resulting in viable calves, and over half of these cases were in dolphins with moderate to severe lung disease (Lane et al. 2015). Furthermore, a study by Kellar et al. (2017) showed the reproductive rate of BBES dolphins was less than one-third that of populations from non-oiled areas.

The health issues observed in BBES dolphins were atypical when compared to non-oiled dolphins but aligned with outcomes documented in other studies involving oil-exposed model organisms. Additionally, these researchers suggest multiple mechanistic links to oil exposure. Morey et al. (2022) reinforced these health findings through genomic studies, in which altered gene expression was observed in BBES dolphins, particularly for genes related to immunity, inflammation, reproductive failure, and pulmonary dysfunction. Similarly, Barratclough et al. (2024) found epigenetic age acceleration in BBES dolphins alive during the spill.

These health issues have significant implications for the survival and recovery of BBES dolphins. Venn-Watson et al. (2015) noted an increased frequency of strandings in areas that suffered extensive and prolonged oil exposure, suggesting a direct impact on dolphin mortality and population dynamics. An estimated 35% of the BBES population was killed as a result of the spill (DWH NRDAT 2016). Schwacke et al. (2017, 2022) estimated a loss of over 30,000 cetacean years for BBES dolphins, projecting a recovery period of 35-39 years to reach 95% of pre-spill population abundance in the absence of active restoration.

A.2.2 MSS Stock

Within the habitat range of the Mississippi Sound, Lake Borgne, Bay Boudreau Stock of common bottlenose dolphins, reports indicated light to trace amounts of oil along the majority of Mississippi's mainland coast, with varying degrees of oiling ranging from heavy to light observed on Mississippi's barrier islands (Michel et al. 2013). Based on one year of surveys, an estimated 22% of MSS dolphins were killed as a result of DWH (DWH NRDAT 2016). In terms of sublethal effects, health assessments conducted in 2013 found that MSS dolphins exhibited low serum cortisol levels and a higher-than-expected prevalence of moderate to severe lung disease, although these conditions were generally less severe than those observed in BBES dolphins (Smith et al. 2017). Given these health effects, approximately 24% additional MSS dolphins were given a prognosis of “guarded” or worse (i.e., grave, poor) above baselines (DWH NRDAT 2016). As described for BBES dolphins, epigenetic age acceleration was found in MSS and BBES dolphins alive during DWH (Barratclough et al. 2024). Combined data from BBES and MSS also showed 46% excess failed pregnancies above expected baseline failure rate (DWH MMIQT 2015). However, unlike BBES dolphins, MSS dolphins did not have poor body condition or significant clinicopathologic abnormalities (Smith et al. 2017), and the immunological impacts observed among BBES dolphins were largely absent in MS dolphins. However, it is important to note that samples from MSS were not collected until 2013, by which time the effects observed in BBES dolphins had been dampened with increasing years post-spill (Deguise et al. 2017).

A.2.3 MRD Stock

In the MRD stock, an estimated 59% of the population was killed as a result of DWH (DWH NRDAT 2016). Based on empirical data from BBES and MSS, excess reproductive failure in the MRD stock was estimated to be 46% (DWH NRDAT 2016).

A.2.4 TTBES

According to the latest NMFS stock assessment report, the most severe oiling in Louisiana from the *Deepwater Horizon* oil spill was concentrated at the tip of the Mississippi Delta, extending westward from the Mississippi River into Barataria, **Terrebonne, and Timbalier Bays**, as well as eastward from the river onto the Chandeleur Islands (Michel et al. 2013; Nixon et al. 2016). While health assessment studies were not conducted in the TTBES stock, both the barrier islands and marshes of Terrebonne and Timbalier Bays encountered oiling levels akin to those in Barataria Bay (Nixon et al. 2016). Thus, it is reasonable to infer that dolphins in these areas also suffered adverse health effects from this spill (Hayes et al. 2023). Stranding rates in TTBES were higher than baseline rates in the spring and summer following the spill, but attempts to distinguish mortalities resulting from a concurrent cold weather event and those due to the spill were unsuccessful, so no injury quantification was done for this stock.

A.2.5 NCS & WCS

Studies conducted for the natural resource damage assessment (NRDA) revealed that about 82% (95% CI: 55–100) of the Northern Coastal Stock of common bottlenose dolphins in the Gulf were exposed to oil and 38% were estimated to have been killed in the immediate aftermath of the spill (DWH NRDAT 2015). Among the surviving individuals, approximately 37% (95% CI: 17–53) of females experienced reproductive failure, while 30% (95% CI: 11–47) suffered adverse health effects (DWH MMIQT 2015). Additionally, a population model projected that the stock underwent a maximum reduction in population size of 50% (DWH MMIQT 2015). An estimated 23% of the WCS was exposed to oil, which resulted in about 1% mortality (DWH NRDAT 2016). Approximately 10% of pregnancies in females from the WCS failed as a result of the spill and (DWH NRDAT 2015).

A.3 Chemical Pollution

By one estimate, pollution was ranked as the second highest risk to marine mammals globally, with over 80% of the species impacted by various pollutants (Avila et al. 2018). Chemical pollution, in particular, has been linked to a wide range of individual-level health effects as well as population-level impacts (Desforges et al. 2016; Guo et al. 2021; Schaap et al. 2023). Dolphins and other marine mammals are susceptible to bioaccumulating these chemicals due to their position as apex predators, their long lifespan, lipid-rich tissues that are ready-stores for lipophilic contaminants, and lower capacity for degradation of these compounds (Bossart 2011).

Historically, research on chemical contaminants has primarily targeted persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs; flame retardants), dichlordiphenylthrichloroethanes (DDTs), dioxins, chlordanes (CHLs), hexachlorobenzene (HCB), dieldrin, and mirex (referred to as legacy pollutants). In recent years, the focus has expanded to include polyfluorinated compounds (PFCs), plasticizers, microplastics, and other emerging contaminants (e.g., pharmaceuticals, antiseptics). However, in one non-targeted study of all halogenated organic compounds (HOCs), the broad category that includes many of the above, researchers found 180 anthropogenic HOCs in the blubber of California dolphins (Shaul et al. 2015). Some of the detected compounds are derivatives of the chemicals listed above, but 74% of those detected are not currently monitored. Similarly, Mackintosh et al. (2016) identified six major DDT isomers in southern California dolphins, as well as 45 bioaccumulative DDT-related compounds that are not routinely monitored, suggesting that the list of contaminants of emerging concern (CECs) could grow in coming years and that the decreases in POPs detected in some dolphin populations (Kucklick et al. 2022) may not tell the whole story.

A.3.1 Persistent Organic Pollutants (POPs)

Despite long-term bans on many POPs, such as PCBs and DDTs, their lingering presence continues to pose a risk of long-term exposure to resident dolphin stocks (Weijs et al. 2020; Kucklick et al, 2022). Even though some compounds have been phased out, the volatility of certain pollutants like HCB allows for atmospheric transport, contributing to ongoing contamination. The legacy of pesticides like chlordane and dieldrin, possibly from their use in termite control, suggests a persistent contamination source (Kucklick et al. 2022). In some dolphin populations, levels of PCBs and PBDEs have increased over the last several decades even as inputs of these chemicals into the environment have presumably declined or ceased entirely (Weijs et al. 2020).

PCBs are generally the POP found in the highest concentrations in dolphins, ranging from 33.1 – 450 µg/g in dolphins sampled from various sites across the southeastern US (Kucklick et al. 2011). According to models by Hickie et al. (2013), approximately 66% of estuarine dolphins exposed to PCBs are likely to accumulate concentrations exceeding safe thresholds at some point in their lives, with males potentially having lifelong exposure above these thresholds. Females, on the other hand, may only exceed these thresholds during their first 12 years of life due to maternal offloading to their calves (Hickie et al. 2013). The consequences of toxic exposure are severe, including serious health problems, such as liver toxicity (Fair et al. 2013), hyperadrenocorticism, reproductive failure and dysfunction (Schwacke et al. 2002; Murphy et al. 2018), and endocrine disruption (Houde et al. 2006b; Schwacke et al. 2009; Murphy et al. 2018; Galligan et al. 2019; Trego et al. 2019). Desforges et al. (2016) found systemic suppression of immune function in marine mammals exposed to various contaminants, including PCBs, which they suggest is likely to contribute to an increase in infectious disease outbreaks. Beyond contributing to morbidity, exposure to chemical contaminants has been linked to mortality, evidenced by PCB detection in carcasses from unusual mortality events (Finklea et al. 2000) and negative impacts on calf survival (Schwacke et al. 2002; Kucklick et al. 2022). These effects on morbidity and mortality are significant enough to potentially impact overall growth rates of dolphin populations (Hall et al. 2005).

Numerous studies have demonstrated that sex and age significantly influence the concentrations of POPs detected in different tissues. For bioaccumulative compounds such as PCBs and DDTs, the concentrations observed in adult males and juvenile dolphins are generally higher than those in adult females (Berrow et al. 2002; Schwacke et al. 2002; Storelli and Marcotrigiano et al. 2003; Hansen et al. 2004; Wells et al. 2005; Litz et al. 2007; Balmer et al. 2011; Hickie et al. 2013; Balmer et al. 2015; Genov et al. 2019; Levandier et al. 2019; Zanuttini et al. 2019; Kucklick et al. 2022). This disparity is often attributed to maternal offloading, the process through which pregnant and nursing females transfer bioaccumulated compounds to their offspring (Schwacke et al. 2002; Hansen et al. 2004; Houde et al. 2005; Hickie et al. 2013; Genov et al. 2019; Noren et al. 2024). In calves, Hickie et al. (2013) used evidence-based modeling approaches to demonstrate that PCB exposure initially increases during nursing, then decreases post-weaning as body mass increases until five years of age. This leads to contaminant accumulation during the juvenile years, with subsequent diverging concentrations in males and females due to reproduction. Although this trend is typical for bioaccumulative compounds, some studies found that the degree of exposure can vary because some chemical compounds may be eliminated more efficiently (e.g., HCH vs. PCB; Noren et al. 2024).

Habitat is another significant risk factor for contaminant exposure among bottlenose dolphins, particularly for stocks occupying estuarine and nearshore waters due to their close proximity to various pollution sources (Adams et al. 2014). For example, dolphins inhabiting waters near St. Andrews Bay, FL experienced varying levels of POP exposure based on their habitat range. Dolphins in estuarine areas had significantly higher POP concentrations compared to their coastal counterparts, a disparity linked to pollution sources such as agricultural runoff and a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site, along with physical features such as tidal flushing and bay depth that may enhance contaminant persistence (Wilson et al. 2012; Balmer et al. 2019). Litz et al. (2007) also reported habitat-specific variations in POP exposure within Biscayne Bay, FL, associating higher PCB concentrations in dolphins from the bay’s northern region to local land use and proximity to a major tributary. The impact of habitat on POPs exposure was also demonstrated by studies of dolphins near Brunswick, GA, where those using the Turtle/Brunswick River Estuary (TBRE) had extremely high PCB concentrations attributed to a known pollutant discharge (Balmer et al. 2011). Urbanization and industrialization activities are also contributors to contaminant exposure risk, as evidenced by studies in Charleston, SC. Dolphins in this area, with its heavy industrial and wastewater outputs, showed higher concentrations of perfluorinated and polybrominated compounds compared to those in less-developed regions of the southeastern US (Houde et al. 2005; Houde et al. 2006a; Houde et al. 2009; Fair et al. 2012; Fair et al. 2013). Collectively, these studies emphasize the heightened vulnerability of estuarine bottlenose dolphin stocks to anthropogenic contaminants, particularly in areas marked by industrial activity, substantial tributary inflows, sewage discharge, proximity to pollution sources, and extensive agricultural practices (Berrow et al. 2002; Fair et al. 2007; Balmer et al. 2011; Fair et al. 2012; Wilson et al. 2012; Adams et al. 2014; Zanuttini et al. 2019).

A.3.2 Polyfluorinated Compounds (PFCs)

PFCs, encompassing a broad spectrum of individual chemicals, have been identified in bottlenose dolphins along the Atlantic Coast and Gulf, with PFOS (perfluorooctane sulfonate) and PFAS (per- and polyfluoroalkyl substances) being the most prevalent (Houde et al. 2005a, 2005b, 2006a; Fair et al. 2012, 2013; Lynch et al. 2019). In fact, Houde et al. (2006a) found PFOS in both zooplankton and fish, indicating widespread contamination in estuarine ecosystems. Studies have shown higher PFC concentrations in dolphins from more urbanized estuaries, such as Charleston, SC, yet the specific health implications remain unclear (Houde et al. 2005; Fair et al. 2013; Lynch et al. 2019). Nolen et al. (2024) proposed that PFC exposure could interfere with metabolism and may be linked to dyslipidemia, which could be associated with altered expression of CYP4A and PPAR genes (Kurtz et al. 2019). Lynch et al. (2019) reported a decline in PFC exposure in Charleston dolphins over time, attributing this trend to stricter regulation and reduced usage, or possibly the substitution of certain PFCs with less-known alternatives.

A.3.3 Contaminants of Emerging Concern (CECs)

Plastics and plasticizers are now considered CECs for estuarine dolphin populations. Traditionally, research on plastic exposure in marine mammals has focused on physical threats such as entanglement or ingestion of marine plastic debris (Baulch and Perry 2014; Fossi et al. 2018; NOAA 2014), but micro- and nano-plastics pose a significant threat due to their ability to penetrate cellular barriers (von Moos et al. 2012) and circulate through the bloodstream (Browne et al. 2008), potentially leading to inflammation (von Moos et al. 2012), oxidative stress (Bhuyan 2022), and other adverse health impacts (Bhuyan 2022; Yuan et al. 2022) documented in human and other studies. Recent findings have confirmed microplastic ingestion in both stranded dolphins in South Carolina (Battaglia et al. 2020) and free-ranging dolphins in Sarasota Bay, FL (Hart et al. 2022), in which microplastics were observed in all examined gastric samples. Merrill et al. (2023) found microplastics in 68% of sampled individuals across 12 species of marine mammals, and in four different tissues–confirming translocation of microplastics from ingestion to other parts of the body. This widespread presence of microplastics, along with their detection in prey fish (Hart et al. 2023), highlights the extent of estuarine pollution.

Additionally, chemicals in plastics and consumer products (e.g., phthalates, triclosan, alkylphenols) can leach into marine environments, raising concern about endocrine disruption (Chen et al. 2014) in exposed animals. Investigations in Sarasota Bay have shown a high prevalence of phthalate exposure (~75% of sampled dolphins; Hart et al. 2018; Dziobak et al. 2021) among dolphins, regardless of sex or age (Dziobak et al. 2021), with levels exceeding those in human reference populations (Hart et al. 2020). The health implications of this exposure remain unclear, although Dziobak et al. (2022) observed associations with free thyroxine (FT4). Triclosan, an antimicrobial agent added to many personal care products, was detected in approximately one-third of the dolphins sampled in Charleston, SC and the Indian River Lagoon, FL at levels similar to humans and indicative of bioaccumulation (Fair et al. 2009). Research on alkylphenol exposure in cetaceans reveals widespread contamination, particularly in species residing closer to the coast (Guo et al. 2023), highlighting the potential impact of urban proximity on exposure (Litz et al. 2007; Fossi et al. 2016; Dziobak et al, 2022).

A.3.4 BBES, MSS, & NCS

A.3.4.1 POPs

Several studies have compared POP levels in dolphins from multiple locations with the southeastern US including in Barataria Bay (BBES stock), Mississippi Sound (MSS stock), and in Chandeleur Sound (NCS). For dolphins in all three populations, the primary POPs identified were PCBs, DDTs, and CHLs, detected in both blubber (Schwacke et al. 2014a; Balmer et al. 2015) and plasma (Balmer et al. 2018) samples from male dolphins. Geometric mean concentrations of PCBs in BBES dolphin blubber from these studies ranged from 26.7 to 51.4 µg/g lipid (Schwacke et al. 2014a, Balmer et al. 2015), and in plasma was 26.9 µg/g lipid (Balmer et al. 2018). MSS dolphins exhibited higher levels of total plasma POPs than BBES dolphins (Balmer et al. 2018) with plasma PCB levels at 55.5 µg/g lipid. In the study measuring blubber POPs, the authors found no significant difference among the six sites that included BBES, MSS, and Chandeleur Sound (NCS) and three other sites in the northern Gulf (Balmer et al. 2015). Geometric mean concentrations of PCBs in the blubber of MSS dolphins was 43.4 µg/g lipid, and in Chandeleur Sound was 42.1 µg/g lipid (compared to BBES at 51.4 µg/g lipid; Balmer et al. 2015).

For DDTs, BBES dolphin blubber concentrations had a geometric mean ranging from 15.7 to 16.2 µg/g lipid (Schwacke et al. 2014a; Balmer et al. 2015) aligning with values measured in dolphins from MSS (21.9 µg/g lipid) and NCS (15.9 µg/g lipid) (Balmer et al. 2015), but lower than those in Sarasota Bay dolphins (Schwacke et al. 2014a). Plasma DDT concentrations in BBES dolphins (5.6 µg/g lipid) were also lower than those measured in Sarasota Bay (11.0 µg/g lipid) and in MSS (19.6 µg/g lipid), with the latter being significantly higher than in Sarasota (Balmer et al. 2018).

CHL concentrations in BBES dolphins varied between 3.7 and 10.4 µg/g (geometric mean) in blubber (Schwacke et al. 2014a; Balmer et al. 2015), with plasma concentrations reported at 1.5 µg/g (Balmer et al. 2018). Plasma values of CHLs in MSS dolphins (4.2 µg/g lipid) were higher than in BBES, but lower than in Sarasota Bay, FL (8.0 µg/g lipid). The levels in blubber of dolphins from BBES were similar to those observed in dolphins from the MSS and NCS stocks (3.9 and 4.1 µg/g lipid, respectively; Balmer et al. 2015), but slightly higher than blubber concentrations in dolphins from Florida populations (GM: 1.7-2.7 µg/g, Balmer et al. 2015, 2019).

The level of POPs in the plasma of MSS dolphins was higher than in BBES and, in some cases, in other northern Gulf populations (Balmer et al. 2018), but in the study measuring blubber POP concentrations, the levels in MSS and BBES were not significantly different (Balmer et al. 2015). It is not clear why the studies found different results, but one potential explanation is the difference between concentrations in blubber versus plasma. The lipid content of blubber can influence the relationship between POP measurements in blubber versus plasma within the same animal, with lower blubber lipid stores potentially allowing POPs and other lipophilic pollutants to redistribute into the blood (Yordy et al. 2010). However, Balmer et al. (2018) measured POPs in a subset of their samples and found that plasma and blubber concentrations were highly correlated and that the correlations did not differ by site. The implications of the potential differences are unclear and warrant more study.

In general, POPS concentrations in BBES, MSS, and NCS tended to be comparable to or lower than those observed at other northern Gulf sites and other coastal stocks outside of the Gulf (Balmer et al 2018). Despite these lower levels, it is important to highlight that those POPs concentrations were within ranges associated with health impacts (17 ug/g lipid; Litz et al. 2007; Balmer et al. 2015) and that there is still a significant background exposure (Schwacke et al. 2013; Balmer et al. 2015). The concentrations of some chemical classes are at levels that could increase their vulnerability to other stressors or hinder population recovery efforts. This concern is especially relevant for adult males and first-born calves. Research has shown that land use substantially influences exposure. Despite residing in a rural estuary, the planned freshwater diversion project may introduce upstream contaminants (legacy and emerging), potentially worsening the health outcomes and mortality of this already vulnerable population. Furthermore, Houde et al. (2009) note that natural sources of PBDEs and OH-PBDEs exist, suggesting that these chemicals could pose a risk to Louisiana dolphins, even in their rural habitat.

Despite a general decreasing, and then leveling off, trend in POP exposure over recent years in estuarine stocks of bottlenose dolphins (Kucklick et al. 2022), BBES dolphins may be vulnerable to both emerging and legacy contaminants, particularly following the freshwater diversion project.

A.3.4.2 PFCs

Dolphin exposure to PFCs in Louisiana has not been studied, but work done on other northern Gulf populations found lower plasma PFC levels in Florida than in populations on the US

Atlantic coast (Houde et al. 2005a, 2005b, 2006a). Whether dolphins from the BBES, MSS, NCS, and other Louisiana stocks also have lower levels of plasma PFCs is unclear.

A.3.4.3 CECs

While the specific effects of plastic and other CEC exposure on BBES, MSS, and NCS dolphins remains unknown, the ubiquity of marine plastic pollution and widespread use of chemical additives warrant future monitoring efforts. These contaminants could potentially intensify oil-associated health issues, thereby further limiting the population's recovery from the DWH spill. Although BBES dolphins inhabit a remote estuary, the freshwater diversion project may lead to the introduction of plastics and other CECs from the entire Mississippi River watershed, or worsen existing levels. Because plastics could be a source of additional xenobiotic exposure for BBES dolphins, future restoration efforts could target plastic and marine debris cleanup to avoid additional ecosystem damage.

A.4 Heavy Metal Pollution

Heavy metals are generally recognized as those metals on the periodic chart with heavy atomic weights that have toxic effects to living organisms. They are also sometimes called trace elements or non-essential trace elements because they are not required for biological functions and can replace essential trace elements within biological processes, thus disrupting vital functions (Delgado-Suarez et al. 2023). These elements include lead, cadmium, mercury, arsenic, barium, zinc, copper, manganese and iron (Ansari et al. 2004). Of these, mercury is the most widely studied in the marine environment, in part because other heavy metals have been found to be in lower concentrations in marine mammals (e.g., cadmium and lead; Delgado-Suarez et al. 2023). The heavy metals in marine systems derive from both natural and anthropogenic sources. For example, about a quarter of environmental mercury inputs come from vapor exhausted from coal-fired power plants and from small-scale gold mining, but a variety of other sources like volcanoes, weathering rock, and manufacturing processes also contribute (Chen and Driscol 2018; Obrist et al. 2018). In the US, the southeast has the highest wet deposition rate of mercury (Selin and Jacob 2008), and mercury has been found to be concentrated in some estuarine ecosystems (Reif et al. 2015). In the Gulf, mercury comes from atmospheric and river deposition as well as ocean currents from the Atlantic, with the latter estimated to be the largest source (Fitzgerald et al. 2007; Selin and Jacob 2008; Harris et al. 2012). Local point sources of mercury include coal-fired power stations, oil and gas operations, and hydrothermal vents (McCormack et al. 2022 and sources therein).

Dolphins are thought to be exposed to mercury and other heavy metals primarily through their prey (Hong et al. 2012), which accumulate it from both respiration and feeding. As long-lived, apex predators, dolphins bioaccumulate heavy metals and other pollutants found in their environment and are, thus, considered sentinel species whose health reflects the health of the ecosystems in which they live (Wells et al. 2004; Bossart 2011; Kershaw and Hall 2019; Griffin et al. 2024).

Exposure to mercury and other heavy metals is linked to a range of adverse health effects, including impacts on hematological, hepatic, renal, neurological, endocrine, and immunological systems. For example, studies of bottlenose dolphins in Charleston, SC and the Indian River Lagoon, FL, have shown positive correlations between mercury exposure and several biomarkers, such as ACTH, estradiol, gamma glutamyl transferase, lactic dehydrogenase, BUN, and segmented neutrophils. However, higher mercury concentrations were associated with reduced concentrations of some thyroid hormones, absolute lymphocytes, eosinophils, and platelets (Schaefer et al. 2011; Reif et al. 2015). In contrast, a study conducted by Woshner et al. (2008) found that blood and skin concentrations of total and methylmercury were not associated with any hematological parameters except for mean corpuscular hemoglobin. Immunological effects of heavy metal exposure were explored in an *in vitro* study by Pellisso et al. (2008), which demonstrated impacts on cellular viability, lymphocyte proliferation, phagocytosis, and apoptosis, particularly for mercury, cadmium, and aluminum. Additionally, neurodegenerative effects of methylmercury were investigated by Davis et al. (2021), who suggested that the brain acts as a ‘toxic reservoir’ for methylmercury and BMAA, as evidenced by their presence in brain tissue. Importantly, levels of methylmercury observed were comparable to those in humans who have experienced neuronal loss and cerebellar gliosis (Davis et al. 2021). Desforges et al. (2016) found systemic suppression of immune function in marine mammals exposed to various contaminants, including mercury and cadmium, which they suggest is likely to lead to increases in infectious disease outbreaks.

Dolphin exposure to heavy metals and trace elements has been quantified using a variety of tissue types including liver (Beck et al. 1997; Malcolm et al. 2023; Storelli and Marcotrigiano 2000; Pompe-Gotal et al. 2009; Shoham-Frider et al. 2009; Page-Karjian et al. 2020), skin and blood (Schaefer et al. 2011), blubber (Parsons and Chan 2001), brain (Malcolm et al. 2023), muscle and kidney (Pompe-Gotal et al. 2009; Shoham-Frider et al. 2009). While concentrations and detection of specific metals and elements varied across tissue types (Malcolm et al. 2023; Parsons and Chan 2001; Durden et al. 2007; Pompe-Gotal et al. 2009; Shoham-Frider et al. 2009; Stavros et al. 2011), the highest concentrations were observed in liver samples, suggesting it as a crucial tissue for assessing exposure to these contaminants. Age appears to significantly influence individual exposure, with older dolphins having higher concentrations of metals such as mercury, selenium, copper, cadmium, and lead (Beck et al. 1997; Stavros et al. 2007; Durden et al. 2007; Pompe-Gotal et al. 2009; Schaefer et al. 2011; Stavros et al. 2011; Page-Karjian et al. 2020). Sex, however, does not seem to significantly impact exposure, although one study noted higher concentrations of selenium in adult females (Beck et al. 1997), but this finding was not widely observed for other elements such as mercury (Durden et al. 2007; Reif et al. 2017).

Exposure to heavy metals and other trace elements also varies geographically and across populations (Malcolm et al. 2023; Stavros et al. 2007; Stavros et al. 2011; Reif et al. 2015; Reif et al. 2017; Barragan-Barrera et al. 2019; McCormack et al. 2020a, 2020b, 2022). In fact, Stavros et al. (2007) proposed that the distinct profile of these contaminants within dolphin tissues could be used to differentiate dolphin stocks. For example, dolphins in Florida, particularly in the Indian River Lagoon and the Everglades, have higher mercury concentrations than other southeastern US locations (Stavros et al. 2007; Stavros et al. 2011; Reif et al. 2015; Damseaux et al. 2017; Reif et al. 2017; Page-Karjian et al. 2020). Even within the Indian River Lagoon, mercury exposure varies, with dolphins in the northern areas showing higher exposure than those sampled in the southern portion of the lagoon (Reif et al. 2017). Factors influencing these population differences may include proximity to pollution sources such as industrial waste (Storelli and Marcotrigiano 2000), regional atmospheric deposition differences due to rainfall and currents (Stavros et al. 2007), natural features such as mangrove habitats (Damseaux et al. 2017; Barragan-Barrera et al. 2019), and dietary habits, particularly prey selection (Barragan-Barrera et al. 2019). Despite documented high concentrations, overall mercury exposure appears to be declining over time (Reif et al. 2017).

Recently, a study by Griffin et al. (2024) explored mercury contamination in BSE stocks at multiple sites along the US Atlantic and Gulf coasts. Mercury concentrations measured in skin samples were highest in dolphins from sites in the northern Gulf (Florida), and lowest at two sites along the Atlantic coast (Charleston, SC and Skidaway River Estuary, GA; Griffin et al. 2024). Similar to other studies previously discussed, the authors attribute this spatial variation in contamination to anthropogenic and natural factors. Although specific point sources of mercury contamination were not identified for most sites, dolphins sampled in areas with less industrial and municipal discharge, greater tidal flushing or freshwater input, and varied saltmarsh plant composition had lower mercury concentrations (Griffin et al. 2024).

A.4.1 Louisiana Stocks

To our knowledge, only one study (with multiple publications) has measured the level of heavy metals in Louisiana dolphins (McCormack et al. 2020a, 2020b, 2022), but multiple studies have assessed exposure to both essential and contaminant metals in dolphin populations in the northern Gulf more broadly. The dolphins sampled in Louisiana were dead animals stranded during the 2010-2014 UME (Litz et al. 2014) and were not identified to stock, but the map of stranding sample site shows broad coverage of the Louisiana coast from Calcasieu Lake to Mississippi Sound, with the heaviest concentrations of samples appearing to come from TTBES, BBES, MRD, and MSS stock areas (McCormack et al. 2020a). Below we describe all the findings from the Gulf, including from the samples collected in Louisiana.

Together, the northern Gulf studies examined both stranded (Kuehl and Haebler 1995; Meador et al. 1998; McCormack et al. 2020a, 2020b, 2022) and live (Bryan et al. 2007; Griffin et al. 2024) dolphins. Samples from stranded dolphins, which included liver, kidney, brain, blubber, lung, and skin, were analyzed for multiple elements (aluminum, arsenic, chromium, cadmium, copper, manganese, mercury, nickel, lead, selenium, zinc; Kuehl and Haebler 1995; Meador et al. 1998; McCormack et al. 2020a, 2020b, 2022). Key findings highlighted positive correlations between mercury (Hg) concentrations and age (Kuehl and Haebler 1995; Meador et al. 1999; McCormack et al. 2020a) and a strong association between Hg and selenium (Se) (Kuehl and Haebler 1995; Meador et al. 1998). The studies also demonstrated variations in metal concentrations by tissue type (Meador et al. 1998; McCormack et al. 2020a) and sampling location (Meador et al. 1998; McCormack et al. 2022; Griffin et al. 2024). For example, total mercury (THg) in various tissues collected from stranded dolphins in Louisiana were lower than dolphins sampled along the Florida panhandle and Sarasota Bay (McCormack et al. 2020a, 2020b, 2022). Additionally, Meador et al. (1998) observed higher concentrations of Hg in dolphins from Florida than Texas, but higher lead (Pb) levels were detected in Texas, particularly among older dolphins. Compared to dolphins sampled along the Atlantic coast, both Texas and Florida Gulf dolphins had lower Pb concentrations, aligning with earlier findings by Kuehl and Haebler (1995) in the Gulf (Meador et al. 1998). As noted above, Griffin et al. (2024) found higher levels of mercury in skin samples taken from dolphins from the Florida panhandle and Everglades compared to dolphins sampled from South Carolina and Georgia. Bryan et al. (2007) examined skin and blood samples from live dolphins during capture-release health assessments to identify less-invasive tissues suitable for detecting heavy metal exposure. Their research revealed that, except for copper (Cu), trace element concentrations were 2-25x higher in skin than blood, suggesting that skin may be a more reliable indicator of exposure. However, concentrations in blood and skin were generally lower than those in other tissues from stranded dolphins, but THg and methylmercury (MeHg) levels in blood and skin were still above EPA thresholds (Bryan et al. 2007). Bryan et al. (2007) suggested that dolphins might be adapted to manage exposure levels that are toxic to other mammals. Consistent with other research, their study also provided evidence that Hg concentrations increase with age and are higher in females (Bryan et al. 2007).

Currently, the population-level impacts of heavy metal accumulation in dolphins are unknown.

A.5 Algal Blooms

Harmful algal blooms (HABs) are caused by the growth of dense colonies of phytoplanktonic algae species that release biotoxins into the water that bioaccumulate in species at higher trophic levels. Anderson et al. (2021) found an increasing trend in HAB events between 1999 and 2019, some of which could be attributed to increasing awareness and monitoring, but some is likely a result of warming ocean temperatures, and increasing nutrient inputs into marine environments. HAB-associated toxins are harmful, and even lethal, to a wide variety of organisms, including humans, dolphins, sea birds, and marine mammals, and have been associated with large fish kills (Kreuder et al 2002; Magana et al. 2003; Anderson et al. 2021). Of the approximately 5,000 species of extant phytoplankton worldwide, about 300 can periodically proliferate enough to cause discoloration of the water (i.e., red tides), but only about 80 species produce the biotoxins that negatively affect other species (Hallegraeff 2003).

In marine mammals, many studies suggest that oral ingestion and diet are critical pathways for exposure to HAB toxins (Twiner et al. 2012). This hypothesis is supported by the high concentrations of these toxins found in organs and tissues associated with digestion and metabolism, such as the liver, stomach contents, and feces (Fire et al. 2008, 2011, 2015, 2020b, 2021a, 2021b; Twiner et al. 2012). Maternal, fetal, and neonatal exposure has also been demonstrated (Fire et al. 2015). Additionally, these toxins have been detected in prey fish, further corroborating dietary exposure as a significant risk factor (Twiner et al. 2011). A study by

Danil et al. (2021) observed variability in toxin concentrations among different marine mammal species, which the authors attributed to variations in diet (i.e., a more diverse diet increases the likelihood of consuming contaminated fish) and feeding strategies (i.e., differences between filter feeders and those that consume whole fish).

Exposure to biotoxins can also vary by season and location (Brown et al. 2018; Davis et al. 2019, 2021; Fire et al. 2020a, 2021b; Nash et al. 2017), likely due to environmental conditions conducive to algal proliferation. Nash et al. (2017) noted seasonal fluctuations in stranding events linked to *Pseudo-nitzschia* blooms, possibly related to chlorophyll activity and atmospheric dust. In New England, a clear temporal pattern in the exposure of marine mammals to domoic acid and saxitoxin (algal toxins) was observed, with peak levels from July to October, attributed to factors that support algal growth, such as increased daylight and nutrient abundance (Fire et al. 2021b).

Recently, a group of neurotoxins typically associated with freshwater algae has emerged as a potential health threat to dolphin populations. These toxins, including microcystins, nodularines, and beta-N-methylamino-L-alanine (BMAA), have been detected in dolphin samples from the Atlantic coast of Florida and New England (Brown et al. 2018; Davis et al. 2019, 2021). In fact, Davis et al. (2019) found that BMAA concentrations in bottlenose dolphins from Florida were three times higher than concentrations in common dolphins from New England. Additionally, BMAA concentrations in some dolphins exceeded levels detected in humans diagnosed with dementia and ALS (Davis et al. 2019). Although these toxins originate from freshwater cyanobacteria, their emergence in estuarine environments is concerning. Additionally, these neurotoxins are particularly resilient, capable of withstanding temperature fluctuations, pH changes, and low light – allowing them to persist in the environment (Brown et al. 2018; Davis et al. 2019, 2021).

In dolphins, HAB toxins can be a significant stressor that can lead to a number of negative health effects (Schwacke et al. 2010; Litz et al. 2014; Fire et al. 2015, 2020a). Investigating the underlying health conditions associated with biotoxin exposure during these events can be complicated by carcass decomposition (Fire et al. 2011). Despite these challenges, research has revealed links to immune and neurological impacts. For example, domoic acid exposure has been associated with eosinophilia (Schwacke et al. 2010; Twiner et al. 2011), and BMAA exposure has been associated with neuropathologies similar to those seen in human Alzheimer's disease. Additionally, respiratory symptoms, including increased chuffing behavior, have been observed in dolphins exposed to *K. brevis* blooms (Fire et al. 2020c).

HABs have also been suggested as the cause of mortality for dolphin and other marine mammal species populations (Schwacke et al. 2010; Litz et al. 2014; Fire et al. 2015, 2020a). For instance, during a UME in the Indian River Lagoon, FL, 80% of stranded dolphins tested positive for brevetoxin during a *Karenia brevis* bloom, and 57% positive for saxitoxin during an *Alexandrium* bloom. Additionally, brevetoxin-exposed dolphins had a higher probability of concurrent saxitoxin exposure (Fire et al. 2020a). Similarly, exposure to multiple algal toxins (saxitoxin and domoic acid) were observed among several marine mammal species that stranded during a UME in New England (Fire et al. 2021b). In southern California, sampling of

19 stranded cetacean species also revealed concurrent exposure to multiple toxins including domoic acid, saxitoxin, and okadaic acid (Danil et al. 2021). Although some toxin exposures were associated with algal blooms, some positive detections were noted in the absence of a bloom (Danil et al. 2021). Although these studies were not conducted in the northern Gulf, they illustrate the susceptibility of marine mammals to multiple concurrent toxins, underline the risk of HAB-related mortality, and highlight the possibility of chronic exposure even in the absence of active blooms.

Within the northern Gulf, HABs are more sporadic than on the west or east coasts of the US, but are nonetheless a persistent problem (Anderson et al. 2021) and are often linked to bottlenose dolphin UMEs (Litz et al. 2014; Fire et al. 2015, 2020b) due to direct exposure to the toxins and/or the depletion of prey. HAB toxins implicated in UMEs in the Gulf include brevetoxin (Fire et al. 2011, 2015, 2020b; Twiner et al. 2012), domoic acid (Schwacke et al. 2010; Fire et al. 2011; Twiner et al. 2012), and okadaic acid (produced by *Dinophysis* spp. and *Prorocentrum* spp.; Fire et al. 2011). Samples collected from stranded dolphins during multiple UMEs in the Florida panhandle (1999-2006, Twiner et al. 2012) indicate that dolphins can be positive for a single or multiple, concurrent toxins (Fire et al. 2011, 2020), depending on bloom/algal occurrence. Although the HAB-linked biotoxins cannot always be definitively identified as the cause of large-scale mortality in marine mammals or their prey, often, UME mortalities correspond spatially and temporally with local algal blooms (Danil et al. 2021; de la Riva et al. 2009; Fire et al, 2011, 2020a; Twiner et al. 2012).

Litz et al. (2014) provides a historical overview of bottlenose dolphin UMEs in the northern Gulf and Sarasota Bay (SSB) from 1990 to 2009. Brevetoxin was declared a contributory cause of death for several cases in a 1991 Sarasota Bay UME. In 1996, a red tide occurred in Mississippi, leading to increased strandings following the peak of the bloom, but no brevetoxin testing was conducted. Three UMEs in the Florida panhandle were attributed to brevetoxicosis (1999-2000; 2004; 2005-2006) due to the prevalence of brevetoxin detected in samples. Along the central west coast of Florida, half of samples collected during a 2005-2006 UME tested positive for brevetoxin, and high brevetoxin concentrations were linked to a bloom in the area. In 2007, samples collected during UMEs in Texas and Louisiana were negative for saxitoxin and brevetoxin, but some were positive for domoic acid, and *Pseudo-nitzschia* was detected in water samples. Finally, biotoxin sampling was not extensively conducted for dolphins involved in a 2008 UME event in Texas, but there were positive samples for brevetoxin, domoic acid, and saxitoxin. Additionally, the timing of the UME overlapped spatially and temporally with phytoplankton blooms (Litz et al. 2014).

In areas such as Sarasota Bay, some algal blooms are frequent occurrences, resulting in a chronic, ambient exposure source for resident dolphins. In fact, studies have demonstrated detectable concentrations of brevetoxin even in the absence of a bloom (Fire et al. 2007, 2020b; Twiner et al. 2011). These baseline concentrations significantly increase during a bloom event (Fire et al. 2015, 2021a), often peaking just prior to death (Fire et al. 2007). Additionally, despite having high toxin concentrations, exposed dolphins may not be symptomatic of toxicosis (Fire et al. 2008), suggesting the utility of continuous monitoring. Domoic acid has also been detected in samples from Sarasota Bay dolphins, and although *K. brevis* blooms are frequent occurrences in this region, Twiner et al. (2011) found evidence that dolphins were exposed more often to domoic acid than brevetoxin. In fact, similar to brevetoxin, domoic acid exposure was observed in the absence of *Pseudo-nitzschia* blooms, suggesting a ‘cryptic’ source of domoic acid (Twiner et al. 2011).

A.5.1 Louisiana Stocks

In Louisiana, there have been no UMEs with strong evidence of HAB-related exposures (Litz et al. 2014). Concern over the relatively recent detection of freshwater-associated neurotoxins in marine systems is heightened by salinity fluctuations due to climate change and the potential increase in freshwater into Louisiana waters from new Mississippi River diversion projects, which could introduce these toxins more broadly into coastal and estuarine ecosystems. Thus, these neurotoxins could be a new threat to the health of BBES dolphins.

While HABs may not currently represent a significant threat to Louisiana dolphins, future shifts in climate and salinity are expected to foster conditions favorable for algal growth (Hallegraeff et al. 2021). Such changes may expose Louisiana dolphins to new freshwater neurotoxins such as BMAA, microcystin, and nodularin (Brown et al. 2018; Davis et al. 2021). Considering the neurodegenerative effects associated with some algal toxins, it seems plausible that dolphins exposed to these neurotoxins would be more susceptible to trauma, including interactions with vessels and fisheries (Danil et al. 2021). Furthermore, exposure to HABs can compromise immune function, increasing vulnerability to infectious diseases and posing additional challenges to the recovery of the BBES and other Louisiana stocks.

A.6 Hypoxia

Hypoxia occurs when the dissolved oxygen levels in an aquatic environment significantly decrease from typical levels (Phillips and Rosel 2014). Water containing less than 2 mg/l of dissolved oxygen is categorized as hypoxic (Rabalais and Turner 2001). This is below the critical thresholds for the survival of many aerobic organisms. Two primary factors contribute to hypoxia, stratification and high levels of organic decomposition (Rabalais and Turner 2001). Stratification of the water column resulting from a density barrier caused by temperature or salinity (or both) creates a separation between the bottom layer and the surface layer, which hinders the oxygen replenishment of lower layers (Rabalais et al. 2009). The process of organic matter decomposition requires oxygen, thus depleting the amount of dissolved oxygen in the water. In the absence of strong stratification, moderate levels of decomposition will generally not result in hypoxic conditions, but when high levels of nutrient input enhance the growth of planktonic algae (i.e., eutrophication), and that growth exceeds consumption by planktivores, the excess algae die, sink to the bottom, and are decomposed by the microbial community – a process that consumes dissolved oxygen (Counsell 2013).

The phenomenon of hypoxia in coastal waters has been increasing worldwide (Rabalais et al. 2009). One of the most prominent causes of hypoxia is human-caused nutrient enrichment (He & Xu 2015). Freshwater inputs from rivers often bring heavy loads of nutrients, including nitrogen and phosphorus from upstream fertilizer use (Rabalais et al. 2009). Beyond freshwater discharge and its nutrient deposits, hypoxia can also be exacerbated by increasing temperatures, posing a management challenge both now and in the future as temperatures are projected to continue to increase with climate change (Rabalais and Turner 2019).

The impacts of hypoxia can be profound, resulting in immediate or prolonged alterations in biological communities, trophic interactions, biogeochemical processes, and habitats (Jarvis et al. 2021). Because only bottom waters tend to be hypoxic, primarily benthic and sessile communities experience the direct impacts. Nonetheless, numerous consequences can occur for more pelagic and benthopelagic species, such as displacement, disruption of life cycles, habitat compression, increased susceptibility to predation, increased competition, and alterations to food webs (Glaspie et al. 2019). Prolonged hypoxia can trigger mortality of benthic organisms and decreased benthic diversity, but ecosystem level consequences of hypoxia on Louisiana's bays, sounds, and estuaries have not been detected. The potential negative impacts of hypoxia occur within a matrix of other stressors and may be partially offset by increases to fisheries productivity associated with eutrophication (Chesney et al. 2000; de Mutsert et al. 2016).

For bottlenose dolphins, hypoxia impacts are expected to be relatively less severe, and primarily indirect. Dolphins have the ability to actively avoid hypoxic areas–a behavioral response that is only available for swimming organisms (Rabalais et al. 2002). Much of the impact on dolphins will be dependent on the response of their target prey to low dissolved oxygen conditions. Displacement of fishes and other nekton from hypoxia occurs horizontally and vertically. Nekton are displaced horizontally and aggregate along the edges of the hypoxic zone (Craig et al. 2001). Nekton, including demersal and pelagic species, also migrate vertically into the well oxygenated waters that overlay hypoxic waters (Reeves et al. 2018; Carver et al. 2025). From a fish eye's point of view, the water column becomes vertically compressed and dense aggregations of nekton persist in the well oxygenated waters overlaying the hypoxic zone throughout the summer (Reeves et al. 2018; Carver et al. 2025). If enough prey remains in the area to sustain them, a dolphin population may be mostly unaffected by hypoxia or their foraging efficiency may even increase if they are able to exploit aggregations of nekton where they are vertically compressed (e.g., Prince and Goodyear 2006; Hazen et al. 2009). If, however, dolphins are forced to find other food sources or follow their prey, they may experience increased conspecific competition, predation, or an increase in the frequency of interaction between fisheries operations that may themselves be shifting their operations in response to hypoxic conditions (Craig et al. 2001). Very few studies have measured the effect of hypoxic zones on dolphins, but one study from China found that a decline in dolphin sightings in an area experiencing habitat loss/degradation occurred faster in hypoxic areas compared to adjacent non-hypoxia affected areas (Guo et al. 2022).

A.6.1 Louisiana Stocks

The largest zone of oxygen-depleted coastal waters in the United States and the entire western Atlantic Ocean, and the second largest human-caused hypoxic zone in the world, is in the northern Gulf over the Louisiana/Texas continental shelf (Rabalais and Turner 2001, 2019; Rabalais et al. 2009). Hypoxic bottom waters of the zone are typically found at depths ranging from 5 to 30 meters, and distances of 5 to 30 kilometers from shore (Craig et al. 2001). However, hypoxic instances have been documented at depths of up to 60 meters and distances as far as 130 kilometers from shore. This zone expands westward from the Mississippi River birdfoot delta and spans across the Louisiana shelf to the upper Texas coast (Rabalais et al. 2002) and can reach 23,000 km^2 (Rabalais and Turner 2019). The zone is seasonal, reaching its peak intensity from June to August, but has also been observed to begin as early as February and extend as late as October (Craig et al. 2001). It is the result of freshwater outflow from the Mississippi River system, which creates strong water-column stratification and brings a heavy nitrogen and phosphorus load (Turner and Rabalais 1994; Rabalais et al. 2007a; Rabalais and Turner 2019). The river system now delivers two to three times the nutrient load than it did in the 1950's, a trend that can be traced to increasing amounts of phosphorus and nitrogen from the growing use of fertilizer, starting in the 1950s (Rabalais et al. 2002, 2009). However, temporary reductions in the level of nitrogen loading over time have not resulted in a reduction in the areal or temporal extent of the northern Gulf hypoxic zone (Kemp et al. 2009). This lack of recovery from hypoxic conditions with decreased nitrogen input has been attributed to non-linear system responses, time-lags, and a regime shift in the ecological communities, something that has been documented in other coastal hypoxic regions as well (Kemp et al. 2009).

It's important to note that previous hypoxia research has not focused on dolphin stocks. With respect to the nine Louisiana dolphin stocks considered here, the seasonal northern Gulf hypoxic zone is likely to primarily affect the Northern and Western coastal stocks (NCS & WCS), but more periodic hypoxic conditions have been documented within five of the seven BSE stocks, including Barataria Bay, Terrebonne/Timbalier Bays, Sabine Lake, Calcasieu Lake, and Vermilion Bay.

A.6.1.1 BBES & TTBES Stocks

Barataria and Terrebonne/Timbalier Bays were the locations of the first documented coastal hypoxia events in the northern Gulf in the early 1970s, as part of environmental assessments related to oil production and transportation studies (Ward et al. 1979; Hanifen et al. 1997; Rabalais and Turner 2001). In 2008, Hurricane Gustav in the Gulf was another cause of hypoxia (Eddlemon and Boopathy 2013). The hurricane brought in high levels of organic carbon, which triggered a large decrease in oxygen levels, and resulted in a mass fish die-off within the upper Barataria Bay Estuary. Unfortunately, we know little about the effect of these hypoxic events on dolphins.

A.6.1.2 Vermilion, Calcasieu Lake, & Sabine Lake Stocks

A long-term study by He and Xu (2015) aggregated data from four significant Louisiana coastal rivers: the Sabine, Calcasieu, Mermentau, and Vermilion. The study used river discharge and nutrient concentration data spanning 1980–2009 to estimate the daily, monthly, and annual inflows of nitrate and nitrite nitrogen ($NO_3 + NO_2$), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) into the northern Gulf. The study found that the Mermentau and Vermilion Rivers, which drain heavily agricultural regions, exhibited notably higher concentrations of NO3 + NO_2, TKN, and TP compared to the Sabine and Calcasieu Rivers, which drain from forest-pasture-dominated areas. Another study attributed significant fish mortality events in Sabine Lake to hypoxia (Thronson and Quigg 2008; Phillips and Rosel 2014). Approximately 1.1 million fish deaths occurred between 1990 and 1994, and 6.1 million fish deaths occurred between 1995 and 1999.

A.6.1.3 MSS, WCS, & NCS

The effects of these specific instances of hypoxia on Louisiana dolphins is unknown and very few studies have documented the effects of hypoxic conditions on dolphins in general, but one study focused on the effect of the northern Gulf hypoxic zone on dolphins (Counsell 2013). Based on maps and descriptions of their study area, their surveys likely included dolphins from the MSS stock and the northern and western coastal stocks. They found that dolphins were more commonly sighted at the edge of hypoxic areas where bottom dissolved oxygen levels were rapidly changing, but that dissolved oxygen levels alone were not good predictors of dolphin presence. This lends support to the idea that hypoxic conditions indirectly affect NCS and WCS dolphin habitat use. Since many other factors also contributed to where dolphins were sighted in this study, it is unclear whether the same pattern would hold for the BSE stocks.

A.7 Extreme Weather Events

Extreme weather events, most prominently in the form of seasonal tropical systems, but also including heatwaves and severe winter weather resulting in cold snaps (Miller 1992; Wang et al. 2023), can inflict disastrous impacts on the Gulf coast, including coastal Louisiana. Additionally, severe weather beyond the Gulf can have knock-on effects along the Gulf coast in the form of increased freshwater input through rivers that drain into the Gulf (Carmichael et al. 2012) as well as coastal erosion and subsequent land loss (Wang et al. 2023). Extreme weather events can bring catastrophic amounts of rainfall, strong winds, storm surge–occasionally impacting areas miles from the coast–freezing temperatures, sleet, snow, and ice, severe thunderstorms, up to and including tornados. These can subsequently alter physical oceanic properties, including temperature, salinity, dissolved oxygen, turbidity, pH (Fury and Harrison 2011; Ortega-Ortiz et al. 2019).

Taken together, extreme weather events have been documented to negatively impact dolphins in a wide range of ways. For example, they may experience temporary or permanent displacement in response to unfavorable conditions (Fury and Harrison 2011; Ortega-Ortiz et al. 2019; Fazioli and Mintzer 2020). Changes in prey distribution or altered habitat can result in changes in their habitat use and foraging patterns (Fury and Harrison 2011; Fandel et al. 2020; Fazioli and Mintzer 2020). Such shifts can lead to secondary effects such as increased predation risk (Fearnbach et al. 2011). Skin lesions and other negative health impacts can result from exposure to lower salinity (Fazioli and Mintzer 2020; McClain et al. 2020; Takeshita et al. 2021), lower dissolved oxygen, increased turbidity, and decreased pH (Fury and Harrison

2011). Whether due to these physical oceanic changes, reductions in prey abundance (e.g., due to mortality from a cold snap or heat wave), direct mortality, injury, or other factors, extreme weather events have been shown to lower survival in dolphin and other marine mammals (Miller 1992; Langtimm & Beck 2003; Wild et al. 2019; Mann et al. 2021; Coxon et al. 2022). Some of these mortalities occur as a result of increased strandings (Marsh 1989; Mignucci-Giannoni et al. 1999; Miller 1992; Carmichael et al. 2012) or entrapment in unsuitable habitat as a result of storm-surge (Rosel and Watts 2008). Weather-related increases in mortality and emigration have been shown to result in changes to dolphin social structure (Elliser & Herzing 2011). A long-term reduction in reproductive success in dolphins following a marine heatwave was documented in Australia, and was likely due to severely impacted habitat and mass mortality of fish and invertebrates (Wild et al. 2019).

The type and size of a weather event as well as the resulting changes in habitat structure, prey distribution and availability, and human-behavior can change the direction and degree of dolphin impact. Miller et al. (2010) observed a short-term increase in calf numbers in Mississippi Sound in the wake of Hurricane Katrina, possibly due to an increase in prey as a result of less fishing activity, as well as an increase in reproductively active females following storm-related calf loss. Other studies, again in Mississippi Sound, as well as from the western North Atlantic, have documented post-storm increases in foraging behavior by bottlenose dolphins (Smith et al. 2013; Fandel et al. 2020; respectively), which could be indicative of increased numbers or density of prey. And while displacement of dolphins following some extreme weather events has been documented, one study in Florida found little change in site fidelity and ranging patterns pre- and post-hurricane (Bassos-Hull et al. 2013).

Louisiana experiences a high number of extreme weather events. According to NOAA's database, a total of 57 hurricanes impacted Louisiana between the mid-nineteenth century and 2023. From 1980 through March 2025, Louisiana experienced a total of 106 confirmed weather/climate disasters (the highest of any state; including droughts, floods, freeze events, storms, and tropical cyclones) that resulted in losses exceeding $1 billion each (NOAA NCEI 2025). Not all of these would have affected the Gulf coast and dolphin habitat, but many are likely to have, including droughts that are accompanied by heat waves. The average number of these disastrous events in Louisiana per year has increased from 2.4 over the whole time period (1980–2025) to 6.8 from 2020 to 2024 (NOAA NCEI 2025). Documented cases of impacts to dolphins from extreme weather events are rare, with the exception of entrapment (i.e., out-of-habitat animals), which is most often the result of storm surge following hurricanes or other severe storms. Incidents of entrapment are typically documented when stranding networks are notified. Many of the documented cases of these out-of-habitat animals result in rescue and release back into suitable habitat and do not end in immediate mortality. Aside from entrapments, the three other documented Louisiana cases come from a UME that affected dolphins from Louisiana to the panhandle of Florida that was partially attributed to extreme weather, and two studies on weather-related impacts to Mississippi Sound dolphins. Below we summarize all of these documented cases.

A.7.1 Louisiana-Wide

In the early months of 2011, a UME was documented from Louisiana to western Florida in which 186 dolphins washed ashore, 46% of which were perinatal calves (Carmichael et al. 2012). The UME impacted the majority of the Louisiana coastline. The timing of the UME coincided with the first calving season following three environmental perturbations: the Deepwater Horizon oil spill, a sustained cold-weather event in the winter of 2010, and an unusually large influx of cold freshwater from high snowmelt in January of 2011. Evidence suggests that the weather-related stressors were partially responsible for the UME (Carmichael et al. 2012).

A.7.2 MSS Stock

Hurricanes Katrina and Ida both resulted in cases of out-of-habitat animals in the MSS stock. Lake Pontchartrain, a brackish lagoon with few historical records of dolphins, experienced one of the most prolonged and, in terms of the number of animals involved, severe cases of entrapment in the Gulf region. The entrapment was thought to be the result of storm surge and flooding from Hurricane Katrina in August of 2005. Dolphins were reported to have been in the lake since the hurricane, and subsequent surveys between 2007 and 2010 documented well over 200 animals. After 2010, none were sighted and were presumed to have died given the lack of resights during continued surveys in the lake and elsewhere and the dolphins' ubiquitous skin lesions across many years (Mullin et al. 2015). In spring of 2010, 27 dolphins stranded in the Lake Pontchartrain area, following unusually cold temperatures and low salinities the previous winter.

Other effects of Hurricane Katrina on dolphins were documented within Mississippi Sound itself, using long-term data that allowed for comparisons of pre- and post-storm. As noted above, an increase in reproductive rates following the hurricane was documented in the Sound and attributed to a sharp reduction in commercial and recreational fishing activity and landings, resulting in an increase in prey densities (Miller et al. 2013). Another likely factor was an increase in reproductively active females as a result of loss of calves during the hurricane. Mississippi Sound dolphins also demonstrated an increase in foraging activity for about two years after Katrina as well as a shift in foraging locations (Smith et al. 2013).

In 2021, one young dolphin was stranded in a canal, presumably washed inland by the storm surge associated with Hurricane Ida, and was successfully caught, given a satellite-linked tag, and released.

A.7.3 MRD Stock

We found no records of entrapped animals, weather-event related or otherwise, associated with the Mississippi River Delta, nor any studies specific to the MRD stock related to impacts of extreme weather events.

A.7.4 BBES & TTBES Stocks

In September of 2008, a dolphin was captured from a constructed pond in Pointe Aux Chene, in Terrebonne Parish. It was believed that the animal had been displaced by Hurricane Gustav. The animal's young age prevented release into the wild, and the dolphin was transferred to Audubon facilities.

In 2021, a subadult dolphin was trapped in a flooded pasture near the border between the BBES and TTBES by storm surge associated with Hurricane Ida; it was subsequently rescued and released.

A mom and calf were reported trapped in a tidal pond system near Grand Isle, LA in January 2022 (NMFS 2023), likely as a result of the storm surge and flooding from Hurricane Ida. Although the dolphins could not navigate back to open water, they had adequate prey and water conditions. The calf was too young to be handled as part of an intervention, so the pair were monitored until June 2023, when they were caught and released into open water.

A.7.5 Vermilion Stock

Six dolphins from this stock area were washed inland by Hurricane Rita in August of 2005, and stranded in unsuitable habitats until interventions could be conducted (Rosel and Watts 2008). An additional out-of-habitat animal found months later may also have been a result of storm surge from Rita. All seven were rescued and released. In 2021, a single, subadult dolphin was trapped in a lake near Pecan Island, LA following (and likely a result of) Hurricane Laura; it was caught and released.

A.7.6 Calcasieu & Sabine Lake Stocks

The Calcasieu and Sabine Lake Stocks have the most cases of entrapment on record of any of the stocks with the vast majority of cases connected to extreme weather events. Between 2000 and 2020, 19 dolphins (including two mother-calf pairs) were reported as out-of-habitat in the Sabine and Calcasieu Lake areas, many of which were thought to be the result of storm surge from Hurricanes Rita, Barry, Delta, and Laura. Of the 19, 16 were released following assessment and determination of fitness, two died, and one died after attempted rehabilitation.

A.7.7 Coastal Stocks (NCS & WCS)

Given their coastal habitat, animals from these stocks are much less likely to become entrapped, and even if they are washed shoreward by storm surge and entrapped, they are unlikely to be linked to their appropriate coastal stock without genetic analysis. As a result, examples of animals from these stocks becoming entrapped are rare. There was one example of dolphins becoming entrapped in an offshore restoration zone in June of 2009, in which six dolphins became trapped where offshore island restoration work was underway. The personnel on site noticed the animals, cut a break in the barrier, spotted at least one animal swimming free, and sealed the barrier again with approval from NOAA.

A.8 Habitat Loss

Dolphins face a range of threats, including habitat loss (Ross et al. 2010). Human activities such as coastal development and tourism have destroyed or disrupted the natural environment of dolphins, reducing their available habitat and affecting their ability to find food. Briefly, habitat loss has taken the form of land reclamation for coastal development, industrial, aquaculture, and agricultural development (Slooten et al. 2013).

Coastal and estuarine waters are vital ecosystems known for their high levels of primary and secondary productivity; however, they are vulnerable to habitat loss due to human activities. For dolphin populations that exclusively inhabit these areas, irreversible habitat loss in these ecosystems can significantly threaten their population viability (Wu et al. 2017). Loss of coastal wetlands can also indirectly impact dolphins via impacts to their prey. The extensive coastal wetlands in the northern Gulf, which is estimated to constitute more than 40% of coastal wetlands in the US, provides critical nursery habitat for fish and invertebrates (Baltz et al. 1998; Grimes 2001; Mendelssohn et al. 2017; CPRA 2023), some of which are important prey species for dolphins.

Since 1900, Louisiana has lost over 1 million acres (2,000 mi^2) of wetlands and barrier shoreline due to both natural processes and human activity, bringing its coastal wetlands to the brink of collapse (Couvillion et al. 2017). More than 1,500 mi^2 of coastal Louisiana have disappeared in the past 50 years. Without intervention, an additional 1,000 mi^2 of land could be lost by 2050. These areas are crucial habitats for fish and wildlife and serve as vital storm buffers for communities, transportation routes, and energy infrastructure (Gagliano et al. 1981; Couvillion et al. 2017; Blum et al. 2023).

Since 1930, coastal Louisiana has lost over 4,833 km^2 (~1,900 mi^2) of land, which represents 80% of the total coastal wetland loss in the U.S. (Couvillion et al. 2011; Blum et al. 2023). This extensive land loss poses significant challenges, including severe damage to local fishery industries, disruptions to wetland ecosystem balance, and heightened risks of coastal hazards for residents and energy infrastructure. The widespread land loss in coastal Louisiana is attributed to a combination of factors, including constructing levees along the Mississippi River that disrupt natural deltaic processes, oil and gas development, land subsidence, global sea-level change (Blum and Roberts 2009, 2012), and shoreline erosion (Boesch et al. 1994).

Coastal wetland degradation in Louisiana, now exceeding 100 km^2/year, stems from a myriad of interactions among physical, chemical, biological, and cultural dynamics (Walker et al. 1987). Geologically, phenomena like sea-level fluctuations, land subsidence and compaction, and shifts in deltaic depocenters are significant contributors. Hurricanes are among the biggest contributors to coastline erosion in Louisiana (Walker 2001). Biological factors, such as marsh growth rates (especially concerning subsidence, compaction, and saltwater/freshwater balance) and the degradation by marsh fauna (nutria and muskrat), also play pivotal roles (Holm et al. 2016). Over recent decades, human activities have markedly exacerbated wetland loss (Perry and Mendelssohn 2009). The construction of dams and levees along the Mississippi River's tributaries has interrupted natural deltaic processes such as deposition of sediment in wetlands during spring floods, which has reduced both quantity and quality of wetlands. Furthermore, canal and highway development within wetland areas have disrupted drainage and tidal flow patterns, while fluid extraction exacerbates subsidence (Walker et al. 1987).

The effect of these coastal ecosystem habitat losses on dolphins has not been measured. Direct impacts to dolphins from displacement from former estuarine habitat is likely, but the population-level effects of these changes is uncertain. The level of indirect impacts from potential reductions in prey due to wetland habitat loss is also unclear. Chesney et al. (2000) found that fisheries yields have remained relatively stable over the previous several decades despite significant loss and degradation of wetland nursery habitat. The authors hypothesized that land loss may increase fisheries productivity initially because more edge habitat is created as wetlands degrade and those habitats are key for the early life histories of many species; however, the ecosystem may ultimately reach a tipping point where entire areas convert to open water and fisheries decline. If the latter is true, then dolphin prey may be more impacted by habitat loss than is evident from fisheries landings.

Due to the lack of information about the impacts of habitat loss on dolphins, below we primarily focus on describing the level of habitat loss and the planned and on-going restoration efforts within each stock area. Louisiana has developed a wetland restoration master plan for the region aimed at creating and preserving land (CPRA 2023). But the restoration projects have the potential to introduce further changes to dolphin habitat, including alterations in the salinity levels. Dolphins typically inhabit waters with salinities ranging from 20-35 ppt and can suffer severe health consequences or mortality from extended exposure to low salinity (e.g., Fautin et al. 2010; Garrison et al. 2020; Takeshita et al. 2021). See the Freshwater Strategy Report for more on the impacts of freshwater.

A.8.1 Sabine Lake

Approximately 40,000 acres of habitat within the Sabine refuge have been lost due to a mix of human-induced and natural factors, including channel excavation, levee construction, hurricanes, and wildlife-induced vegetative degradation. Significant endeavors are underway to rehabilitate marsh habitat and halt further habitat loss (CPRA 2023). Management strategies employed at Sabine encompass water quality regulation, marsh development, and controlled burning. Methods used for marsh creation or restoration from open water areas include utilizing dredge spoil from the Calcasieu Ship Channel and constructing low-lying levees known as terraces (Perkey et al. 2022). Terraces serve to attenuate wave action in open water areas, thereby enhancing water clarity, facilitating plant growth, and fostering the formation of new marshlands. Additionally, wildland fire management is employed to clear dead vegetation, promote the growth of beneficial wildlife food plants, and mitigate wildfire risks (Pausas and Keeley, 2019).

Significant hydrological transformations occurred in the Sabine sub-basin with the implementation of the Sabine-Neches Waterway (SNWW) and the creation of the Toledo Bend Reservoir (Qian et al. 2022). Previously, all inflows from the Sabine and Neches rivers fed into Sabine Lake. However, the construction of the SNWW and the deepening of the Sabine and Neches Rivers altered this dynamic, leading to saltwater intrusion into the historically low-salinity Sabine Lake estuary (Qian et al. 2022). This also accelerated freshwater discharge into the Gulf, consequently diminishing inflows into neighboring marshlands, and amplifying tidal fluctuations.

The 318,000-acre Sabine sub-basin has lost over 84,000 acres of marshland (38.5%) since 1932 due to both human-induced factors like channelization and natural causes. Projections indicate a further loss of 38,400 acres (12.1%) by 2050, totaling a projected loss of 160,382 acres from 1932 to 2050. This represents a loss of over 50% of the original 220,000-acre marshes in the Sabine sub-basin (USFW 2004).

Within the 39,539-acre East Sabine Project area, wetland losses amounted to a total of 49% loss from 1932 to 1990 (Dunbar et al. 1994). If the modest land loss rate from 1983 to 1990 is projected to 2050, another 2,552 acres (12%) could be lost from the project area, constituting a 61% loss from 1932 to 2050 (Dunbar et al. 1994). Sabine Lake shoreline erosion rates are estimated to be 10 feet per year (Dunbar et al. 1994).

According to the CPRA 2023 Coastal Master Plan, there is one marsh creation project scheduled for the Sabine Lake area to create new wetland habitat, restore degraded marsh, and reduce wave erosion. The West Sabine Lake Refuge Marsh Creation project will involve the creation of marsh in the western portion of Sabine Lake (CPRA 2023).

A.8.2 Calcasieu Lake

In total, 116,791 acres (33% of the historic land area) of wetlands in the Calcasieu/Sabine Basin have been converted to open water since 1932 (Dunbar et al. 1994). Extensive channelization, increased energy levels, and saltwater intrusion caused much of the marsh loss in the basin. Current land loss rates range between approximately 1,000 (Dunbar et al. 1994) and 1,650 (Barras et al. 1994) acres per year. At these rates, up to 33,000 acres will be lost during the next 20 years if coastal restoration projects are not implemented.

According to the CPRA 2023 Coastal Master Plan, there are four marsh creation projects scheduled for the Calcasieu Lake area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) Mud Lake Marsh Creation project (creation of marsh within a footprint of approximately 8,100 acres at Mud Lake south of West Cove Calcasieu Lake), (2) Southeast Calcasieu Lake Marsh Creation project (creation of marsh within a footprint of approximately 9,200 acres SE of Calcasieu Lake), (3) East Calcasieu Lake Marsh Creation project (creation of marsh in the western portion of the eastern Cameron-Creole watershed), and (4) Calcasieu Ship Channel Marsh Creation project (creation of marsh within a footprint of approximately 3,200 acres south of Calcasieu Lake near Cameron). The restoration effort will significantly expand essential habitats for various aquatic species, including red drum, brown and white shrimp, as well as for avian inhabitants such as pelicans, gulls, waterfowl, and marsh birds (CPRA 2023).

A.8.3 Vermilion Stock

The three major bays occupied by the Vermilion stock are separated from the Gulf by Marsh Island, resulting in primarily fresh, intermediate, and brackish marshes with fewer salt marshes. Despite a loss of 42,293 acres (14.8%) of marshland since 1932, the rate of loss has been relatively slow due to the later stages of the delta lobe cycle, though the expected rapid wetland creation associated with the emerging Atchafalaya River delta is hindered by controlled water flow (Couvillion et al. 2017). Additionally, the basin faces alterations in geomorphology and hydrology from human activities like canal dredging and levee construction, which disrupt wetland maintenance processes. Wetland loss primarily occurs through shoreline erosion, exacerbated by factors such as reduced oyster reefs and increased wave energy. Shoreline erosion, driven by natural forces and human activity, can lead to the direct loss of wetlands and their connection with dynamic water bodies, contributing to overall wetland loss in the basin (Couvillion et al. 2017).

The Cole’s Bayou Marsh Restoration Project aims to restore 3,840 acres of marshland in the Teche Vermilion Basin. This includes creating approximately 365 acres of new marsh and nourishing 53 acres of existing marsh in shallow open water areas. To enhance restoration efforts, the project plans to increase freshwater nutrient and sediment inflow from Freshwater Bayou by installing a series of culverts throughout the project area. The proposed location for the project is situated east of Intracoastal City and Freshwater Bayou Canal, west of Little Vermilion Bay, and just south of the Gulf Intracoastal Waterway (GIWW) (Mouledous 2019). The Atchafalaya Basin stands out among other basins due to its expanding delta system and relatively stable wetlands (Day et al. 2000). Wetland loss in the northern areas, including Atchafalaya Bay, is minimal compared to other regions, with approximately 3,760 acres lost between 1932 and 1990, averaging 87 acres per year from 1974 to 1990 (Day et al. 2000). The causes of wetland loss vary by site and include erosion, human activities, and natural conversion. Storms and hurricanes contribute to shoreline erosion, particularly between Wax Lake Outlet and Point Chevreuil. Oil and gas pipelines disrupt natural flow and sediment movement within the wetlands, while the development of the Lower Atchafalaya River into a riverine system has led to the formation of natural levees along its banks, further disrupting flow and sediment movement into the wetlands (Day et al. 2000).

According to Couvillion et al. (2017), the Atchafalaya Basin has seen a net gain of over 4,000 acres (~16 km2) of wetlands since 1932. Initially, land change rates were negative, but after the opening of the Wax Lake Outlet in 1942, sediment deposition increased, leading to the emergence of a subaerial active delta following the 1973 flood. These developments have positively impacted land change rates in the basin. The Atchafalaya Basin's wetlands are likely to remain sustainable in the future due to the high rates of river sedimentation they receive during flooding events.

According to the CPRA 2023 Coastal Master Plan, there are three marsh creation projects scheduled for the Vermilion Bay/West Cote Blanche Bay/Atchafalaya Bay area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) East Rainey Marsh Creation project (creation of marsh in the northern portion of Rainey Marsh), (2) Marsh Island Barrier Marsh Creation project (creation of marsh within a footprint of approximately 16,000 acres on Marsh Island), (3) Central Coast Marsh Creation project - Point Au Fer (creation of marsh within a footprint of approximately 8,200 acres on Point Au Fer Island; CPRA 2023). CPRA is also specifically developing an Atchafalaya Master Plan (CPRA 2024).

A.8.4 TTBES Stock

The TTBES stock area has witnessed considerable loss of wetlands and barrier islands, leading to increased open water areas and diminished marsh habitats (CPRA, 2023). It has, in fact, experienced the greatest loss of wetland area in the state of Louisiana, with approximately 321,730 acres (502 mi^2; 1,302 km^2) of net loss since 1932 (Couvillion et al. 2017). Various factors such as subsidence, sea-level rise, storms, winds, tides, and human activities like levee construction, sediment input reduction, and channelization (such as navigational channels and oil and gas canals) contribute to this degradation of habitat (Couvillion et al. 2017; CPRA 2023). The effects of these habitat alterations on common bottlenose dolphins remain uncertain.

According to the CPRA 2023 Coastal Master Plan, there are five marsh creation projects scheduled for the Terrebonne-Timbalier Bay area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) West Terrebonne Marsh Creation project (creation of marsh within a footprint of approximately 22,000 acres in between Caillou Lake and Caillou Bay in western Terrebonne), (2) North Lake Mechant Marsh Creation project (creation of marsh in Terrebonne Parish between Lake Decade and Lake Mechant), (3) North Terrebonne Bay Marsh Creation project (creation of marsh within a footprint of approximately 6,200 acres south of Montegut between Bayou St. Jean Charles and Bayou Pointe-aux-Chênes), (4) Belle Pass-Golden Meadow Marsh Creation project (creation of marsh within a footprint of approximately 29,000 acres of northeast portion of marsh from Belle Pass to Golden Meadow), and (5) Eastern Terrebonne Landbridge project (creation of marsh including filling areas deeper than 2.5 feet, from Bayou Pointe-aux-Chênes to the south Lafourche Levee near Catfish Lake. 30,000 feet of shoreline revetment to limit erosion in exposed areas and channel armoring to maintain channels at current dimensions at Bayou Pointe-aux-Chênes and Bayou Blue to reduce the tidal prism (CPRA 2023).

According to the CPRA 2023 Coastal Master Plan, there is one barrier island restoration project scheduled for the Terrebonne-Timbalier Bay area: Terrebonne Basin Barrier Island Restoration project. The Terrebonne Basin Barrier Island and Beach Nourishment project includes the construction of approximately 1,100 acres of beach, dune, and marsh habitat within the Terrebonne Basin barrier shoreline system. It uses dredged material from Ship Shoal, and includes restoration of beach, dune and marsh habitat on West Belle Headland, Timbalier Island, and Trinity Island (CPRA 2023).

A.8.5 BBES Stock

Barataria Basin has experienced the second greatest land loss of the nine basins in coastal Louisiana, with a net loss of approximately 277,000 acres (430 mi^2; 1,120 km^2) of wetlands since 1932 (Couvillion et al. 2017). Rates of wetland loss have ranged from a net loss of approximately 6,178 acres/year (25.0 km^2/year) at the peak of wetland loss rates, to a loss of 210 acres/year (0.8 km^2/year) most recently (Couvillion et al. 2017). Wetland loss within the basin is attributed to a combination of natural and anthropogenically-influenced factors, including sea level rise, subsidence, shoreline erosion (from storms, wind, and tides), herbivory, and human development, such as channelization and levee construction (CPRA 2023). Day et al. (2000) found that 72% of wetland loss in Barataria Basin was statistically associated with direct loss due to canals. Tropical storm impacts are also a major contributor to wetland loss in the basin (Couvillion et al. 2017).

The planned Mid-Barataria Sediment Diversion (MBSD) project is the single largest ecosystem project in the history of the US. The sediment diversion project, situated near Myrtle Grove along the west bank of the Mississippi River, aims to address the degradation of brackish and freshwater wetlands in the surrounding area. This degradation is caused by saltwater intrusion, reduced freshwater supply, changes in hydrology, and a lack of sediment input. By reconnecting the river to the influence area, the project intends to divert sediment, nutrients, and significant amounts of freshwater to facilitate the creation of new land, sustain existing marshes, and enhance habitat resilience against sea-level rise and storm events (U.S. Army Corps of Engineers, 2021). Researchers used modeling techniques to forecast the habitat changes anticipated from the implementation of the MBSD project and assess the probable impacts on the Barataria Bay dolphin population. Their projections indicate a devastating decline in the Barataria Bay dolphin population, with over 500 dolphins (approximately one quarter of the population) projected to perish within the initial year of MBSD operation. Dolphins inhabiting the central and western regions of the bay are anticipated to face a state of "functional extinction" within a decade of MBSD operation. By the 50-year mark of operation, bottlenose dolphins across the entirety of the bay are forecast to be nearly depleted, with only a sparse population remaining in close proximity to the bay's barrier islands (Thomas et al. 2022).

Aside from the MBSD project, according to the CPRA 2023 Coastal Master Plan, there is one other diversion project scheduled for the Barataria Bay area: Upper Basin Diversion Program - Barataria. Multiple freshwater and sediment diversions into the swamps of the Western Pontchartrain and Upper Barataria basins were modeled for inclusion in the plan. These projects showed complex interactions with other diversions assumed to be operating on the landscape. This program will evaluate how diversions into the upper basins could be operated in conjunction with currently planned diversions to maintain swamps and coastal marshes, sustain estuarine gradients, and aid in Mississippi River flood control. These studies will lead to the construction of one or more diversion features into Barataria or Maurepas basins.

According to the CPRA 2023 Coastal Master Plan, there are seven marsh creation projects scheduled for the Barataria Bay area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) Large-Scale Barataria Marsh Creation project (creation of marsh within a footprint of approximately 15,000 acre in western portion of Barataria Bay), (2) Lower Barataria Landbridge project (creation of marsh within a footprint of approximately 6,900 acres including filling areas deeper than 2.5 feet, from Bayou Dogris to Port Sulphur, 130,000 feet of shoreline revetment to limit erosion in exposed areas, and channel armoring to maintain channels at current dimensions at Wilkinson Canal, Wilkinson Bayou, Bay Chene Fleur, multiple channels north of Bay Batiste, Two Sisters Bayou, Socola Canal, and Grand Bayou to reduce the tidal prism), (3) Mid-Barataria Landbridge project (creation of marsh within a footprint of approximately 3,800 acres including filling areas deeper than 2.5 feet, from Galliano to Bayou Perot, 63,000 feet of shoreline revetment to limit erosion in exposed areas and channel armoring to maintain channels at two canals in the Clovelly Oil Field to reduce the tidal prism), (4) North Barataria Bay Marsh Creation project (creation of marsh within a footprint of approximately 7,200 acres on western portion of Barataria Bay shoreline), (5) Southeast Golden Meadow Marsh Creation project (creation of marsh including filling areas deeper than 2.5 feet along portions of the South Lafourche levee alignment), (6) East Bayou Lafourche Marsh Creation project (creation of marsh within a footprint of approximately 33,000 acres east of Bayou Lafourche and along the Caminada Headland), and (7) Caminada Bay Marsh Creation and Fifi Island Ridge project (creation of marsh within a footprint of approximately 1,600 acres in Caminada Bay to create new wetland habitat, restore degraded marsh, and reduce wave erosion and approximately 14,000 feet of shoreline protection along Fifi Island).

According to the latest NMFS stock assessment report, the marshes and swamp forests that define Barataria Bay serve as crucial breeding and nursery habitats for various commercially and recreationally significant species. These include finfish, shellfish, alligators, songbirds, geese, and ducks (Fautin et al. 2010).

A.8.6 MRD Stock

The Mississippi River Basin has seen a net reduction in wetland area from 1932 to 2016. The total wetland area has decreased by 92,665 acres (375.0 km^2), representing a significant decline of approximately 55% compared to the 1932 area (Couvillion et al. 2017). The primary factors driving land loss in the Mississippi River Delta are subsidence and compaction. Unlike other coastal areas in Louisiana, the delta benefits from a relatively high influx of fresh water and sediments (Couvillion et al. 2017).

There is one planned diversion project scheduled for the MS River Delta region (Mid-Breton Sediment Diversion project). The project, which is currently in the engineering/design phase, will increase construction activity in the northeastern portion of the delta, but we are currently data deficient on potential impacts to dolphins (CPRA Coastal Projects Map 2024).

According to the CPRA 2023 Coastal Master Plan, there are ten marsh creation projects scheduled for the Mississippi River Delta area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) North and East Lake Lery Marsh Creation project (creation of marsh within a footprint of approximately 14,000 acres in north and east Lake Lery), (2) Hopedale Marsh Creation project (creation of marsh within a footprint of approximately 1,900 acres in northern Breton Sound in the vicinity of Hopedale), (3) West Delacroix Marsh Creation project (creation of marsh within a footprint of approximately 5,100 acres south and west of Delacroix Island), (4) Tiger Ridge/Maple Knoll Marsh Creation project (creation of marsh within a footprint of approximately 4,700 acres in Plaquemines Parish near Tiger Ridge), (5) Spanish Lake Marsh Creation project (creation of marsh within a footprint of approximately 840 acres in Plaquemines Parish along the eastern shore of Spanish Lake), (6) Oak River to Delacroix Marsh Creation project (creation of marsh within a footprint of approximately 2,400 acres in Plaquemines Parish between Grand Lake and Lake Lery), (7) Pointe a la Hache and Carlisle Marsh Creation project (creation of marsh along the east side of the Mississippi River from White Ditch to Bohemia), (8) Uhlan Bay Marsh Creation project (creation of marsh within a footprint of approximately 960 acres on east bank of Plaquemines Parish around Uhlan Bay), (9) Sunrise Point Marsh Creation project (creation of marsh within a footprint of approximately 2,200 acres on east bank of Plaquemines Parish around Auguste Bay), and (10) Belle Pass Island Marsh Creation project (creation of marsh within a footprint of approximately 3,800 acres on Belle Pass Island near Bohemia).

A.8.7 MSS Stock

In the last several decades, the encroachment of saltwater, coastal erosion, and human activities has transformed Lake Borgne and its environs from marsh into vast expanses of exposed, open water (CWPPRA 2025). However, an ongoing Coastal Protection and Restoration Authority project, valued at $114.6 million, endeavors to reclaim this lost territory. Commencing 18 months ago, the Lake Borgne Marsh Creation Project remains a work in progress and is scheduled for completion in 2025. Upon its conclusion, the project aims to establish over 2,769 acres of marshland along a four-mile stretch of the southern shoreline, extending from Lake Borgne near Shell Beach to Lena Lagoon. Construction of the marsh involves the creation of seven containment dikes, where 4.5-foot walls are being erected around sections of open water and marshland. During the initial 18-month phase, excavators have been tasked with gathering soil to bolster these dikes. Ultimately, the sediment dredged from Lake Borgne and deposited within these enclosures is anticipated to rehabilitate deteriorated marshland (CPRA 2023).

The Pontchartrain Basin has experienced a decline in wetland area of approximately 116,634 acres (472 km^2) since 1932 (Couvillion et al. 2017). Despite this, the rate of land change in the basin remained relatively stable from 1932 to 2016. The loss of wetlands in this area is primarily attributed to factors such as limited riverine input, erosion, and the deterioration of land bridges on the east and west sides of Lake Pontchartrain (Couvillion et al. 2017). Between 1932 and 2001, approximately 415 mi^2 of these wetlands underwent conversion into open water or upland habitat (Couvillion et al. 2017). Recent findings indicate a significant escalation in the rate of loss during the last decade (1990–2001) (Couvillion et al. 2017). Initial assessments suggest that Hurricane Katrina in 2005 led to marsh loss equivalent to that seen in the entire preceding decade, amounting to approximately 80 mi^2. Given that the Pontchartrain Basin encompasses major port cities like New Orleans and Baton Rouge, its fate holds national significance.

According to the CPRA 2023 Coastal Master Plan, there is one diversion project scheduled for the Lake Pontchartrain area: Upper Basin Diversion Program - Pontchartrain project. Multiple freshwater and sediment diversions into the swamps of the Western Pontchartrain and Upper Barataria basins were modeled for inclusion in the plan. These projects showed complex interactions with other diversions assumed to be operating on the landscape. This program will evaluate how diversions into the upper basins could be operated in conjunction with currently planned diversions to maintain swamps and coastal marshes, sustain estuarine gradients, and aid in Mississippi River flood control. These studies will lead to the construction of one or more diversion features into Barataria or Maurepas basins (CPRA 2023).

According to the CPRA 2023 Coastal Master Plan, there are four marsh creation/restoration projects scheduled for the Lake Pontchartrain area to create new wetland habitat, restore degraded marsh, and reduce wave erosion: (1) New Orleans East Marsh Creation project (creation of marsh within a footprint of approximately 29,000 acres in a portion of the New Orleans East Landbridge Marsh Creation project), (2) Three Mile Pass Marsh Creation and Hydrologic Restoration project (creation of marsh within a footprint of approximately 11,000 acres including a 660 acre footprint filling areas deeper than 2.5 feet to create new wetland habitat and restore degraded marsh in Malheureaux Point and Grand Pass. 20,000 feet of oyster reef creation along the created marsh in Three Mile Bay to reduce hydrologic connectivity between Mississippi and the interior of the Biloxi Marsh Complex), (3) Chandeleur Sound Island Restoration projects (creation of marsh within a footprint of approximately 940 acres in the eastern Biloxi Marsh Complex to create new wetland habitat, restore degraded marsh, and reduce wave erosion on Comfort Island, Mitchell Island, Martin Island, and Brush Island), and (4) Fritchie North Marsh Creation project (creation of marsh within a footprint of approximately 4,400 acres in St. Tammany Parish along the eastern Lake Pontchartrain shoreline to create new wetland habitat, restore degraded marsh, and reduce wave erosion; CPRA 2023).

A.9 Climate Change

Climate change is impacting ocean and bay temperatures, circulation patterns, pH, salinity, oxygen levels, sea level, freshwater input, and the frequency and intensity of extreme weather events (EPA 2016 ; Mann et al. 2017; Pörtner et al. 2019; Kebke et al. 2022; Gulland et al. 2023). These oceanic changes can impact cetaceans both directly and indirectly via changes to habitat, prey availability, predation, and human activities such as fishing (Nowicki et al. 2019; Kebke et al. 2022; Gulland et al. 2023). Climate change is also expected to cause an increase in occurrence of HABs (Hallegraeff et al. 2021), infectious disease outbreaks (Burek et al. 2008; Barratclough et al. 2023), and higher concentrations of contaminants resulting from increased rainfall and the resulting runoff (Kebke et al. 2022). These impacts could negatively affect cetacean's survival, reproductive success, and health, but research is lacking about the extent to which these population-level impacts are occurring and which species they are impacting (Gulland et al. 2023). Based on relative environmental suitability models and projections of future climate conditions, one study estimated that, worldwide, 31% of Delphinid species would experience range contractions (mean 4.55% decrease), and about 69% would experience some level of range expansion (mean 6.4% increase; Kaschner et al. 2011).

However, not all regions are experiencing the same climate changes and impacts. Lettrich et al. (2023) estimated that 72% of marine mammal stocks along the US Atlantic and Gulf coasts had a high or very high vulnerability to climate change due in part to the high levels of climate-related environmental change expected. The northern Gulf is experiencing all of the oceanic changes being seen elsewhere, but of particular note in this region is the accelerating rate of sea level rise (Dangendorf et al. 2023) and the decreases in dissolved oxygen levels (Rabalais et al. 2010). Because of these changes and projected future changes, the number of species, including small odontocetes, is expected to decline in parts of the northern Gulf via the indirect effects of changes in prey and habitat availability (Kaschner et al. 2011). However, some mobile and adaptable species may be able to adjust to the changes wrought by the warming climate (Simmonds and Isaac 2007; Kaschner et al. 2011).

A.9.1 Louisiana Stocks

Climate change is expected to significantly impact Louisiana dolphin stocks both directly and indirectly. A recent analysis by Lettrich et al. (2023) estimated that the overall vulnerability to climate impacts of Louisiana stocks was very high, with the exception of WCS, which they ranked as having a high level of vulnerability (Table A1). Each stock’s overall ranking derived from a combination of its level of exposure to climate impacts and its estimated sensitivity to those impacts. Exposure took into account the regional expected changes to sea surface temperature, air temperature, precipitation, salinity, acidification, dissolved oxygen, circulation, and sea level rise (Lettrich et al. 2023). For example, a stock that relies on estuarine or other shallow habitats for one or more life stages, and regional sea level rise is expected to increase greater than or equal to 7mm per year by 2050, then that stock would get a “very high” score for sea level rise. Combining all exposure factors, all nine Louisiana stocks were estimated to have a very high risk of exposure to high levels of climate-linked environmental change. The sensitivity of Louisiana stocks to climate-related changes, defined as their ability to tolerate those changes, ranged from very high to moderate. Most BSE stocks were very high except Calcasieu and MSS, which were high. The WCS had a moderate level of sensitivity and the NCS had a high level. The sensitivity scores were based on things like diet specificity, site fidelity, reproductive potential and plasticity, stock abundance and trends, and cumulative stressors, among other stock/species characteristics. To illustrate, given the geographical constraint of the northern Gulf coast, Louisiana dolphins have a limited ability to move, particularly latitudinally, in response to increased ocean temperatures and other physical perturbations, whereas dolphins in the western North Atlantic could, in theory, move northward in response to warming ocean waters (i.e., Learmonth et al. 2006; see also Wells 2010; Tornero et al. 2014). Coastal stocks could be more insulated from the effects of climate change due to their generally larger ranges, tendency to move over greater distances, and relatively higher abundances, whereas BSE dolphins typically have more restricted ranges and are much less likely to move beyond these boundaries (Lettrich et al. 2023).

Table A1. Assessment from Lettrich et al. 2023 of how vulnerable each of the Louisiana stocks are to climate change impacts, based on a combined score of their risk of exposure to climate-induced environmental changes and their estimated sensitivity to those changes.

Stock	**Exposure**	**Sensitivity**	**Vulnerability**
BBES	Very High	Very High	Very High
Calcasieu Lake	Very High	High	Very High
Sabine Lake	Very High	Very High	Very High
MRD	Very High	Very High	Very High
MSS	Very High	High	Very High
TTBES	Very High	Very High	Very High
Vermilion	Very High	Very High	Very High
NCS	Very High	High	Very High
WCS	Very High	Moderate	High