National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Gulf Islands National Seashore

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/GUIS/NRR—2023/2525

ON THE COVER

Carcharias taurus (Sand Tiger Shark) upper tooth, recovered on West Petit Bois Island in March 2022.

NPS / MICHAEL CLINTON

Gulf Islands National Seashore

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Note: Paleontological resources in National Park Service lands are protected by law. Unauthorized collection of fossils from National Park Service lands is prohibited except under the terms of an approved research and collecting permit. See the text for more information on protecting and preserving these non-renewable resources for the benefit of all.

June 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Executive Summary

Gulf Islands National Seashore (GUIS) encompasses areas of the mainland as well as eight main offshore barrier island areas over the Florida and Mississippi coasts. Mainland areas of GUIS include the Pensacola Naval Air Station and Naval Live Oaks in Florida, and Davis Bayou in Mississippi. Floridian barrier islands include Santa Rosa Island and the eastern end of Perdido Key. Mississippian barrier islands include East and West Petit Bois Islands, Horn Island, Ship Island, and Cat Island. The lands at GUIS are composed primarily of Pliocene, Pleistocene, and some Holocene sediments which have been deposited over the previous 5.3 million years (Schupp 2019). The barrier islands within the boundaries of the park are younger, having been formed over the past 5,000 years. The islands and mainland coastlines of GUIS are constantly changing due to interactions with natural coastal processes such as storms, waves, tides, sediment transport, inlet dynamics and sea level change (Schupp 2019). Additionally, GUIS is being altered by more recent anthropogenic activities including inlet dredging and shoreline engineering which have disturbed the Quaternary sediments within the park.

Known paleontological resources at GUIS were previously limited to mollusks and microfossils including foraminifera ("amoebas with shells") identified in drill cores taken at a few islands in the park (Schupp 2019). As of the most recent Paleontological Resource Inventory and Monitoring summary report for the Gulf Coast Inventory & Monitoring Network (Kenworthy et al. 2007), no documented surficial fossils had been found on land managed by GUIS. The only known fossil specimens in the GUIS collections included several specimens collected outside of park boundaries in the 1940s. Recent anecdotal information by park staff and visitors pointed to the presence of additional fossil resources at GUIS not previously documented. During the synthesis of this inventory, new paleontological resources were officially documented and new localities were identified. These new finds consisted primarily of shark teeth found on island beaches. The discovery of these new resources also brought with it many questions. One of the more pressing questions explored in this inventory is the potential source sediments and geologic formations of the newly discovered fossils at GUIS. Additionally, suggestions are made for how GUIS can more effectively manage and educate about these fossil resources to ensure they can be protected and appreciated for generations to come.

The hundreds of chondrichthyan (shark and ray) fossils collected at GUIS throughout 2021 and 2022 and described within this inventory hold special significance. There is a noted gap in scholarly knowledge relating to chondrichthyan fossil assemblages of any age from the coastal units managed by GUIS. Apart from ancillary studies such as those conducted at Dauphin Island, Alabama (Ebersole et al. 2017), there is no mention in the literature of chondrichthyan fossils from the western panhandle of Florida or the Mississippi–Alabama barrier islands. Most, if not all, of the fossil chondrichthyan specimens at GUIS are presumed to have been inadvertently placed there through anthropogenic means. The localities with the greatest fossil abundance at GUIS are all areas that have been subject to beach renourishment using dredged ocean sediment which is very likely to be pre-Holocene and fossiliferous. While GUIS should take the necessary steps to ensure proper

management of these newly discovered fossils, the national seashore may also want to investigate avenues of preserving and sharing this resource's significance with the scientific community.

Acknowledgments

We would like to thank both the National Park Service and the Paleontological Society for collaborating to form the "Paleontology in the Parks" Fellowship Program. This recently established program provided both the means and funding for this project. The continued relationship between the National Park Service and the Paleontological Society aims to contribute new knowledge and establish lasting stewardship of paleontological resources in 286 NPS units across the country.

This inventory could not have been completed without the assistance of the National Park Service and staff at GUIS. Kelly Irick, former Natural Resources Manager at GUIS, was our primary park contact during much of this work. Kelly coordinated housing needs, park-wide communications, and GUIS personnel assistance for us during park visits. Kelly also provided extensive background knowledge of historical park activities at GUIS which aided in our research. Bruce Leutscher succeeded Kelly as GUIS Chief of Science & Resource Stewardship in early 2022. Bruce provided additional support and information along with Shawn Jones, who was the GUIS Archeologist and Cultural Resource Program Manager.

Many staff members and interns at GUIS assisted with multiple site surveys during 2021 and 2022. Joe Burgess, GUIS Biologist, provided transport and fossil locality advice at Perdido Key. Cody Haynes, GUIS Biologist, provided transport and fossil locality advice for several barrier islands in Mississippi. Cody additionally provided a wealth of pertinent knowledge and documentation related to dredging and beach nourishment activities conducted by the USACE. We would like to thank Joe Burgess, Cody Haynes, Grady Jakobsberg, Darby McGhee, Victor Pillow, and Barrett Warmbein at GUIS for their assistance with fieldwork. Thanks also to Darrell Echols (GUIS Superintendent), John Bernstiel (GUIS Lead Park Ranger), Ronda Harper (GUIS Law Enforcement Ranger), Danise Fairchild (GUIS Remittance Technician), Robert Pitts (GUIS Visitor Use Assistant), Casimer Rosiecki (GUIS Ranger), and Stephenie Wade and Nava Kiss (GUIS Social Media Staff).

Other NPS personnel to thank are Martha Segura (Gulf Coast Inventory & Monitoring Network Program Manager), Linda York (Southeast Region Coastal Geomorphologist), and the staff at the NPS Geologic Resources Division, including Stephanie Gaswirth, Harold Pranger, Julia Brunner, Jim Wood, Jack Wood, and Jason Kenworthy.

Additionally, we would like to thank Sara LeCroy and Jeremy Higgs at the Gulf Coast Research Laboratory, Robert Dixon at the Dauphin Island Sea Lab, Stephen Godfrey at the Calvert Marine Museum, David Dockery at the Mississippi Department of Environmental Quality, and Pete Skrmetta and Kevin Buckel at Ship Island Excursions. Special appreciation goes to Victor Perez (then Calvert Marine Museum, now St. Mary's College of Maryland) for his repeated assistance and support with specimen IDs, and also to Jonathan Hendricks for his insight on potential fossil mollusks on these beaches. Additional recognition and thanks goes to James Starnes at the Mississippi Department of Environmental Quality, Office of Geology, for his assistance with updated interpretations of the geology and geomorphology of the Gulf Coast.

We would like to thank the Geosciences Department at Georgia State University for temporarily housing the fossil specimens, and for providing a facility to research them. A special thanks to Megan Rich and Fern Baird-Clark for their assistance and support throughout this inventory.

Finally, we appreciate Peer Review Coordinator Martha Segura, and James Flocks (U.S. Geological Survey) and Jun Ebersole (McWane Science Center) for reviewing the manuscript. James and Jun provided invaluable insights which greatly improved the final report.

Dedication

We are pleased to dedicate the Gulf Islands National Seashore Paleontological Resource Inventory report to Stephen J. Godfrey, Ph.D., Curator of Paleontology at the Calvert Marine Museum in Solomons, Maryland. Stephen was born and raised in the Province of Quebec, Canada. He has always been fascinated with nature and natural history museums. As an early teen, he began to collect fossils, seashells, pinecones, and road-kill skeletons to fill his own bedroom natural history museum! He received his B.Sc. in biology from Bishop's University and a Ph.D. under Dr. Robert L. Carroll in paleontology from McGill University. Following a two-year Postdoctoral Fellowship with Dr. Robert R. Reisz at the University of Toronto, he moved to Drumheller, Alberta, the "Dinosaur Capital of Canada," where he became involved in paleontological exhibit work for museums around the world (Skullptures.com). While in Drumheller, he also had the pleasure of collaborating with Dr. Philip J. Currie. In 1998, Dr. Godfrey became the Curator of Paleontology at the Calvert Marine Museum in Solomons, Maryland where his mandate is to collect, preserve, and interpret fossils from the famous Calvert Cliffs along the Chesapeake Bay. Most of the fossils that he quarries from the cliffs are of extinct whales and dolphins that lived between 18–8 million years ago. During his time at the Museum, he has learned how beneficial collaborations are with the large avocational paleontological community. Furthermore, he has been honored to host numerous interns and research assistants.

"Christy Visaggi was one of my first summer interns. We sorted and identified over 24,000 locally sourced Miocene shark teeth for a study on their stratigraphic abundance and taxonomic diversity. It was a pleasure to have spent that summer with so gifted a young paleontologist. That project was published in 2010 with Christy as the senior author. Years later, I was contacted by Victor Perez, but alas I had to inform him that our docket that summer for interns was already filled. He responded by asking if he could intern with us after the summer interns were gone, and he did, and what a welcome year-long internship that proved to be. Among many other things, we worked on documenting the morphological transition between two apex predators, *Otodus chubutensis* and *Otodus megalodon*. That project was published in 2019 with Victor as the senior author. More recently, I have been able to assist the National Park Service and Dr. Vince L. Santucci (NPS Senior Paleontologist) to excavate and prepare Miocene dolphins from National Park lands along the Potomac River. It is exciting for me to see how former interns, now Dr. Christy Visaggi and Dr. Victor Perez have been able to assist another promising young paleontologist Michael Clinton with his interests in fossil shark teeth from Gulf Islands National Seashore."

Photo of Stephen Godfrey posing in front of an exposure of the Choptank Formation (Miocene) in Maryland (December 2022).

Introduction

Park Establishment and Setting

Gulf Islands National Seashore (also referred to as “GUIS” or the “park” throughout this document) was authorized by the United States Congress on 8 January 1971 (Schupp 2019). The park’s purpose is to preserve and interpret an interconnected system of barrier islands, wilderness, and coastal and marine ecosystems and coastal defense fortifications in Mississippi and northwest Florida, while providing for public use and enjoyment (NPS 2016a). GUIS has units in both Florida and Mississippi. The Florida units of the park include the Naval Live Oaks, Santa Rosa, Okaloosa, and Perdido Key areas, Fort Barrancas (at the Pensacola Naval Air Station) and Fort Pickens (Figures 1–3), in Escambia, Okaloosa, and Santa Rosa Counties. Apart from the Naval Live Oaks and Fort Barrancas areas, all land-based Florida units are on Santa Rosa Island or Perdido Key. The Mississippi units of the park consist of five barrier islands (Petit Bois, Sand [also known as “West Petit Bois”], Horn, and Ship Islands, as well as part of Cat Island) in Harrison and Jackson Counties. The Davis Bayou area is on the mainland (Figures 1 and 4). The park preserves both natural and cultural resources along the Gulf of Mexico, a large marine sedimentary basin that extends roughly 1,600 km (1,000 mi) from the western coast of Florida to the US–Mexico border (Williams et al. 2012). The park is more than 160 km (100 mi) long and encompasses 56,322 ha (139,175 ac), although 80% of the park’s area is submerged or intertidal (Schupp 2019). GUIS features many different natural and cultural resources ranging from remote wilderness islands with limited visitation to more-accessible white sand beaches and historic military fortifications. The natural environment at GUIS supports a wide assortment of plant and animal communities. These complex communities characterize the greater northern Gulf Coast and include bayou, salt marsh, and live oak forests (NPS 2014). Increased development in recent decades has highlighted the importance of GUIS as a refuge for threatened and endangered species. The US Fish and Wildlife Service has designated critical habitat for several special-status species within the park (Schupp 2019). Additionally, seagrass beds, migratory bird habitat, and turtle nesting sites are a few of the habitats at risk from the pressures of human development, increased visitation, and greater storm frequency in the Gulf of Mexico (NPS 2014). Between 2011 and 2014, annual average visitation was almost 5 million visitors (NPS 2016a).

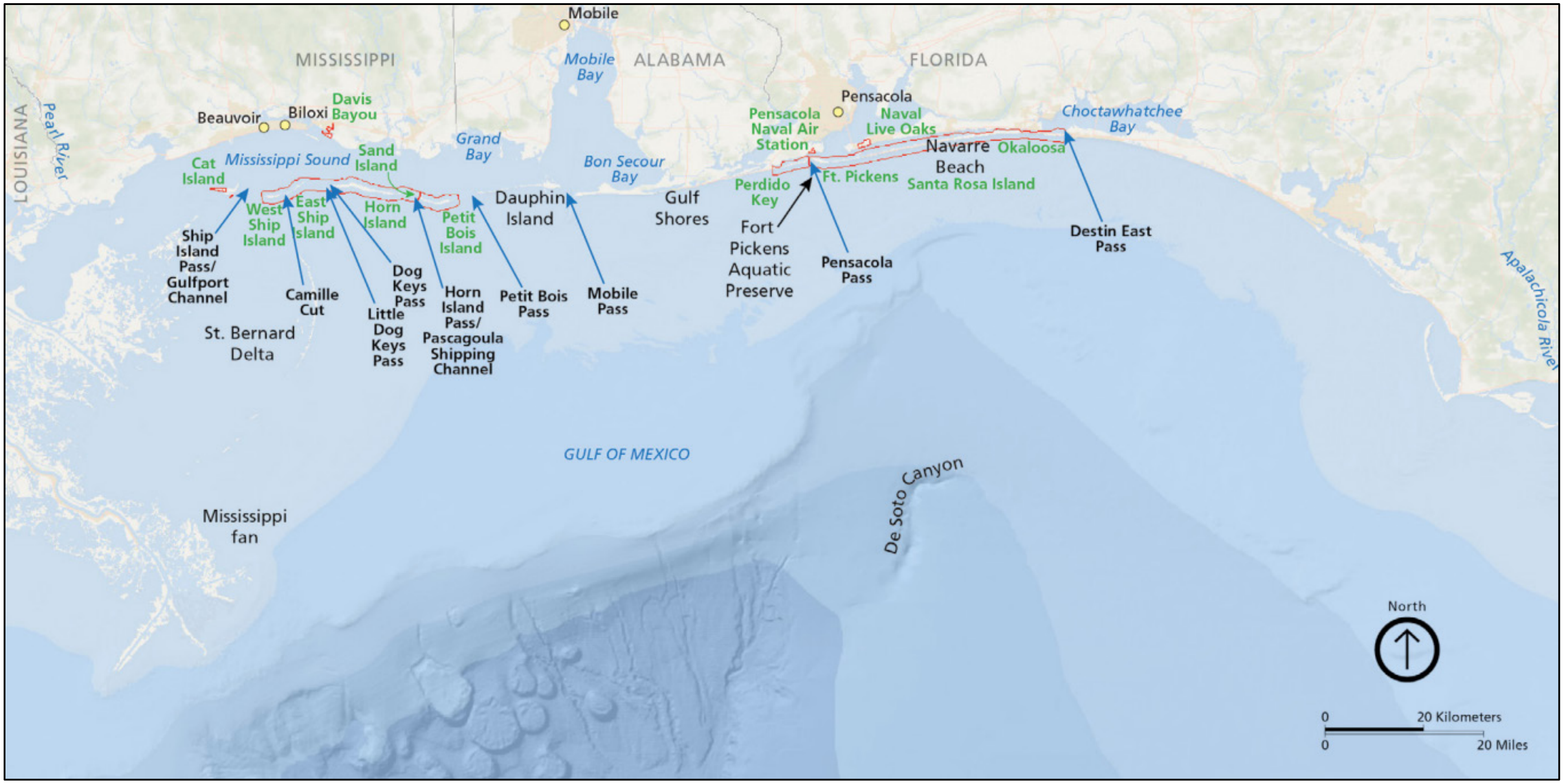

Figure 1. Map of significant features in and near GUIS. This figure identifies the locations of towns (yellow dots); islands and park areas (labeled in green); natural and artificial inlets, referred to as channels, cuts, and passes (labeled in black); bathymetric features (also labeled in black), and water bodies (labeled in blue). The park boundary is delineated in red. Bathymetry is from ESRI oceans base map. Reproduced from Schupp (2019, Figure 1). Graphic by Trista Thornberry-Ehrlich (Colorado State University).

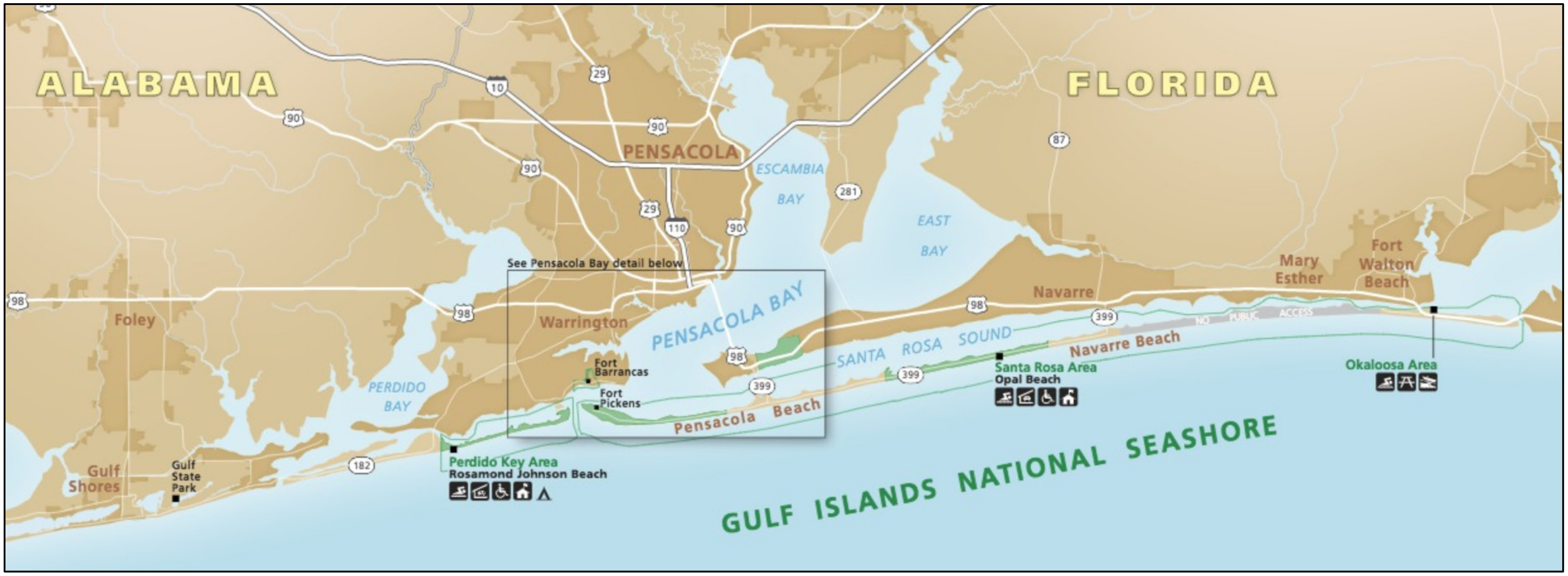

Figure 2. Location map of GUIS Floridian units. The park consists of easily accessible areas along the coast in northwest Florida. Reproduced from Schupp (2019, Figure 2). NPS graphic available at the Harpers Ferry Center cartography website.

Figure 3. Location map for Fort Barrancas, Fort Pickens, and Naval Live Oaks. Most Florida areas are accessible by car and include historic forts and beautiful beaches. Reproduced from Schupp (2019, Figure 3). NPS graphic available at the Harpers Ferry Center cartography website.

Figure 4. Location map of GUIS Mississippian units. *Note*: Ship Island is now reconnected as a single island unit. Ship Island had been separated into east and west islands during the latter half of the 20th century, and was recently reconnected in the past decade thanks to efforts by the Mississippi Coastal Improvements Project. Reproduced from Schupp (2019, Figure 2). NPS graphic available at the Harpers Ferry Center cartography website.

Florida Units

The northern water boundaries of both Santa Rosa Island and Perdido Key are delineated by the Intracoastal Waterway, an active shipping route that is maintained by the US Army Corps of Engineers (USACE) via dredging. The southern water boundary of the two islands lies 2 km (1 mi) south of the average low tide line (Schupp 2019). Santa Rosa Island extends east-west for about 76 km (47 mi) from Pensacola Pass (western extent) to East Pass near Destin, Florida (eastern extent) (Figure 1). Perdido Key has a total length of approximately 24 km (15 mi), although GUIS manages only the easternmost 11 km (7 mi). Santa Rosa Island is separated from the mainland by Santa Rosa Sound, a shallow (~9 m [30 ft] deep) lagoon that extends 58 km (36 mi). Santa Rosa Sound is connected to Pensacola Bay on the north and to Big Lagoon on the west. Big Lagoon separates Perdido Key from the mainland—and the Pensacola Naval Air Station—to the north. Santa Rosa Sound, Pensacola Bay and Big Lagoon all let out into the Gulf of Mexico via Pensacola Pass. Pensacola Pass separates the western extent of Santa Rosa Island and the easternmost extent of Perdido Key; it is approximately 1.2 km (0.8 mi) wide and has an average depth of 18 m (59 ft). Santa Rosa Island and Perdido Key generally exhibit broad, sandy beaches on their north (sound side) shores, and beaches with backshore dune complexes on the south (Gulf side) shores. Dunes on Santa Rosa Island's south beaches can vary from less than 2 m (7 ft) in height to more than 6 m (20 ft) (Houser et al. 2015). The eastern end of Perdido Key contains extensive dune complexes, with dune height averaging 4 to 5 m (13 to 16 ft) (Sankar 2015). The sediment on the Florida beaches is primarily composed of white quartz sands; the Mississippi barrier island beaches contain higher levels of clays (Foxworth et al. 1962; Hatt et al. 2016).

Mississippi Units

The boundary of the Mississippi units of the park extends 2 km (1 mi) from the mean low tide lines of the northern and southern shorelines and is contiguous from Petit Bois Island to Ship Island (Schupp 2019). All submerged lands within the 2 km (1 mi) boundary, except those around Cat Island, are part of GUIS. Only the west end and southern tip of Cat Island are managed by GUIS; the rest of the island is privately owned. Petit Bois and Horn Islands are designated as barrier island wilderness areas; the wilderness ends at the mean high tide line and does not extend over submerged lands within the park boundary. West Petit Bois Island (also known as "Spoils Island" or "Sand Island"), located within the park's water boundaries, is designated as a disposal area for nearby dredging operations of the Pascagoula Shipping Channel. This island is denoted as Disposal Area 10 (DA-10) in USACE documents (Clark 2014) and is composed almost entirely of dredge spoils. The Mississippi Sound is the relatively shallow (average of 3 m [10 ft] deep) body of water separating the Mississippi barrier islands from the mainland (NPS 2014). The islands are located from 15 to 19 km (9 to 12 mi) from the mainland across the sound. With the exception of Cat Island, all of the Mississippi barrier islands have an east-west trend along the Gulf of Mexico. The natural passes between the Mississippi barrier islands average under 5 m (16 ft) deep. There are several active navigation channels that cut through the passes; these channels are routinely dredged to depths of 9 to 20 m (30 to 66 ft) in depth (Byrnes et al. 2013). The USACE manages all regular dredging and maintenance of navigation channels in the Mississippi Sound (USACE 2016a).

Preface

This report provides detailed information on the paleontological resources of GUIS, including the history of paleontological work in the lands now within the park, geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are five appendices: Appendix A, tables of paleontological taxa; Appendix B, collections data; Appendix C, contact information for repositories; Appendix D, paleontological resource law and policy; and Appendix E, a geologic time scale.

Significance of Paleontological Resources at GUIS

GUIS has been found to have fossils, particularly shark teeth, on its shores as a result of beach management. Marine vertebrate fossils of Quaternary age are rare in the northern Gulf of Mexico, making GUIS a window on these animals. Because the fossils have also become known to amateur fossil collectors, there is also a pressing resource management concern.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Those authorities and guidance directly applicable to paleontological resources are cited below in Appendix D. Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific, and may include no action, surveys, site monitoring, cyclic prospecting, stabilization and reburial, shelter construction, excavation, closure, patrols, and alarm systems or electronic surveillance. See Appendix D for additional information on applicable laws and legislation.

Additionally, the results of paleontological resources inventories at NPS units can provide new and invaluable scientific information. In the case of the paleontological resources inventory for GUIS, the discovery and collection of previously undocumented chondrichthyan (shark and ray) fossils may be very significant. Background literature review and web searches related to chondrichthyan fossil assemblages were conducted as part of this inventory. Apart from recent studies such as those conducted at Dauphin Island, Alabama by Ebersole et al. (2017) (see the “Paleontological Localities Near GUIS” section), there is virtually no mention in the literature of chondrichthyan fossils from the western panhandle of Florida or the Mississippi barrier islands where GUIS is situated. Thus, the fossils recently collected at GUIS should be regarded as significant specimens which may prove to add much to the scientific community’s understanding of shark and ray fossil assemblages from this area.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to GUIS staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at GUIS. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, using photography, GPS data, and standardized forms.
- Identifying fossiliferous formations of interest, given fossil finds, localities and their relationship to hurricanes, dredging and beach renourishment.
- Assessing collections of GUIS fossils maintained within park collections and in outside repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- Interviewing park staff to gather information on the current status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from GUIS.

History of Paleontological Work at GUIS

No previous park-specific paleontological resources inventories have been conducted at Gulf Islands National Seashore (GUIS). However, this park was included in the 2007 Gulf Coast Inventory & Monitoring Network (GULN) paleontological resource summary (Kenworthy et al. 2007). See Figure 5 for information on GULN parks/units and boundaries. Information from the 2007 paleontological resource summary that included GUIS was culled from various articles and correspondences focused upon the geology of the seashore and offshore units encompassing this park. The 2007 paleontological resource summary noted a lack of documented paleontological resources at GUIS, especially compared to several other NPS units within the GULN. For example, the resource summary notes a well-known offshore source of fossil material adjacent to Padre Island National Seashore in Texas (Figure 5). This same summary also noted the geologically young age of the barrier islands within GUIS, with Holocene surficial sediments covering large portions of the national seashore.

Figure 5. Map of Gulf Coast I&M Network parks. Map produced by GULN staff. Reproduced from Kenworthy et al. (2007).

The 2007 network inventory report included brief findings of underlying sediment analysis done by a number of individuals over the past 80+ years. Core samples have been taken from various locations within GUIS, on barrier islands including Horn Island and Santa Rosa Island, as well as mainland areas including Naval Live Oaks, Fort Barrancas and Davis Bayou. Sediment layers ranging from Pliocene to Holocene in age have been described (Brown et al. 1944; Walton 1960; Otvos 1981a, 1988; Gohn et al. 1996; Marsh 1996). Fossil resources in the core samples have been limited to microfossils including foraminifera, ostracods, and mollusks (Table 1). None of the microfossils described from historical core sampling have been collected or stored in a repository.

Table 1. Subsurface paleontological resources at Gulf Islands National Seashore, reproduced from Schupp (2019, Table 5). Original caption: "Documented by NPS (2007, table 3), using data from Brown et al. (1944), Walton (1960), Marsh (1966), Otvos (1981a, 1982a [1982], 1988), and Gohn et al. (1996). Microfossils occur under all Mississippi barrier islands in both Holocene and Pleistocene units (Ervin Otvos, University of Southern Mississippi, professor emeritus, GRI [Geologic Resources Inventory] review comments, 15 September 2017)."

Location	Age	Fossils
Horn Island	Holocene	Microfossils, echinoid spines, fragmented mollusks, and molluscan molds
Horn Island	Late Pleistocene	Foraminifera and other microfossils, ostracods, mollusks, dinoflagellates, and pollen
Santa Rosa Island	Late Pleistocene	Foraminifera and mollusks
Davis Bayou	Pleistocene	Foraminifera, mollusks and ostracods

There are currently several paleontological specimens cataloged into the GUIS park collections, all housed at the Southeast Archeological Center (SEAC) in Tallahassee, Florida. These specimens were collected in 1940 by researchers from Columbia University, at the "Carrabelle Site" in Franklin County, Florida (Hank Kratt, Supervisory Museum Specialist, Southeast Archeological Center, pers. comm., 2019). However, while the "Carrabelle Site" specimens are labeled under the GUIS collections at SEAC, it appears these specimens were collected outside of lands managed by GUIS and are not representative of any paleontological resources present at GUIS proper. One of the specimens, which was described through personal communication to the authors of the 2007 paleontological resource summary, appears to be a mineralized fossil and may be a mollusk shell. This specimen was found in association with an archeological site (Kenworthy et al. 2007). This shell may be specimen GUIS 29237, housed at SEAC, based upon a similar description (Justin Tweet, pers. obs., 2022). Another specimen, labeled GUIS 25726, is a small, 9.5-gram (0.33-ounce) fragment of what may be mastodon tusk. There may be other specimens associated with the 1940 survey attributed to the GUIS collection at SEAC; further information such as the locality or collection coordinates of these specimens is not known (see Appendix C for SEAC contact information).

Summary of Paleontological Surveys

The first official paleontological resources inventory at GUIS was conducted in 2021 and 2022. Multiple field visits were made to Santa Rosa Island, Fort Pickens, and Perdido Key in Florida, and West Petit Bois, Horn and Ship Islands in Mississippi. A total of 711 fossil specimens were collected during the 2021–2022 surveys. Shark teeth dominated the collections with 632 specimens. Other fossils recovered include crab claws; stingray teeth and barbs; a bony fish tooth, spines, and otoliths (ear stones); a porcupinefish mouth plate; and turtle shell. The following are descriptions of each survey year.

2021 Paleontological Survey

Research and collecting permit GUIS-2021-SCI-0037 was approved in early November 2021 to initiate a paleontological resources inventory at GUIS. The permit proposal was made in response to a Technical Assistance Request (TAR 13327) submitted by Kelly Irick, the Natural Resources Manager for GUIS at the time. Kelly and other staff had been made aware of GUIS visitors discovering shark teeth at the beaches within park boundaries (Danise Fairchild, GUIS Remittance Technician, and Bob Pitts, GUIS Visitor Use Assistant, pers. comm., 2021). The shark teeth were believed to be fossilized. Additionally, prior discussions with the GUIS Law Enforcement Ranger raised concerns of rumored unauthorized collection of fossils (presumed to be shark teeth) on Ship Island associated with the ferry concessionaire. These accounts are now stored in the NPS Paleontology Archives in the form of memos-to-file documenting correspondence related to fossils and shark teeth internally by GUIS staff before the first permitted site visits in 2021. Additional information related to rumored unauthorized collections at Ship Island can also be found in "Paleontological Resource Management and Protection". As a result of these concerns, our primary purpose in this survey was to confirm and document the presence and distribution of fossilized chondrichthyan remains (among any other fossil resources), explore the origin of any fossils found, and attempt to collect representative specimens for identification, scientific interest, and to serve as reference voucher specimens for the park.

A paleontological resource inventory team, led by researchers from Georgia State University, participated in seven days of fieldwork during November 2021 to survey the Florida portion of GUIS and gather baseline information on paleontological resources. *Note:* The individuals participating in surveys, fieldwork and collection efforts throughout 2021 and 2022 changed daily, and sometimes even throughout survey days. Members of the main investigative team who participated in field surveys include John Michael Clinton and Christy Visaggi. Additionally, numerous other individuals associated with GUIS participated in field surveys and collection efforts throughout this inventory. For more information on additional participants, please see the "Acknowledgements" section of this report. The areas surveyed within GUIS included Santa Rosa, the Fort Pickens area, and the Perdido Key area of Florida. Park staff stationed in Florida and several local visitors provided information on fossil resources and where they may be found. The following fieldwork/collection locations in Florida are listed from east to west; this listing method is used throughout this report to maintain consistency. However, please note that localities were not necessarily surveyed chronologically from east to west. Additionally, several localities were visited multiple times during the same site visit or over multiple site visits.

As explained in the "History and Influence of Dredging/Beach Renourishment on Fossil Localities" section of this report, the fossils collected during site visits are "float" specimens and are presumed to have been transported to beach areas of GUIS via beach renourishment activities. Float fossils are specimens that have been displaced from their in situ origin location (yet may still retain scientific value). There is a documented history of beach renourishment at GUIS, with most of the sediment being sourced from nearby shipping channels in the passes between barrier islands (Kenworthy et al. 2007; Byrnes et al. 2012; NPS 2016b; Schupp 2019). Pre-Holocene fossiliferous sediment is presumed to have been excavated from the shipping channels and the ocean floor during these dredging operations, and then placed on the beaches at GUIS. While pre-Holocene chondrichthyan fossils made up the vast majority of those specimens collected, it should also be presumed that pre-Holocene Quaternary shell material (Mollusca) and possibly microfossils (dinoflagellates, foraminifera, Ostracoda) were dredged up with those chondrichthyan specimens. Relatively few presumed fossil mollusks were collected. Fossilized mollusk shell has a similar appearance to modern mollusk shell, especially when it has been weathered and exposed. Thus, it is often difficult to discern a fossil from a modern specimen. The context of dredging and beach renourishment with presumed fossiliferous sediments, as well as the confirmed presence of fossilized chondrichthyan specimens, indicates a high likelihood that at least part of the shell material associated with the chondrichthyan specimens at GUIS is fossilized as well.

Santa Rosa Island (Florida)

One day was spent surveying at GUIS beaches on Santa Rosa Island. There are several beach accesses along this stretch of coastline, including "beach access 36A" and Opal Beach (Figure 2).

Fort Pickens Area (Florida)

One collection day was spent at the westernmost portion of Santa Rosa Island, where Fort Pickens is located (Figure 3). The grounds surrounding Fort Pickens proper, the historical 19th century fortification situated at the west end of this GUIS unit, were investigated as well. Suspected fossil mollusks, mixed in a "tabby" cement, were observed within an exposed area of the fort's construction. For more information on this observation, see the "Cultural Resource Connections" section.

Perdido Key (Florida)

Four days during the November survey focused on Perdido Key, the westernmost landmass within the Florida section of GUIS (Figure 3). An additional site visit/survey of the Florida units of GUIS was conducted in December 2021. For the purpose of this site visit, only the Perdido Key section of GUIS was surveyed. One final survey at this location was done in 2022 as described in the next section.

2022 Paleontological Survey

The paleontological resource inventory work continued at GUIS under permit GUIS-2021-SCI-0037 in 2022. The paleontological resource inventory team first spent one week in March 2022 leading surveys of the Mississippi units of GUIS. Unlike the Florida units of GUIS, the Mississippi units are only accessible by watercraft. The areas surveyed for this site visit included Ship Island, Horn Island, and West Petit Bois Island (Figure 4). These areas were prioritized for several reasons. Prior literature review and web searches pointed to occurrences of fossils at Ship Island. Additionally, it was discovered that both West Petit Bois and Ship Islands have been sites of recurring sediment placement and beach renourishment activities, respectively (Byrnes et al. 2012; NPS 2016b; Schupp 2019).

Horn Island, while lacking a history of beach renourishment or any mentions of civilian fossil collecting, was still briefly surveyed in 2022 to confirm or deny presence of fossil material. Petit Bois Island, the easternmost barrier island managed by GUIS in Mississippi, was not surveyed due to a lack of available time after surveying West Petit Bois, Horn and Ship Islands. Petit Bois Island was also not prioritized for surveying because of no history of beach renourishment. However, there is at least one ancillary account of vertebrate fossil material previously collected by civilians on Petit Bois Island (Jun Ebersole, McWane Science Center, pers. comm., 2022). Cat Island, the westernmost barrier island managed by GUIS in Mississippi, was also not surveyed or prioritized; a majority of the island is privately owned, with only a small section of beaches managed by GUIS.

Later, in August 2022, Perdido Key was also revisited primarily to evaluate a beach area that had been recently renourished as well as to collect specimens. See “History and Influence of Dredging/Beach Renourishment on Fossil Localities” below for more information.

Details on localities in the “2022 Paleontological Survey” section are described below as reviewed from east to west. This listing method is used throughout the report to maintain consistency. However, please note that localities were not necessarily surveyed from east to west. Additionally, some localities were visited multiple times during the same site visit or over multiple site visits.

Perdido Key (Florida)

Renourishment was conducted on Perdido Key in the late spring of 2022 and fieldwork was conducted here in August to ensure collection before hurricane season and major storms that might influence redistribution of beach material. The sediment used in the renourishment was dredged from the bottom of the Pensacola Pass shipping channel directly east of Perdido Key (Bruce Leutscher, GUIS Chief of Science & Resource Stewardship, pers. comm., 2022). During the same site visit, previously identified localities were also revisited.

West Petit Bois Island (Mississippi)

One afternoon was spent surveying West Petit Bois Island for fossils during the March fieldwork, including areas where shipping channel sediment was known to have been placed within the previous year.

Horn Island (Mississippi)

During the March fieldwork, one morning of fieldwork was spent surveying beaches on Horn Island. This barrier island does not have a history of beach renourishment activity like other GUIS units such as Ship Island.

Ship Island (Mississippi)

Two collection days were spent on Ship Island during the March survey. Through preliminary research and inquiries to park staff, the fossil inventory team were made aware of extensive beach renourishment activity which had recently taken place at select portions of Ship Island. One of these renourished areas had been renourished with sand dredged from the old Ship Island Channel as recently as 2020. This locality was surveyed during the morning hours of the first collection day. Surveys then moved on to a second locality where the east and west ends of Ship Island had very recently (2020) been rejoined after decades of separation due to storm flooding and coastline erosion. This section of Ship Island is composed entirely of dredge material. The sediment at this locality was sourced from a different location than that of the beach sediment directly west of the main dock, as was evident from the darker-colored sediment and shell material. Another half-day was spent surveying Ship Island later in the week.

Geology

Geologic History

Much of the following content of this section, as well as the chronology for separate sub-sections, was adapted from the Gulf Islands National Seashore geologic resources inventory report authored by Schupp (2019) for the NPS Geologic Resources Inventory (GRI) program. That work, and other contributing sources, are cited when appropriate. Prior to detailing the geologic history and units reported at GUIS, a review of geomorphological features is provided to aid in understanding aspects of coastal geology.

GUIS has a wide variety of geomorphological features unique to coastal units. The following descriptions of common GUIS geomorphological features are reproduced from Schupp (2019). Active dune complexes are barren to sparsely vegetated mounds or ridges of windblown sand that form dune topography landward of the beach. Stable or Stabilized Dune Complexes are mounds or ridges of windblown sand that are typically densely vegetated with salt-tolerant grasses. The sand in these dunes is protected by vegetation and is not moving. An active overwash zone is land frequently flooded by high water and ocean waves generated by storms. It is typically low lying with sparse vegetation and composed of sand with patches of shell at the surface. An inactive overwash zone is an area historically overwashed and flooded by storm surge, such as during Hurricane Katrina in 2005. These areas are not frequently flooded by high water or ocean waves but are still vulnerable to flooding from extreme storms. The former washover sand is commonly reworked into low dunes that may be densely vegetated with salt-tolerant grasses. Beaches are mostly unvegetated strips of sand parallel to the shore that extend from the water to the seaward edge of the dunes or crest of a washover terrace. The seaward part of the beach is regularly inundated by wave run-up during high-water phases of the tidal cycle. For a complete list of geomorphological features at GUIS, please see Schupp (2019). See Figures 6–12 for geomorphological maps of GUIS land areas.

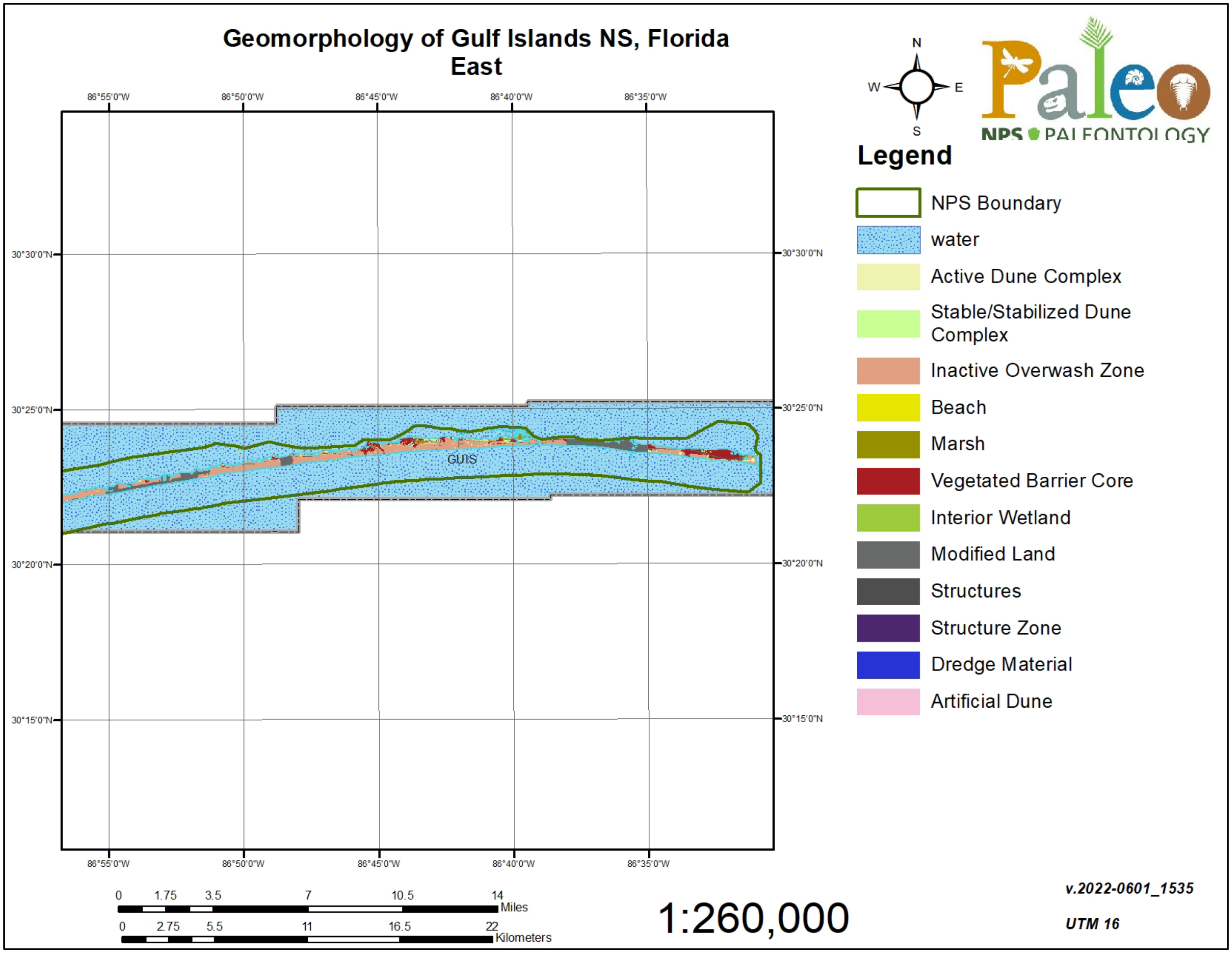

Figure 6. Geomorphological map of the eastern part of GUIS in Florida. Santa Rosa Island is near the left. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

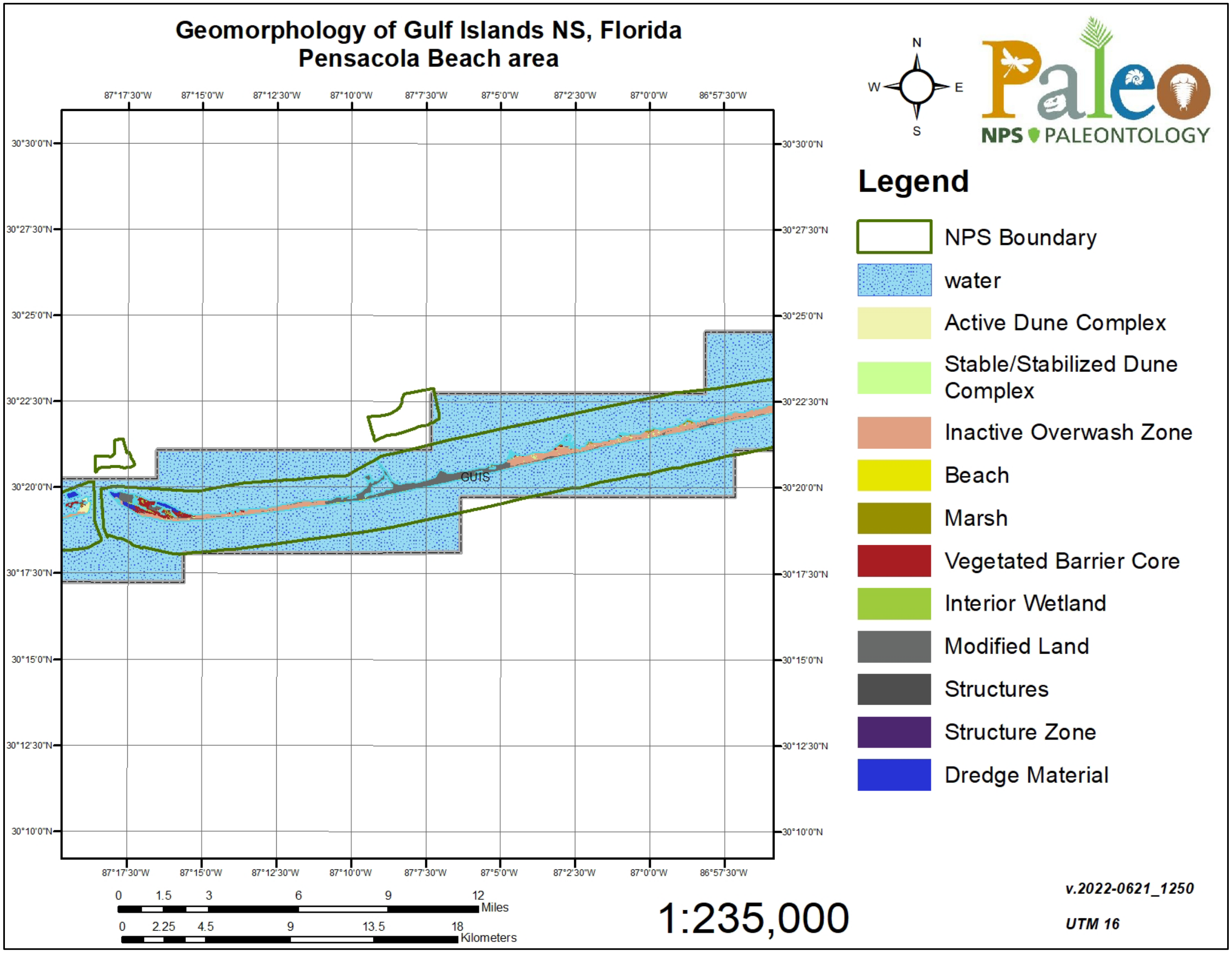

Figure 7. Geomorphological map of central GUIS in Florida. Fort Pickens is near the left. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

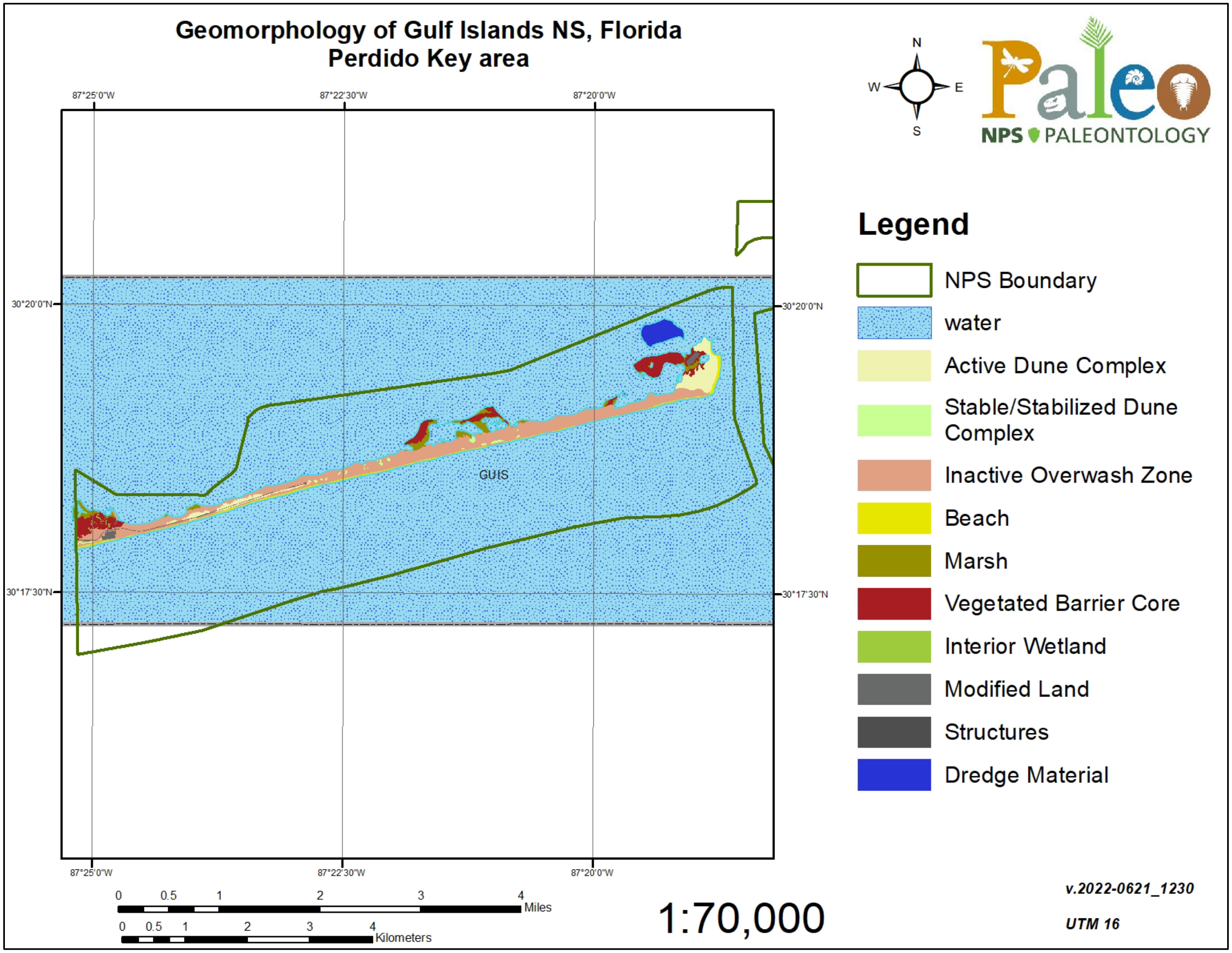

Figure 8. Geomorphological map of the Perdido Key/Johnson Beach area of west GUIS in Florida. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

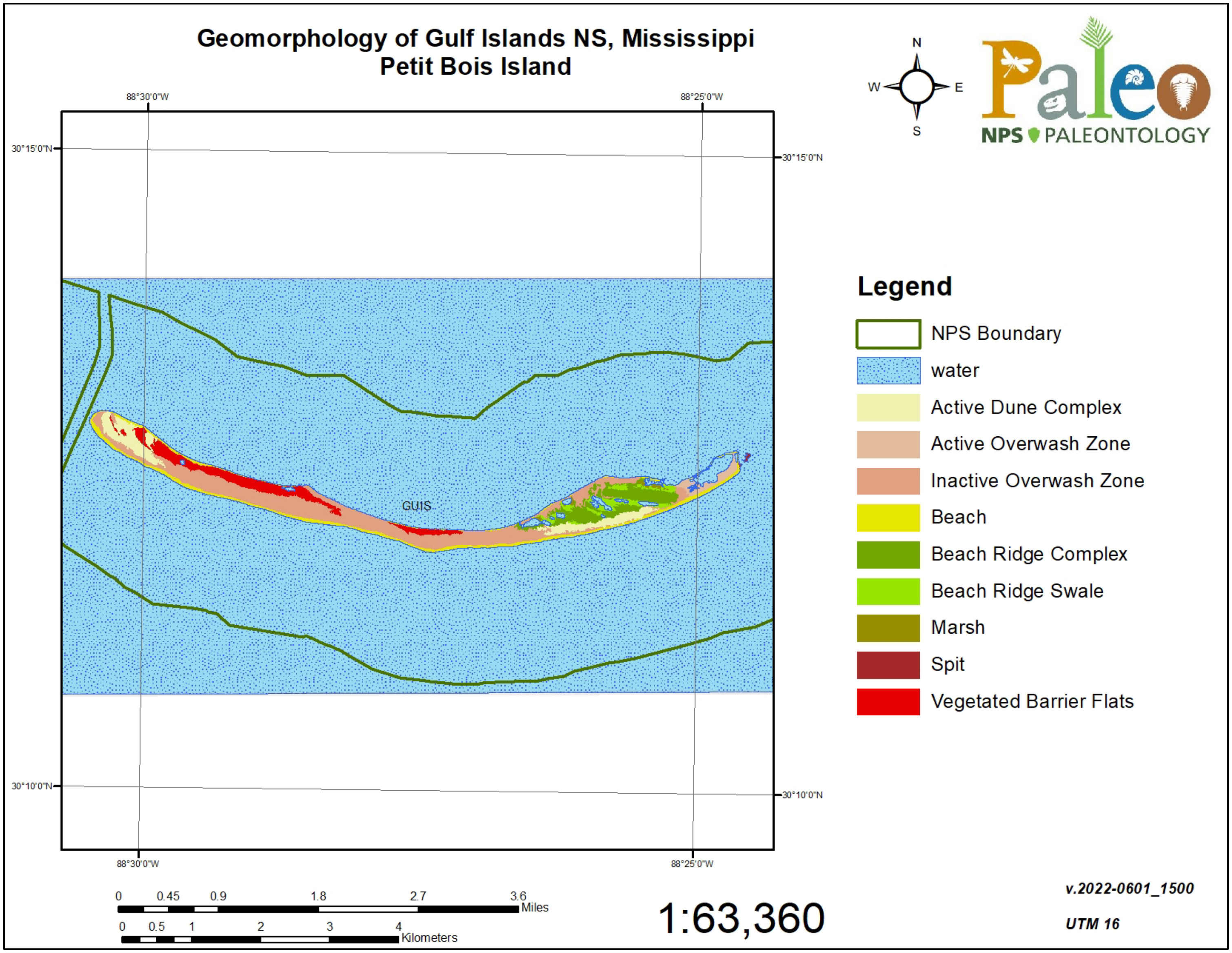

Figure 9. Geomorphological map of Petit Bois Island, GUIS, Mississippi. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

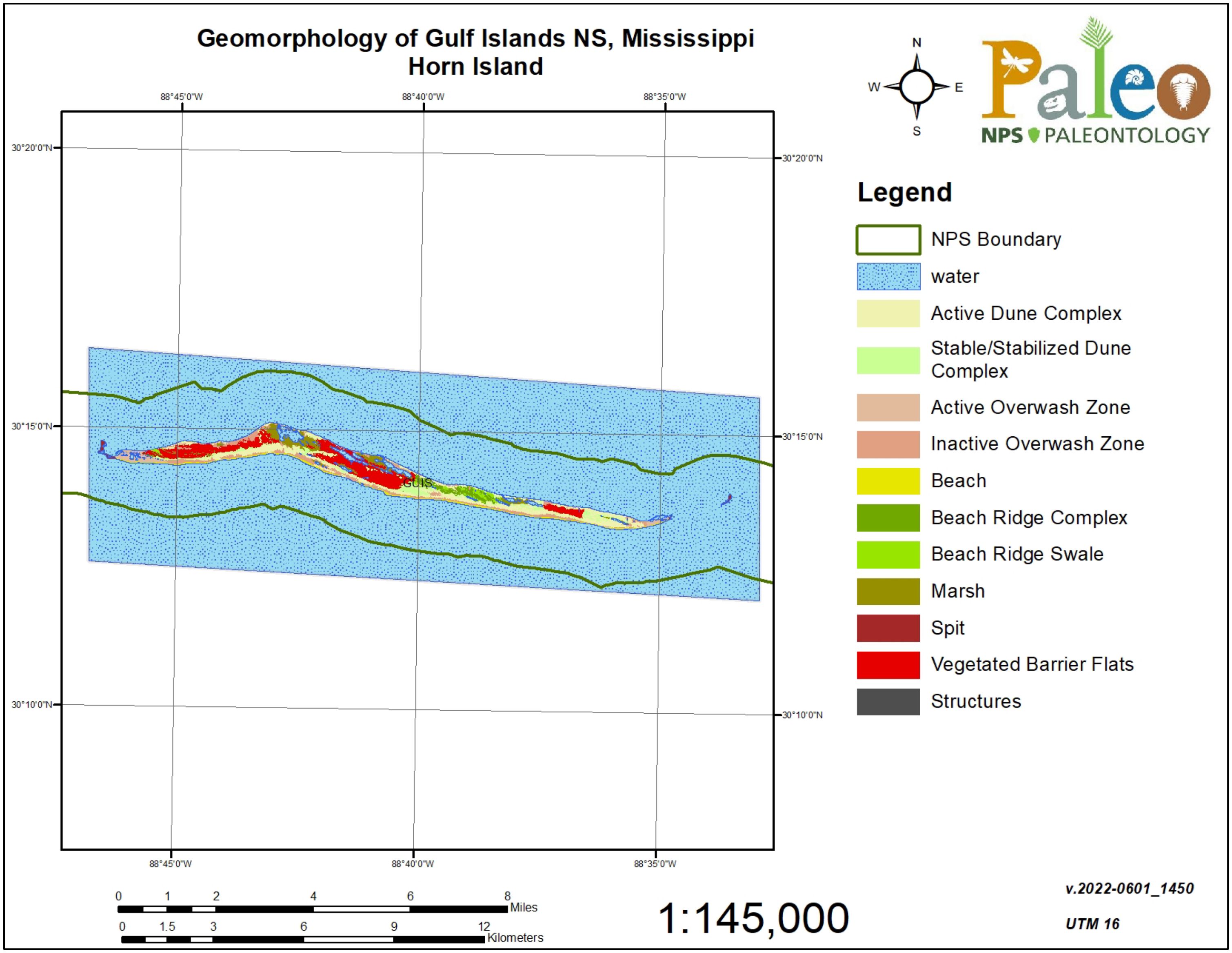

Figure 10. Geomorphological map of Horn Island, GUIS, Mississippi. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

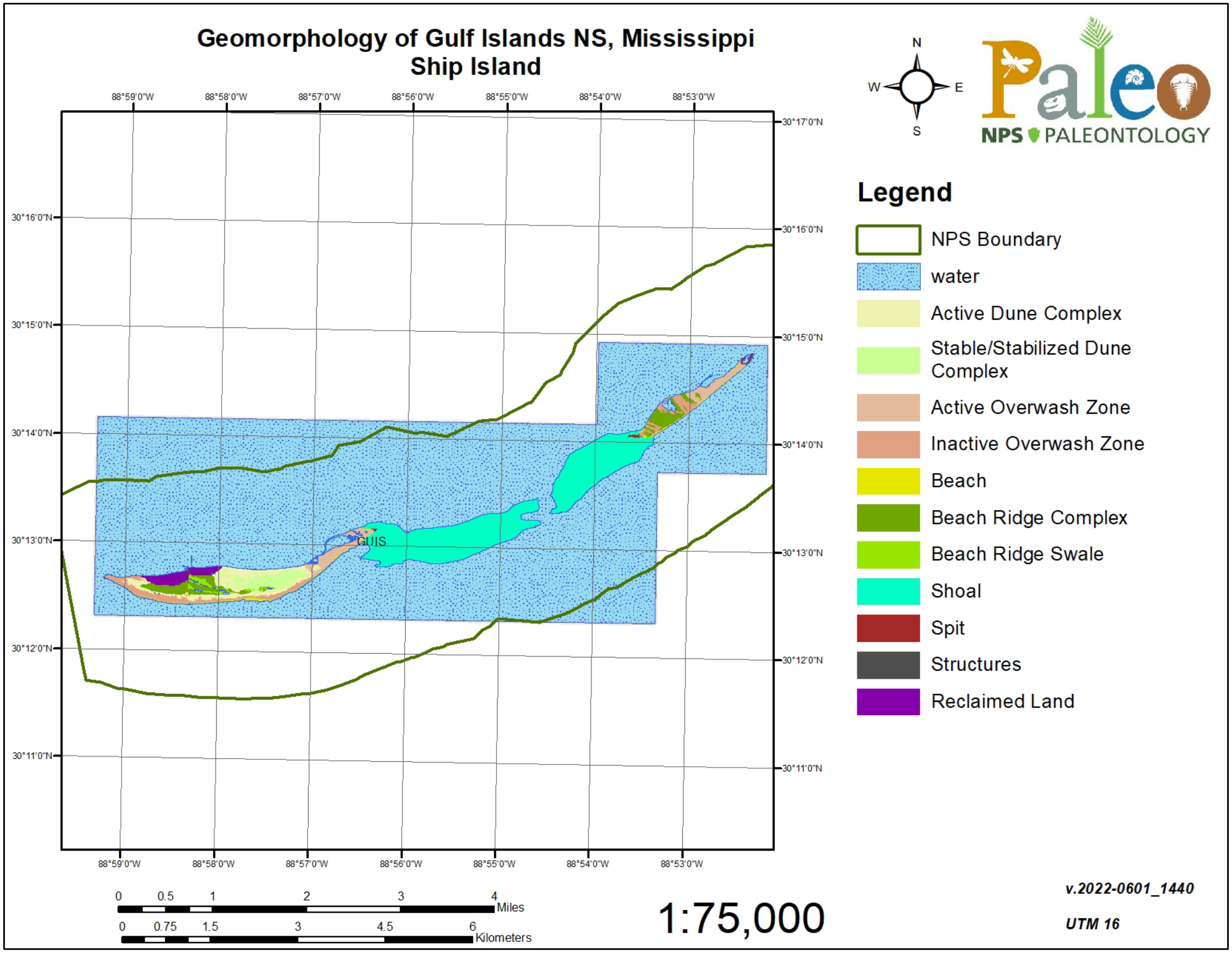

Figure 11. Geomorphological map of Ship Island, GUIS, Mississippi. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

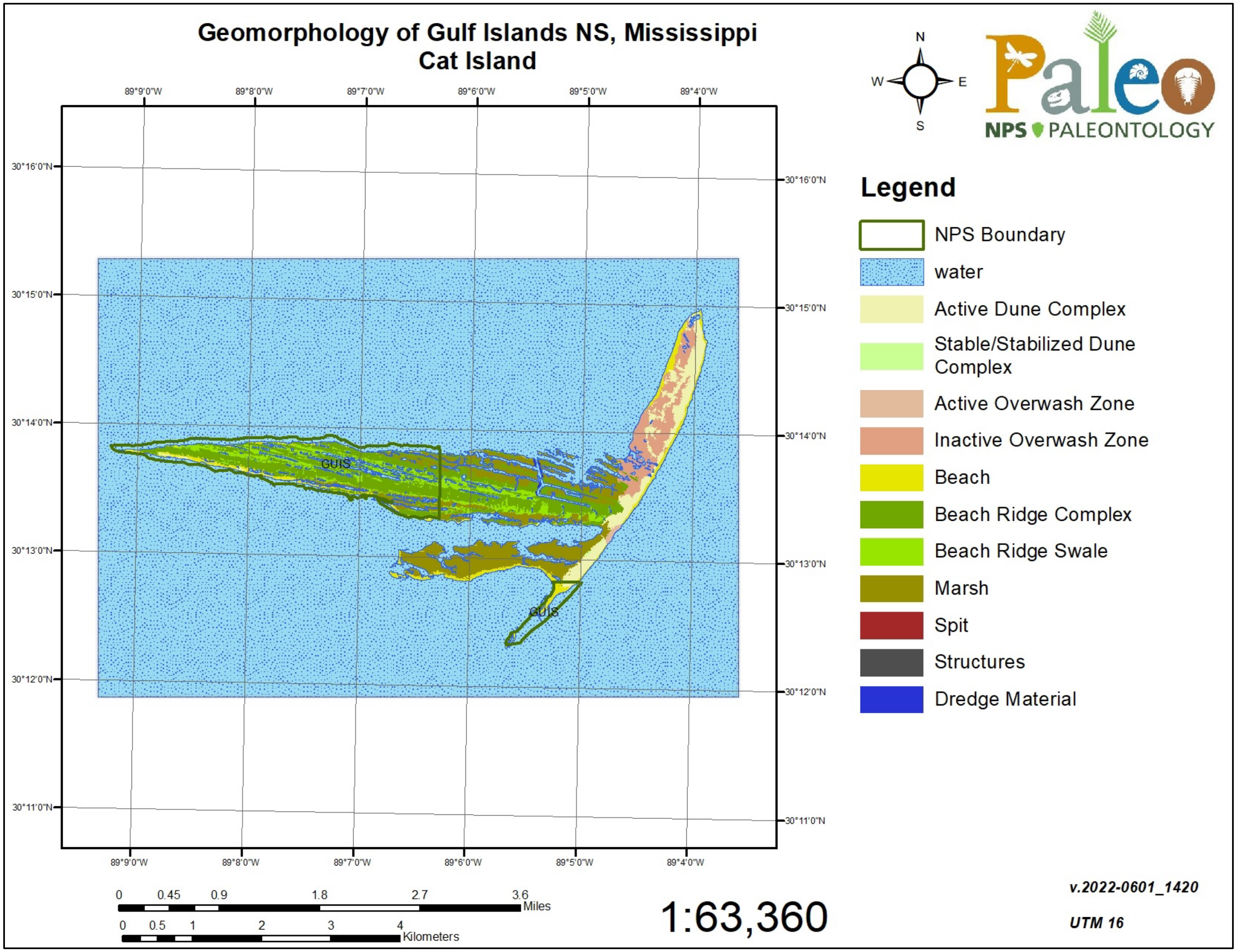

Figure 12. Geomorphological map of Cat Island, GUIS, Mississippi. Modified from GUIS GRI digital geomorphological map data at https://irma.nps.gov/DataStore/Reference/Profile/2166537.

It is important to have an understanding of the geologic history of an NPS unit when conducting a paleontological resources inventory. As sea level fluctuated over millions of years, the geologic units herein described have influenced the geospatial distribution and sediment types deposited along what is now the northern Gulf Coast. The resulting geologic framework influences landform vulnerability to modern-day coastal processes, including the location and persistence of advanced erosion and breaching (Flocks et al. 2011a) and the continuous reshaping of the modern landforms and reworking of Quaternary sediments (deposited in the past 2.6 million years during the Pleistocene and Holocene epochs). The geologic framework of GUIS also influences where potentially fossiliferous formations are located relative to the land surface, and how they formed. A summary of geologic events and corresponding stratigraphic units present beneath GUIS can be found in Table 2. *Note:* Correlation issues may exist among listed formations. There is currently a cohort of experts from Alabama, Florida, Louisiana, and Mississippi working to produce an updated geologic framework for this Gulf Coast region, which may eventually combine or invalidate certain formations listed (J. Ebersole and James Starnes, USGS, pers. comm., 2023). For reference, the descriptors "early" and "late" refer to age, while "lower" and "upper" refer to stratigraphic position. Series are the physical geological equivalent to epochs, units of age.

For Table 2, based on Table 11 in Schupp (2019), the original caption is: "The column is based on information in NPS (2007, table 2) and on interpretations by Brown et al. (1944; Davis Bayou), Marsh (1966; Santa Rosa Island), Williams (1969; Mississippi), Otvos (1982a [1982], 1995, 2001, 2004a, 2009), Champlin et al. (1994; Mississippi), and Gohn et al. (1996; Horn Island). In addition, Ervin Otvos (University of Southern Mississippi, professor emeritus) provided comments during the GRI review process (19 October 2016)… Use of "lower," "middle," and "upper" conforms to usage in source publications and not to current standards set by the International Commission on Stratigraphy." Updates to formation descriptions and dates are referenced from McCartan et al. (1995), Dockery and Thompson (2016), McNair et al. (2019), Stewart and Starnes (2019), and Stringer et al. (2020), particularly with respect to elevating the Graham Ferry Formation and Pamlico Terrace, as well as removal of the previously described Citronelle Formation (no longer listed as valid or observed at GUIS). The ages and descriptions of certain formations are also referenced from the National Geologic Map Database (https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html).

Table 2. General stratigraphic column for Gulf Islands National Seashore, reproduced with modifications from Schupp (2019, Table 11). See text for more background information.

Series	Timing of Event	Geologic Unit	Description
Holocene	3,800–1,800 years ago	Recent marine, beach, and dune sands, and riverine sediments	MS/LA: growth and shoaling of the St. Bernard lobe of the Mississippi Delta ends sand transport to and further growth of Cat Island; delta lobe surrounds and/or buries the western sector of the island chain west of Cat Island in southwest MS and adjacent LA. Perdido Key: lower shoreface shell bed capped by a marine sand sheet.
Holocene	5,400–4,500 years ago	Recent marine, beach, and dune sands	Barrier islands began forming. Strand plains, low supratidal flats, intertidal beach sequence deposited. Under barrier islands: vertical regressive sequence from marine to aeolian deposits.
Holocene	5,400–4,500 years ago	Nearshore marine and brackish inshore sands and muds	Brackish lagoon (Mississippi and Santa Rosa Sounds), bay, salt-brackish marshes, swamps, and river delta. Horn Island: coarsening upward core shows westward migration of island.
Holocene	Less than about 11,000 years ago	Estuarine, beach, and dune deposits	At 5,000 years ago, sea level rise slows at 2–3 m (6–10 ft) below present. At 5,700 years ago, sea level is 7 m (23 ft) below present. Naval Live Oaks: unconsolidated to poorly consolidated light gray, tan, brown to black, clean to clayey, variably organic-bearing sands and blue green to olive green poorly to moderately consolidated sandy, silty, clays. Fort Barrancas: surface expression of beach ridges and dunes. Perdido Key: About 6,070 years ago, estuarine deposits (11,200 years old) are overlain by open bay deposits and a flooding surface. Horn Island: early shoreline established 9,500 years ago.
Pleistocene–Holocene	N/A	N/A	Unconformity between Pleistocene units and Holocene units.
Pleistocene	71,000–11,000 years ago Wisconsin glaciation Marine Isotope Stage (MIS) 2–4	Dunes and sand sheets	FL: dunes and sand sheets form along mainland coast and cover the Gulfport Formation. Source of the sand is the Gulfport Formation. Late in MIS 2, the lowest sea level was 120 m (390 ft) below present.
Pleistocene	130, 000–70,000 years ago Sangamonian Interglacial	Pamlico Terrace	Coastal terrace deposit. Shallow nearshore marine. MS: Forms discontinuous mainland zone north of Mississippi Sound. Comprises three terraces that occur at elevations of approximately 6–8 m (20–25 ft), 3–4 m (10–13 ft), and 1.5–2.4 m (5–8 ft). Not present beneath MS barrier islands.

Table 2 (continued). General stratigraphic column for Gulf Islands National Seashore, reproduced with modifications from Schupp (2019, Table 11). See text for more background information.

Series	Timing of Event	Geologic Unit	Description
Pleistocene	130,000–80,000 years ago Sangamonian interglacial MIS 5e, 5d–a	Prairie Formation	Floodplain alluvial deposits. Fossils uncommon. Muddy and clayey fine sands; moderately silty, fine and very fine sands. At depth, the sediments are yellowish-gray, greenish-gray and gray. Between 125,000 and 122,000 years ago, sea level was 3–6 m (10–20 ft) above present. MS: on mainland coast, bounded by Mississippi Sound and estuarine embayments. Thickness of 4.5–12 m (15–40 ft). Wedge narrows landward. Interfingers with the Biloxi Formation. FL: Deposited seaward of Sangamonian estuarine and marine unit. Light yellowish-gray, yellowish-brown, silty-sandy and sandy deposits. May be present under Santa Rosa Island as unfossiliferous silty-muddy sands.
Pleistocene	132,000–112,000 years ago Sangamonian interglacial MIS 5e	Gulfport Formation	Barrier complex. Shallow nearshore, beach and dune sands. Grades upward. Fossils uncommon. FL: Forms continuous zone north of Santa Rosa Sound. Present in the Pleistocene core below Santa Rosa Island where it is 3–10 m (10–30 ft) thick, well sorted sand. Forms eastern portion of Dauphin Island, AL. MS: Forms discontinuous mainland zone north of Mississippi Sound. Not present beneath MS barrier islands.
Pleistocene	132,000–112,000 years ago Sangamonian interglacial MIS 5e	Biloxi Formation	Present along the entire northern Gulf Coast. Shallow nearshore to estuarine deposits. Nearshore marine sands and estuarine sands-clayey sands. Contains foraminifera fossils. FL: Deposited in open nearshore marine and estuarine-lagoonal brackish environments. Clay and mud units are primarily sandy in FL. Present in the Pleistocene core below Santa Rosa Island. MS: Not present beneath Horn Island. Much muddier in MS and AL than in FL, which is sandier.
Pleistocene	216,000–176,000 years ago MIS 7	Montgomery Terrace deposits	Penultimate interglacial fluvial deposits. Present in AL, LA, and MS. Contains fossil plants.
Pleistocene	2.6 million–11,700 years ago	Undifferentiated fluvial deposits	No fossils.
Pliocene–Pleistocene	N/A	N/A	Unconformity caused by uplift, land surface erosion, and stream incision following deposition of older sediments.

Table 2 (continued). General stratigraphic column for Gulf Islands National Seashore, reproduced with modifications from Schupp (2019, Table 11). See text for more background information.

Series	Timing of Event	Geologic Unit	Description
Pliocene	5.3–2.6 million years ago	Graham Ferry Formation	Deposited in deltaic to nearshore marine environments. Clays tend to weather to a reddish orange to tan color, with outcrops exhibiting a mottled appearance.
lower Pliocene	5.3–3.6 million years ago	Perdido Key Formation	Nearshore fossil-rich marine lens 15–30 m (50–100 ft) beneath Perdido Key in northwest FL at AL border. Overlain by a 5–15-m (17–50-ft)-thick fossil-free, fine siliciclastic sandy Neogene deposit. Glaciation causes sea level to drop 60–70 m (200–230 ft).
lower Pliocene	5.3–3.6 million years ago	Fluvial and paralic deposits	Fluvial deposits found under Bellefontaine, Jackson County, MS, and elsewhere between MS and northwest FL. MS: Beneath present-day Horn Island, deposits from a migrating creek, intertidal mud flats, and estuarine channel.
lower Pliocene	5.3–3.6 million years ago	Undifferentiated fluvial and paralic deposits	Contains lower Pliocene deposits, sparse fossils. May also be in part upper Miocene (see Schupp 2019)
upper Miocene–lower Pliocene	8.9–3.6 million years ago	Pensacola Clay	FL: present beneath Santa Rosa Island (Pensacola Beach east of the Fort Pickens area). May be divided into Pliocene Graham Ferry Formation and Miocene Pascagoula Formation.
upper Miocene	8.9 –5.3 million years ago	Pascagoula Formation	Present 300–900 m (1,000–3,000 ft) below Horn Island, MS. Fluvial, estuarine, and nearshore marine (undifferentiated) deposits. Green and bluish-green clay, sandy clay, and sand; gray siltstone and sand; locally fossiliferous containing mollusks (e.g., bivalves).
Miocene	23.8–8.9 million years ago	Hattiesburg Formation	Present 300–900 m (1,000–3,000 ft) below Horn Island, MS. Fluvial, estuarine, and nearshore marine (undifferentiated) deposits. Green and bluish-green clay, sandy clay, and sand; gray siltstone and sand; locally fossiliferous containing mollusks (e.g., bivalves)
upper Oligocene–lower Miocene	27.9–18.9 million years ago	Tampa Member of Arcadia Formation	FL: present beneath Santa Rosa Island (Pensacola Beach east of the park). Hard, light gray limestone with several beds of clay.
upper Oligocene–lower Miocene	28.5–14.8 million years ago	Catahoula Formation	MS: fluvial-paralic sequences. Top of formation on sound side of islands is about 1,300 m (4,400 ft) thick at Ship Island or 760 m (2,500 ft) thick at Horn Island. Upper layer is clay, shale, and gravelly sands with black chert.
upper Oligocene	~28.5 million years ago	Chickasawhay Limestone (Catahoula Formation)	Present beneath Santa Rosa Island (Pensacola Beach east of the park). Gray, vesicular, dolomitic limestone. Marine facies of lower Catahoula Fm.

Oligocene Epoch (33.9 million to 23.0 million years ago)

Geologic units formed before the Miocene Epoch (more than 5.3 million years ago) occur deep in the subsurface of the park (more than 300 m [980 ft] below the surface). At present, Miocene and older rocks are not involved in processes that are active along the park's coastline. The oldest rock reported beneath GUIS is Oligocene in age and is present more than 1 km (0.6 mi) below the surface; it serves as little more than an aquifer and does not play an active role in modern geologic processes at the park. The Chickasawhay Limestone is present below the Pensacola Beach area of Santa Rosa Island. The Chickasawhay Limestone is considered the marine facies of the lower Catahoula Formation; the Catahoula becomes terrestrial/deltaic towards the Mississippi Embayment (J. Starnes, pers. comm., 2023). Recent work on mapping limestone in the upper Catahoula, along with vertebrate fossils in the Jones Branch Fossil Site in the lower Catahoula, establish this part of the formation as upper Oligocene instead of Miocene as previously published (J. Starnes, pers. comm., 2023). Another Oligocene formation, the Tampa Member of the Arcadia Formation, is a carbonate unit that extends north from GUIS. Both the Chickasawhay and Arcadia are gray in color and porous, and they serve as aquifers for freshwater access in GUIS and the surrounding area (Marsh 1966). The Chickasawhay Limestone is described as a marine shelf deposit (Mancini et al. 1987), while the Tampa Member of the Arcadia Formation is described as a marine deposit (Lazareva and Pichler 2007).

Miocene Epoch (23.0 million to 5.3 million years ago)

Sea levels declined greatly from 14.5 to 14.1 million years ago as the Earth experienced global cooling and increased glaciation (Otvos 1994). The sea regressed (retreated) on the Mississippi coastline during the Miocene as the Hattiesburg and Pascagoula Formations were deposited. These two formations represent paralic water sequences in which fluvial, estuarine and marine environments combined and the sediment formed in sand beds (Otvos 1994, 1997). Deposition of the Catahoula Formation, previously only considered Miocene, is now understood to be in part earlier and separate from these other units (J. Starnes, pers. comm., 2023). Formations similar to the Hattiesburg and Pascagoula were deposited in Florida during the late Miocene–early Pliocene as alluvial, estuarine and marine sands. Miocene formations can be found under Santa Rosa Island (Otvos 1985a, 1988).

Pliocene Epoch (5.3 million to 2.6 million years ago)

Sea level was higher than the present during the very early Pliocene, and the global climate was warmer. The Earth experienced another significant cooling period between 5.3 to 4.8 million years ago, which led to a sea level decline of 60 to 70 m (200 to 230 ft) (Otvos 2001). This was followed by global warming events at 4.8 and 3.2 million years ago (Krantz 1991; Kennett and Hodell 1995; Crowley 1996). The Pensacola Clay is reported as underlying Pensacola Beach east of Fort Pickens (Schupp 2019). Plant fossils, mollusks, and foraminifera have been previously documented in the hard, sandy Pensacola Clay (Marsh 1966). Depending upon the literature cited (Marsh 1966; Otvos 1988, 1994), sediments of the Pensacola Clay may be broken up into and described as the Pascagoula and Graham Ferry Formations (from oldest to youngest). While the Pensacola Clay was originally presumed to have formed from 5.3 to 3.6 million years ago as fluvial deposits collected (Marsh 1966; Schupp 2019), recent developments point to the lower facies of the Pensacola (i.e., Pascagoula Formation) as deposited during the late Miocene instead, starting around 8.9 million years ago

(Stringer and Starnes 2020). The Graham Ferry Formation, a deltaic to nearshore marine sandy clay, was later deposited during the Pliocene (Stewart and Starnes 2019; Stringer and Starnes 2020). This formation is thought to underlie much of the Gulf Coastal Plain, and outcrops are present today in Jackson County, Mississippi (Stewart and Starnes 2019). Lying 15 to 30 m (49 to 100 ft) below Perdido Key, the Perdido Key Formation has been described as a muddy, thin layer of sediment in a nearshore environment (Otvos 1988, 1994). The Perdido Key Formation is reported to be overlain by an unfossiliferous sand deposit 5 to 15 m (16 to 49 ft) thick. Toward the middle Pliocene, another cooling event occurred that resulted in declining sea levels. This was followed by alternating periods of shoreline rise and fall in the Gulf of Mexico (Lawless et al. 1997). In the span of time between 3.5 and 3 million years ago, the seas rose approximately 35 m (115 ft) (Dowsett and Cronin 1990). Beginning in the middle Pliocene up until 2.6 million years ago, higher sea levels began to decline. Toward the end of the Pliocene, the oceans transgressed (advanced) and sediment accumulation halted (Otvos 1998).

Previously, Otvos (1998) described the presumed Citronelle Formation as fossil-bearing and deposited at this time, however, several recent publications state that this is no longer a discrete formation and instead a non-fossiliferous inland terrace deposit (Stewart and Starnes 2019; Stringer et al. 2020). There is also conflicting information pertaining to the depth of the previously described Citronelle Formation under some Mississippi units of GUIS. According to Champlin et al. (1994), deposits categorized earlier as the Citronelle Formation occur 18 to 23 m (59 to 75 ft) beneath Ship Island. However, drill cores at similar depths taken at Ship Island have shown evidence of Pleistocene to Holocene-aged sediments instead (Otvos 1981a). A revised stratigraphic framework for the Pliocene and Pleistocene across this part of the U.S. Gulf Coast is not yet fully clear and more research is needed. Fossils previously attributed to the Citronelle Formation elsewhere (Schupp 2019) may not be relevant for GUIS given changed stratigraphic interpretations.

Quaternary Period (2.6 million years to present)

During the Quaternary Period, frequent fluctuations in sea level and temperature resulted in different oxygen isotope ratios recorded in the microfossils preserved in the sediments (Schupp 2019). When certain ratios are identified in the fossil record, the host stratum can be attributed to a dated Marine Isotope Stage (MIS). More than one hundred (104) marine isotope stages have been identified for the past 2.6 million years (Schupp 2019). Regressions and transgressions in the coastline surrounding GUIS can be correlated to these marine isotope stages (Schupp 2019).

Pleistocene Epoch (2.6 million years ago to 11,700 years ago)

Much like the rest of the Quaternary Period, the Pleistocene Epoch was a time of fluctuating sea levels and temperatures (Schupp 2019). The early and middle portions of the Pleistocene Epoch were characterized by a cooler climate with glacial activity and lower sea levels, and occasional brief interglacial periods (Otvos 1998). The Sangamonian, the last of several interglacial periods in the Pleistocene, occurred 130,000 to 80,000 years ago during MIS 5 (Otvos 2015). The Wisconsin glacial period followed, lasting from 71,000 to 11,700 years ago during MIS 4 through MIS 2 (Otvos 2015). Toward the end of the Wisconsin glacial period from 25,000 to 21,000 years ago, ice sheets expanded to their greatest extent and the last glacial maximum was reached (Otvos 2015).

Pre-Sangamonian Time (2.6 million years ago to about 130,000 years ago)

The northeastern Gulf of Mexico was subject to uplift and valley incisions immediately following the end Pliocene into the early Pleistocene. The regular uplift and incisions inhibited preservation of lower Pleistocene sediments. As a result, all post-Pliocene sediments predating MIS 7 (243,000 years ago) are lost from the geologic record in this area (Otvos 1975, 1981b, 2009). In fact, no pre-Sangamonian Pleistocene-aged sediments survived in the northern Gulf of Mexico (Otvos 1975). The earliest Pleistocene units preserved in the vicinity of GUIS include the Gulfport and Biloxi Formations. Due to the loss of pre-Sangamonian sediments, an unconformity exists at the end of the Pliocene in the northern Gulf of Mexico. Directly above the unconformity, undifferentiated fluvial sediment was deposited (Schupp 2019). The sediments of the Montgomery Terrace are reported as having accumulated in the region west of Mobile Bay in Alabama through Mississippi from 216,000 to 176,000 years ago (Schupp 2019). The Montgomery Terrace is reported as containing abundant terrestrial plant fossil material in Mississippi (Otvos 1997, 2001; Oivanki and Otvos 2005; E. Otvos, University of Southern Mississippi professor emeritus, 19 October 2016, pers. comm. to Schupp 2019).

Sangamonian Interglacial Stage (130,000 years ago to 80,000 years ago)

The Sangamonian Interglacial Stage began 130,000 years ago; at this time, sea levels in the Gulf Coast region were about 80 m (260 ft) lower than the present (Otvos 2001). See Figure 13 for an overview of sea level change in the northern Gulf of Mexico over the last 250,000 years. A rapid transgression ensued as melting glaciers and ice sheets contributed to rising sea levels. Temperatures reached their Sangamonian peak approximately 130,000 to 120,000 years ago, leading to a sea level 6.6 m (22 ft) above current day (Katsman et al. 2011). The Prairie Formation is reported by Schupp (2019) as the first of several Pleistocene deposits from the Sangamonian interglacial stage (although note it is dated as the youngest compared to the Biloxi and Gulfport Formations). Prairie Formation deposits are composed of river channel sediments and alluvium from floodplains, and contain very little fossil material (Schupp 2019). The relatively thin (4.5–12 m [15–39 ft] thick) formation is described as having formed seaward, creating a wedge that tapers toward the mainland (Otvos 2001).

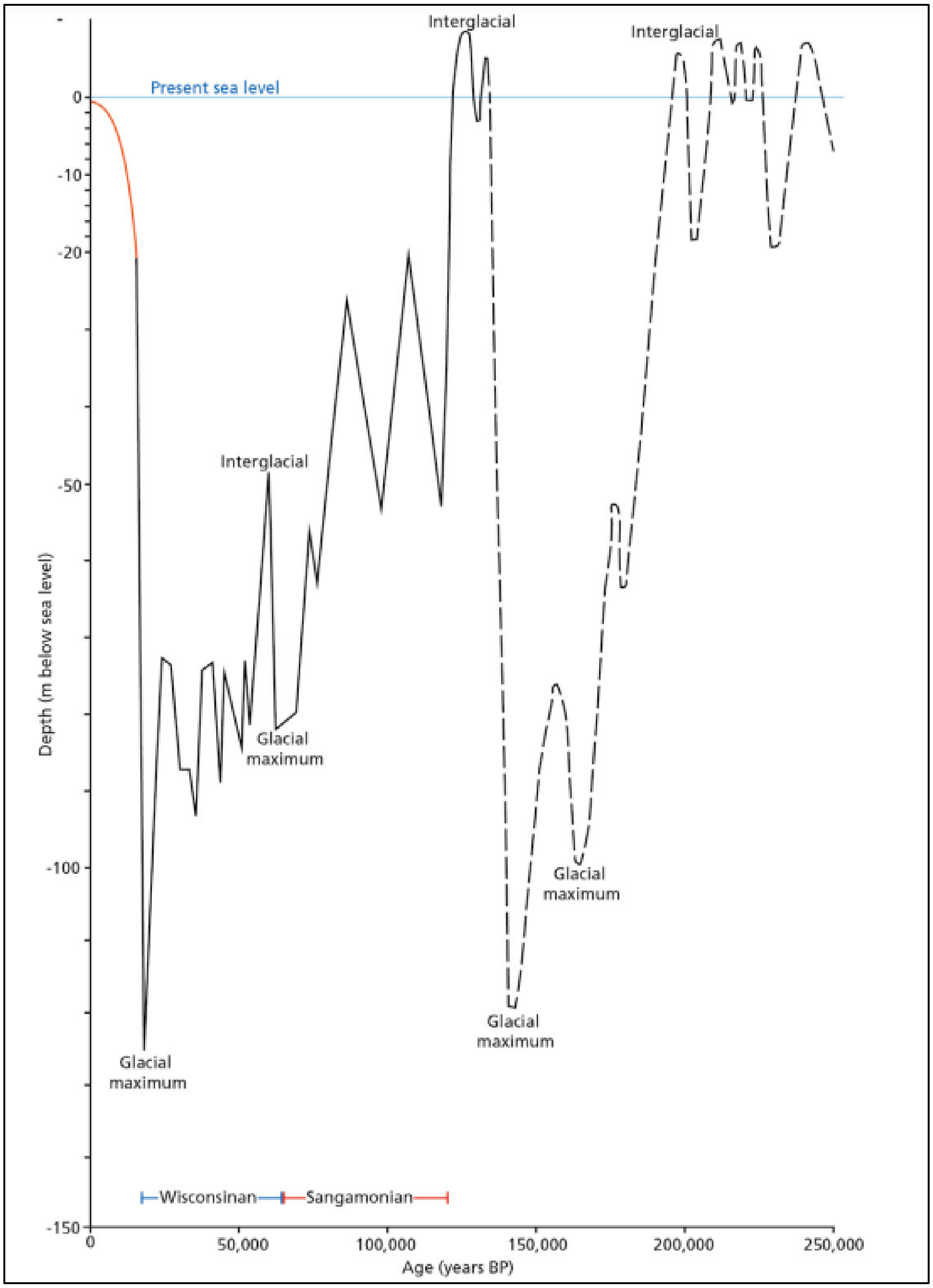

Figure 13. Graph showing sea level during the past 250,000 years. The red line shows the Holocene sea level curve for the northern Gulf of Mexico as reported by Anderson et al. (2014, figure 13). The black line shows the late Pleistocene global sea level curve from Otvos (2005a, Figure 5). The Sangamonian is the most recent interglacial stage. The Wisconsin is the most recent glacial stage. The last glacial maximum took place about 25,000–21,000 years ago. Reproduced from Schupp (2019, Figure 35). Graphic by Trista Thornberry-Ehrlich (Colorado State University).

The Biloxi Formation is reported as overlying and to have formed amid rising sea levels during the warm Sangamonian interglacial stage (Schupp 2019). The Biloxi Formation is composed of both marine sands and muddier estuarine sediments, indicating fluctuating sediment sources (Schupp

2019). Transgressions and regressions in local sea level alternated during the Biloxi Formation's deposition, with phases of both inland brackish paralic and nearshore marine sedimentation (Schupp 2019). The Gulfport Formation is reported by Schupp (2019) as overlying the Biloxi Formation, another Sangamonian interglacial stage deposit. The Gulfport Formation is described as marine sediments that formed from a barrier strand plain which prograded seaward due to wave action (Otvos 2004a). The Gulfport and Biloxi Formations are noted as present in sequence under much of the northwestern Florida coast, extending to Dauphin Island in Alabama (Otvos and Giardino 2004). The two formations tend to be less than 30 m (98 ft) thick combined (Schupp 2019). The Biloxi, Gulfport and Prairie Formations, representing the entire upper Pleistocene sequence in this region, cover an area approximately 10 km (6 mi) wide in the northeast coastal plain (Otvos 2009). This Pleistocene sequence is noted as a reference interval with other interglacial units of similar age worldwide (Otvos 2015); however, varying interpretations noted in the literature (e.g., Dockery and Thompson 2016; Ebersole et al. 2017; Schupp 2019) regarding the order of these units as to what may be overlying vs. representative of facies changes indicates that more work may be needed. The validity of all previously described formations for the Pleistocene in this region may also need to be re-evaluated (J. Starnes, pers. comm., 2023).

The Pamlico Terrace, not originally included in the formations listed by Schupp (2019), was deposited during the Sangamonian interglacial stage approximately 130,000 to 70,000 years ago (Doar 2014). The Pamlico comprises three terraces that occur at elevations of approximately 6–8 m (20–25 ft), 3–4 m (10–13 ft), and 1.5–2.4 m (5–8 ft). It may possess an overall thickness in excess of 30.5 m (100 ft) in some areas (Stewart and Starnes 2019). Cooke (1966) presumed the multi-stepped terraces of the Pamlico deposit were caused by pauses in sea levels as they were retreating from interglacial high stands. After deposition of the Pamlico ceased, sea levels continued to decline during the Wisconsin glacial stage to a depth of approximately 122 m (400 ft) below present day (Stewart and Starnes 2019).

Wisconsin Glacial Stage (71,000 years ago to 11,700 years ago)

The most recent glacial period in North America, the Wisconsin Glacial Stage, began as global climate cooled following the end of the Sangamonian Interglacial 80,000 years ago. The surrounding sea level dropped 20 to 130 m (66 to 430 ft) below present day during the first half of the Wisconsin. However, it wasn't until the last glacial maximum (LGM) approximately 25,000 to 17,000 years ago that the sea level reached its lowest extent of 120 m (390 ft) below present day (Fairbanks 1989). The modern inner and mid continental shelf formed during this time, when sea level was low and fluvial activity cut into the existing coastal plain (Otvos 2001). The Naval Live Oaks area, as well as adjacent coastal mainland areas in Alabama and Florida (including at park headquarters in Gulf Breeze), are reported as comprising reworked sediments from the Gulfport Formation (Otvos 2004a). The near marine sands of this unit are also thought to have formed the narrow core that led to the development of Santa Rosa Island (Otvos 2004a).

The Florida–Alabama–Mississippi continental shelf experienced many depositional and erosional changes throughout the late Pleistocene and Holocene Epochs. During times of low sea level, the shelf and coastal plain was incised by rivers (Flocks et al. 2011b). River deltas also formed, depositing sediment and forming lobes at the edge of the shelf (Sydow and Roberts 1994; Otvos 2018). The ancient deltaic lobes formed adjacent to 11-m (36-ft)-tall reef mounds, called pinnacle reefs (Ludwick and Walton 1957). These reefs were made up of calcareous algae and occurred at two different depths: 74–82 m (240–270 ft) and 105–120 m (345–390 ft) below sea level (Gardner et al. 2002; Flocks et al. 2011b). The two rivers responsible for a majority of the continental shelf incision in this area during the low sea levels of the Wisconsin glacial stage are the Mobile River and the Apalachicola River. The Mobile River Valley created many ancient deltas along the inner and middle continental shelf (Kindinger 1988; Kindinger et al. 1994; Flocks et al. 2011b). Fluvial and estuarine sediments gradually filled in the incised river valleys and channels as the sea level started rising (Flocks et al. 2010).

Holocene Epoch (the past 11,700 years)

Following the LGM and leading into the early Holocene Epoch, ice sheets and glaciers melted due to global warming (Schupp 2019). As the sea level rose, the Mobile and Pascagoula river valleys along the continental shelf were submerged (Anderson et al. 2016a). Between 8,000 and 7,000 years ago, the Mississippi Sound began accumulating a distinctive mix of sandy estuarine and marine mud (Twichell et al. 2011). Later, a thin layer of muddy sand also accumulated on the continental shelf south of the present-day Mississippi barrier island units (Twichell et al. 2011). The sea level was only about 6 m (20 ft) below the current day level 7,000 to 6,500 years ago (Schupp 2019). Much of the nearshore Gulf Coast developed with muddy, brackish waters fueled by runoff from streams (Otvos 2001). As sea levels rose, a high ridge of Gulfport Formation deposits off the coast of Alabama was cut off from the mainland. This newly formed island became what is known as Dauphin Island (Figure 1; Schupp 2019). Sea levels rose steadily until the rate slowed approximately 5,500 to 5,100 years ago (Otvos 2004b; Anderson et al. 2014, 2016a). A submerged shoal platform formed east of Dauphin Island and effectively cut off the Mississippi Sound from the rest of the northern Gulf of Mexico, turning the Sound into a lagoonal environment with lower salinity (Otvos and Giardino 2004). It was on this shoal platform that barrier islands began to emerge, expanding seaward through a series of beach ridges parallel to the coast (Otvos and Giardino 2004). A thick deposit of muddy nearshore marine sediment separates the barrier islands units in the northern Gulf Coast from the earlier Pleistocene deposits and the shoal platform (Schupp 2019). Smaller shoals formed and are present up to 20 m (66 ft) in depth in the northern Gulf Coast (Flocks et al. 2011a). The Mississippi River's St. Bernard delta lobe covered the mid continental shelf and was a major source of infill sediment for the earlier fluvial channels and valleys (Schupp 2019). The previously infilled fluvial channels and valleys present along the continental shelf may be more susceptible to erosion than the surrounding area. As a result, erosional damage and island breaching may be exacerbated in these areas (Flocks et al. 2011a). East of the Mississippi River delta activity, Holocene deposits are present in the form of shoal platforms, transgressive marine sediments, and sand sheets (Schupp 2019). Many of the shoals that formed throughout the Holocene survived to the present day and are present along the continental shelf in this region (Flocks et al. 2011b). The shoals were evidently formed due to reworking of older, lower Pleistocene deposits (Morton 2007). See Figure 14 for a typical geologic composite cross section across northern Gulf of Mexico coastal plain terrace units.

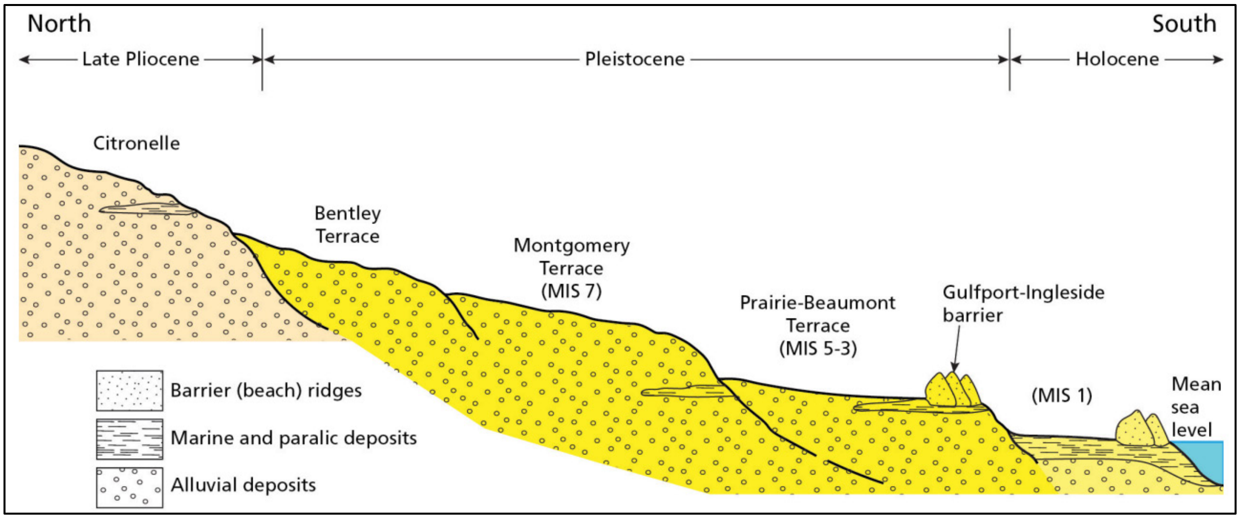

Figure 14. Generalized composite cross section across northern coastal plain terrace units. No scale. This combination of all the major coastal landforms is not found in site-specific shore-normal cross sections, and elevation and width are highly variable between locations. Coastal terrace deposits older than the Montgomery Terrace are present only in northwestern coastal plain and are absent from the northeastern coastal plain. Marine isotope stages (MIS) coincide with times of high and low sea level. Reproduced from Schupp (2019, Figure 37). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Otvos (2005b, Figure 1).

Florida Barrier Islands

Santa Rosa Island

The development of Santa Rosa Island is a topic of debate, with two leading hypotheses. There is evidence to suggest that this island began as a large shoal that accumulated sand from coastal units further east and eventually breached the surface 4,000 to 3,500 years ago (Otvos 1982, 2005a, 2005c). The shoal would have contained a core of reworked Pleistocene deposits and represented a high point in the surrounding continental shelf (Otvos 1985a). The core of the shoal under Santa Rosa Island may have been composed of sands from the Gulfport Formation (Otvos 1982). The other hypothesis for Santa Rosa Island's genesis involves a series of transgressive events, and is supported by findings from Hsu (1960), Kwon (1969), Stone et al. (1992, 2004), Stone and Stapor (1996), and Houser (2012). The island unit would have retreated toward the mainland, leaving a layer of Holocene sands over the Pleistocene Gulfport Formation (Parker et al. 1992; McBride and Byrnes 1995; Otvos and Giardino 2004; Otvos 2005a, 2005c). The sediment contributing to Santa Rosa Island's development was sourced from Pleistocene coastal dune deposits further east, as far as Apalachicola (Otvos 1982, 1997). See Figure 15 for a geologic cross section of the northwest Florida panhandle, spanning Perdido Key and Santa Rosa Sound.

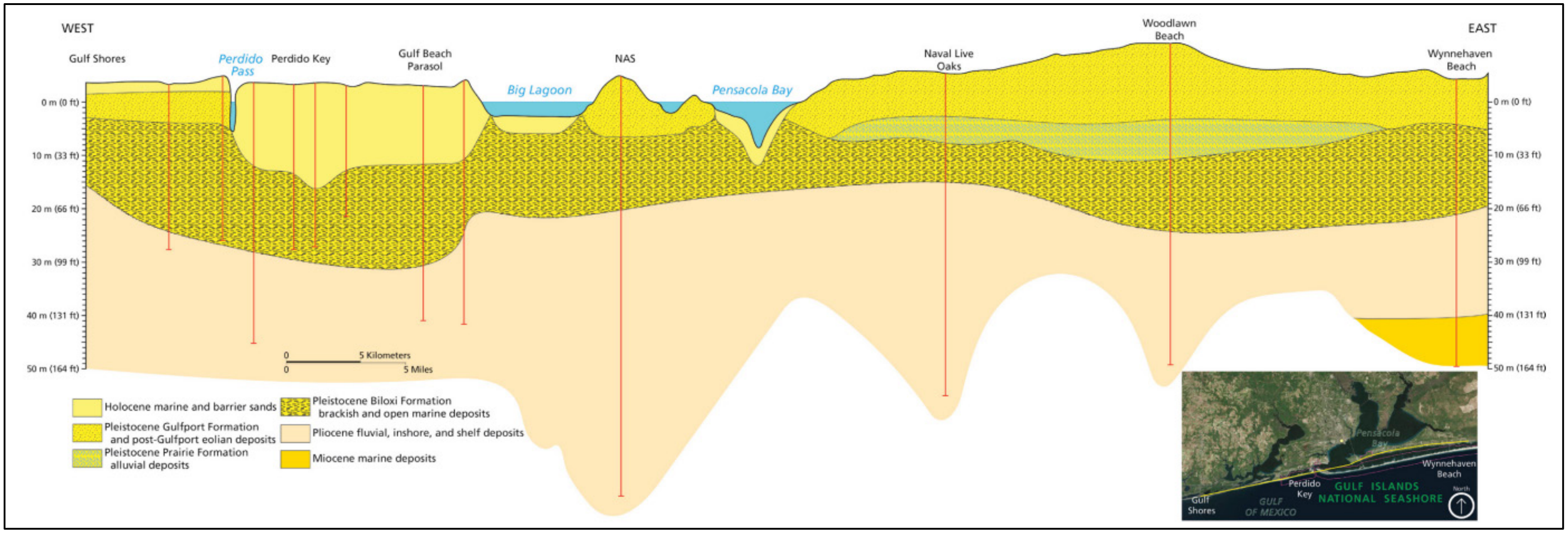

Figure 15. Cross section of the northwest Florida panhandle coastline, from Gulf Shores to Wynnehaven Beach. The cross section extends from Gulf Shores, Alabama, eastward through Perdido Key, Pensacola Naval Air Station (NAS), Naval Live Oaks, and along the mainland shoreline of Santa Rosa Sound (Florida). Red lines indicate locations of cores that support the stratigraphic interpretation. Reproduced from Schupp (2019, Figure 34). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Otvos (1985a, Figure 3) and Otvos (1988, Figure 3).

Perdido Key and Perdido Shoals

Much of the wider western end of Perdido Key shares the same geologic history as the mainland coast to the west, extending to Mobile Bay (Schupp 2019). This region of coastline expanded seaward during the Holocene Epoch, before the formation of Santa Rosa Island (Schupp 2019). Perdido Key became separated from the mainland when the Intracoastal Waterway was created (Schupp 2019). Historical vibracore samples taken at 10 m (33 ft) of depth near Perdido Key show Pleistocene deposits that mark an unconformity (Schupp 2019). Above the Pleistocene deposit are Pleistocene/Holocene estuarine sediments, and above those are open bay sands from the Holocene (Schupp 2019). A shell bed, overlain by sand, was deposited over the beaches of Perdido Key during the latter part of the Holocene Epoch (McBride et al. 1999).

Mississippi–Alabama Barrier Islands

The barrier islands along the coasts of Mississippi and Alabama feature similar geologic sequences with many of the same formations. Holocene sediments have formed a 4 to 7 m (13 to 23 ft)-thick layer on the bottom of the Mississippi Sound (Twichell et al. 2013). Formation of Ship Island began as 2 to 4 m (7 to 13 ft) of Holocene mud and muddy sand accumulated on a Pleistocene unconformity (Otvos 1985b). Approximately 4,600 years ago, two islands which would eventually become Ship Island emerged (Otvos 1985b; Twichell et al. 2011). When the St. Bernard deltaic lobe expanded to its furthest extent 4,000 years ago, wave action decreased in the Mississippi Sound and westward sand transport to Ship Island was limited (Otvos 1981a; Otvos and Giardino 2004). However, Ship Island once again received new sediment as the St. Bernard lobe dissipated 1,800 years ago (Otvos and Giardino 2004). Horn Island began forming 4,000 to 3,000 years ago as sediment aggregate on a platform of Holocene sands (Otvos 1970, 1979).

Dauphin Island

Dauphin Island formed as a result of sediment accumulation on a large Pleistocene beach ridge as sea level rose throughout the Holocene (Schupp 2019). Dauphin Island grows westward due to littoral drift and is fed by sediments from the Mobile Bay ebb tidal shoal (Schupp 2019). At its widest, Dauphin Island is approximately 2 km (1 mi) (Otvos 1985b, 2005c).

Cat Island

Cat Island's core formed about 5,400 years ago, consisting of an ancient barrier island where the north-central Cat Island beach ridge complex is currently located (Miselis et al. 2014). More sediment was deposited beneath the current location of the south beach ridge complex about 4,000 to 3,600 years ago (Miselis et al. 2014). The St. Bernard deltaic lobe contributed sediments to the south and east beaches of Cat Island as it expanded (Miselis et al. 2014). The deltaic lobe simultaneously disrupted transport of sediments to Cat Island from Ship Island, creating a deficit on the eastern margins of Cat Island leading to shoreline erosion (Otvos 1979; Otvos and Giardino 2004).

The eroded sediments migrated to the middle spit and north beach complex of Cat Island 2,000 to 1,500 years ago (Miselis et al. 2014). Cat Island continued to experience erosion as the St. Bernard deltaic lobe diminished in activity (Otvos and Giardino 2004).

Recent Barrier Island Evolution (1848–present)

Perdido Key

Multiple inlets and canals have been constructed in the areas adjacent to Perdido Key over the past 150 years (Schupp 2019). The eastern extent of Perdido Key is low-lying and has historically been subject to storm surge and overwash during large storm events (Doyle et al. 1984).

Santa Rosa Island

The recurved beach ridges present at Pensacola Pass along the Fort Pickens area of Santa Rosa Island are a recent development, having formed in the last 250 years (Lewis et al. 2003). The low-elevation coastline east of Pensacola Beach is highly susceptible to overwash from storms (Schupp 2019). Some of the largest storm events in recent history, Hurricane Frederic in 1979 and Hurricane Opal in 1995, submerged a majority of Santa Rosa Island and wiped out 5-m (16-ft)-tall dunes (Doyle et al. 1984; Pendleton et al. 2004). The island has also been breached on multiple occasions, including Hurricane Ivan (2004) and Hurricane Dennis (2005) (Schupp 2019).

Mississippi–Alabama Barrier Islands

Dauphin Island and Petit Bois Island were once a single island unit, which was breached at some point in the early 18th century by a large storm (Otvos 1979; Otvos and Giardino 2004). Following the breach, the eastern shore of Petit Bois began eroding and the island slowly moved westward (Schupp 2019). At different points in time over the past 250 years, Petit Bois Island has grown and shrunk in both length and area. The island was 19 km (12 mi) long in the mid-1800s, but shrank to 9 km (6 mi) long by the early 1900s (Schupp 2019). See Figure 16 for a geologic cross section spanning from mainland Mississippi to Petit Bois Island. Petit Bois Pass, the span between Dauphin and Petit Bois Islands, continually expanded in width from 2 to 8 km (1 to 5 mi) from the late 1800s to the 1970s (Otvos and Carter 2008). Erosional forces have been exacerbated at the east end of Horn Island as ebb-tidal delta development within the expanding Petit Bois Pass has diminished westward sediment transport (Otvos and Carter 2008; Twichell et al. 2011).

Petit Bois Island represents an example of the effects of human intervention on the natural westward migration of the Mississippi–Alabama barrier islands. Until the mid-20th century, Petit Bois Island was migrating westward at a rate of 39 m (130 ft) per year (Byrnes et al. 2013). Eroded sediment would collect at the west end of the island, and directly west of it in the Horn Island Pass. Due to increased dredging and maintenance of the Pascagoula Channel within Horn Island Pass, much of the westward littoral sediment transport and accumulation from Petit Bois Island has ceased (Schupp 2019). From the 1960s into the 21st century, Petit Bois Island has experienced continued erosion and migration to the northwest (Schupp 2019). More recently, vegetation has limited erosion at the eastern end of the island and has stabilized its beaches (Flocks et al. 2011a).

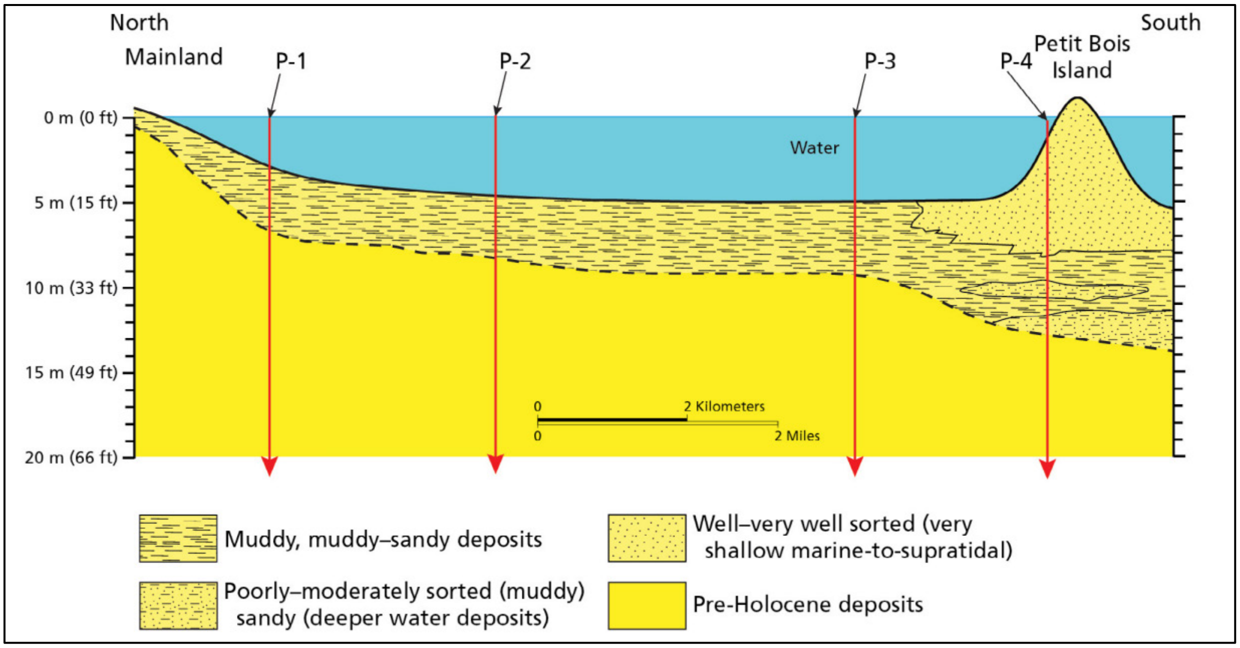

Figure 16. Geologic cross section from mainland Mississippi to Petit Bois Island. This figure includes a cross section that shows the sediments beneath the Mississippi Sound and Petit Bois Island. Red lines indicate locations of cores that support the stratigraphic interpretation. Reproduced from Schupp (2019, Figure 43, lower part). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Otvos (1981a, Figure 4).

West Petit Bois, also known as Sand Island, is composed entirely of dredge spoils from the immediate area. The island was first established in the early 1970s as part of the Pascagoula Harbor Federal Navigation Project (Schupp 2019). After several decades of existence, West Petit Bois Island has developed to feature many characteristics of the other Mississippi–Alabama barrier islands including vegetative growth and wildlife (Gary Hopkins, GUIS biologist, pers. comm., 17 August 2015, as cited in Schupp 2019).

In recent history, Horn Island has remained relatively stable compared to the other Mississippi–Alabama barrier islands. Horn Island has varied in length between 18–21 km (11–13 mi) and held close to about 1 km (0.6 mi) in width, losing only 26% of its total land area since the mid-1800s (Otvos and Carter 2013; Schupp 2019). A small isle, known as the Isle of Caprice, formed west of Horn Island and was periodically resubmerged throughout the 19th and 20th centuries until it eroded and dissipated in 1940 (Otvos 1979). The periodic dredging to deepen the shipping channel within Horn Island Pass has greatly limited littoral sand transport to Horn Island (Knowles and Rosati 1989; Douglass 1994; Otvos and Carter 2013).

Ship Island has an extensive history of erosional processes and storm damage. Throughout the past 200 years, Ship Island has been breached in multiple locations by hurricanes (Falls 2001; Otvos and Carter 2008). There are also relict washover lobes present on West Ship Island, most likely created by hurricanes in the first half of the 20th century (Otvos and Carter 2008). See Figure 17 for a geologic cross section spanning from mainland Mississippi to West Ship Island. Hurricane Camille

(1969) proved very destructive to Ship Island, removing approximately 3 km (2 mi) of the thin island center and separating the east and west sides of the island. East and West Ship Islands (Figure 4) continued to experience erosion into the 21st century, especially after large storms such as Hurricane Katrina in 2005 (Schupp 2019). By the early 2010s, Ship Island had lost approximately 58% of the square area it had in the mid-1800s (Otvos and Carter 2013). Beginning in 2017, restoration efforts have reconnected East Ship Island to West Ship Island through the Mississippi Coastal Improvement Project (USACE 2016b).

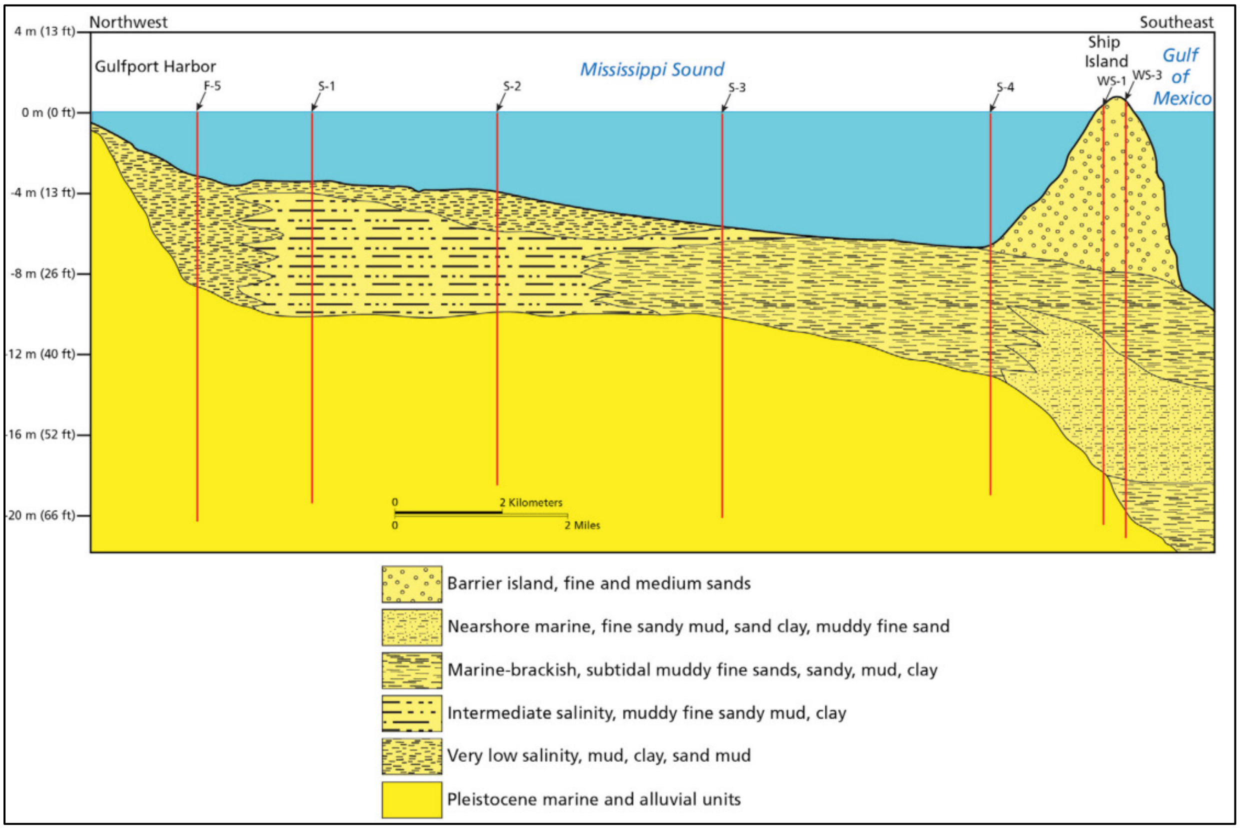

Figure 17. Geologic cross section from Gulfport Harbor, Mississippi, to West Ship Island and the Gulf of Mexico. This cross section shows the Quaternary sediments below Gulfport Harbor (left), across Mississippi Sound and West Ship Island, to the Gulf of Mexico (right). Red lines indicate locations of cores that support the stratigraphic interpretation. Reproduced from Schupp (2019, Figure 42). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Otvos (1981a, Figure 3).

Similar to Petit Bois Island, increased dredge activity west of Ship Island in recent decades has influenced the island's natural westward migration. Continued management of the shipping channel at Ship Island Pass has halted expansion of Ship Island westward (Buster and Morton 2011). There is also a notable sand deficit at the east end of Ship Island, which is eroding at a magnitude three times greater than the amount of sediment provided from the Dog Keys Passes (Schupp 2019). With the continued dredging activity west of Ship Island, littoral sand transport from Ship Island to Cat Island is minimal (Knowles and Rosati 1989; Douglass 1994; Otvos and Carter 2013). The navigation channel west of Ship Island was relocated further west in 1993, abandoning the older channel and allowing some sediment accumulation at the western tip of the island (Buster and Morton 2011).

Cat Island

Cat Island's formation was influenced heavily by the expansion of the St. Bernard deltaic lobe to the south (Schupp 2019). As the delta expanded eastward, wave energy decreased and the strand plains at Cat Island began to erode (Otvos and Giardino 2004). The sediment from the strand plains on the eastern side of Cat Island was transported both north and south, accumulating and expanding into peninsulas (Schupp 2019). The peninsulas on the east side of Cat Island restricted sand transport to the rest of the island, causing the strand plains to flood and marshes to form (Otvos and Carter 2008). More than 40% of Cat Island's total area has been lost since the mid-1800s (Otvos and Carter 2013).

Coring History at GUIS

As noted by Kenworthy et al. (2007) and through recent fieldwork observations, fossil material does not regularly wash up onto the beach areas of GUIS. Prior to this inventory, the main sources of paleontological resources identified at GUIS were from subsurface wells and vibracore samples.

Florida

Marsh (1966) described the contents of a core taken east of Fort Pickens at Pensacola Beach. The core yielded both mollusk and microfossils, presumed to be Pleistocene to Recent in age.

The Gulf Coast Research Laboratory drilled fifteen cores along the entirety of Santa Rosa Island in 1972–1973, the deepest of which reached 26.5 m (86.9 ft) in depth (Otvos 1982). The core samples were dated, and they collectively represented a Pliocene–Pleistocene sequence which were reported to include (from oldest to youngest) the presumed Citronelle (no longer a discrete formation or considered to be at GUIS), Gulfport, Biloxi, and Prairie Formations (Otvos 1982). A vast assemblage of foraminifera, as well as some mollusks, were described in the core samples. A majority of the microfossil assemblages in the cores were attributed to the Biloxi Formation. Otvos (1982) noted unfossiliferous Pleistocene-aged sediments in the core samples west of Santa Rosa Island.

Mississippi

Core samples were taken across Mississippi Sound from Beauvoir to Ship Island in the mid-20th century, according to Rainwater (1964). The cores provided evidence of fossiliferous sediments under the Sound, from the Pleistocene to Recent. Bryozoans, mollusks, ostracods, barnacles, echinoderms, and foraminifera were present among the core sediments (Rainwater 1964; Kenworthy et al. 2007).

The U.S. Geological Survey took a three-unit core sample on Horn Island, Mississippi in 1991 that yielded an abundance of pollen among other microfossils in the lower core (Gohn et al. 1996). The sediment from this core was believed to represent an estuarine, Pliocene-aged paleoenvironment. Pollen was found in the upper unit of the core sample. The lithology of this unit shows a sedimentary and fossil record of sea level rise and island migration extending from the Holocene (approximately 9,470 years before present) to the present day. Pollen was found up to 4.4 m (14 ft) below the surface (Gohn et al. 1996).

Traces of pulverized plant material were noted in the middle lithologic unit of the Horn Island core sample. The sediment the plant material came out of is thought to be Pliocene, based upon lithologic characteristics and similarity to Pliocene units in nearby Jackson County, Mississippi (Gohn et al. 1996, referencing Otvos 1994).

The same USGS core sample from 1991 yielded bivalve mollusks, ostracods, foraminifera, and dinoflagellates in the lower core (Gohn et al. 1994, 1996). Mollusks, ostracods, echinoderms, foraminifera, and dinoflagellates were also found in the upper unit of the same core sample. Mollusks, ostracods, echinoderms, foraminifera, and dinoflagellates were found up to 4.4 m (14 ft) below the surface (Gohn et al. 1996). All mollusk species identified from the core sample are extant.

Geologic Formations

Context

In the following section, individual geologic formations present beneath GUIS are described. Not every formation is present beneath every land area managed by GUIS; each formation's sub-section explains which GUIS area(s) the respective formation underlies. All formations included within this section are known to contain some form of fossil material. However, no fossil specimens collected at GUIS thus far can be definitively attributed to a specific geologic formation. This is, in large part, due to the nature of how the fossils were discovered and subsequently collected. As previously stated, all surficial fossils collected at GUIS have been "float" specimens. It is presumed that pre-Holocene, fossiliferous formations have been excavated from adjacent shipping channels and the ocean floor during historical dredging operations around GUIS coastal units. These fossiliferous sediments have subsequently been placed on the beaches to renourish them, exposing the fossils within over time. No naturally occurring, pre-Holocene, fossiliferous formations are known to exist on the land surface of any of the coastal land areas within GUIS.

The lithologic makeup of GUIS, as well as the depths of individual formations, varies by location. It should also be noted that much of the information we possess related to the underlying lithology of GUIS units has come from core samples (geologic cross sections of several GUIS areas, and the approximate core locations used to determine them, can be viewed in Figures 15–17). Thus, it is difficult to definitively establish which formations are being dredged from the ocean floor and placed on beaches. It is highly probable that multiple pre-Holocene fossiliferous formations have been dredged from the several known source areas in Florida and Mississippi (see "History and Influence of Dredging/Beach Renourishment on Fossil Localities" below).

Despite the difficulty in attributing formations to the fossil specimens collected at GUIS, it is crucial to have a baseline understanding of the individual formations present. If a certain formation is known to exhibit a unique sediment texture or color, these attributes may aid identification efforts in the field. A baseline knowledge of common fossils in different formations, especially index fossils, can also benefit identification efforts. Since index fossils are only present in lithologic material from a certain span of time, their presence in the field can narrow down the possible age of a formation. A review of this section is recommended before future paleontological surveys are conducted, as it gives surveyors brief descriptions of each formation.

The description and information provided for each formation in this section are by no means comprehensive. They serve to only give an overview of the formation characteristics, pertinent fossils, and so forth. The descriptions are based upon prior literature and (in particular) Schupp (2019), the geologic resources inventory report for GUIS. However, recent developments in our understanding of the geological framework in this area of the U.S. Gulf Coast point to a need for widespread revisions of formation terminology and correlation of formations across state lines (J. Starnes, pers. comm., 2023). A cohort of experts from Alabama, Florida, Louisiana, and Mississippi are working on an updated geologic framework of the region. Until such research is published, however, all previously described formations from prior literature are included in this report. Notes have been made in individual formation descriptions for formations that may need to be revised after future research is conducted. A brief summary of all formations is included below (Table 3).

Table 3. Summary of GUIS stratigraphy and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in McCartan et al. (1995), Dockery and Thompson (2016), McNair et al. (2019), Schupp (2019), Stewart and Starnes (2019), and Stringer et al. (2020). The ages and descriptions of certain formations are also referenced from the National Geologic Map Database (ngmdb.usgs.gov). *Note:* Correlation issues may exist among listed formations. As mentioned above (J. Starnes, pers. comm., 2023), a cohort of regional experts are working on an updated geologic framework for the region, which may eventually combine or invalidate certain formations.

Formation	Age	Depositional Environment
Holocene sediments	Less than 11,000 before present (B.P.)	N/A
Pamlico Terrace	Pleistocene (130,000–70,000 B.P.)	Shallow nearshore marine
Prairie Formation	Pleistocene (130,000–80,000 B.P.)	Floodplain alluvial
Gulfport Formation	Pleistocene (132,000–112,000 B.P.)	Barrier complex. Shallow nearshore marine
Biloxi Formation	Pleistocene (132,000–112,000 B.P.)	Open nearshore marine and estuarine–lagoonal brackish
Montgomery Terrace	Pleistocene (216,000–176,000 B.P)	Penultimate interglacial fluvial
Citronelle Terrace	Pliocene–Pleistocene (3.6–1.8 Ma)	Terrestrial, fluvial
Graham Ferry Formation	Pliocene (5.3–2.6 Ma)	Deltaic to nearshore marine
Perdido Key Formation	Pliocene (5.3–3.6 Ma)	Nearshore marine
Pensacola Clay	late Miocene–early Pliocene (8.9–3.6 Ma)	Fluvial, estuarine, and nearshore marine (undifferentiated)
Pascagoula Formation	late Miocene (8.9–5.3 Ma)	Fluvial, estuarine, and nearshore marine (undifferentiated)
Hattiesburg Formation	Miocene (23.8–8.9 Ma)	Fluvial, deltaic, estuarine, and nearshore marine (undifferentiated)
Arcadia Formation (Tampa Member)	late Oligocene–early Miocene (27.9–18.9 Ma)	Marine
Catahoula Formation	late Oligocene–early Miocene (28.5–14.8 Ma)	Lower portion is marine. Upper is deltaic, fluvial–paralic sequences
Chickasawhay Limestone (Catahoula Formation)	late Oligocene (~28.5 Ma)	Marine

Chickasawhay Limestone (Upper Oligocene) (~28.5 Ma)

Description: The Chickasawhay Limestone is present below the Pensacola Beach area of Santa Rosa Island (Schupp 2019). This formation is characterized as a vesicular, dolomitic limestone and will appear gray in color (Marsh 1966). The Chickasawhay Limestone is porous, and serves as an aquifer for the immediate area surrounding Santa Rosa Island including within GUIS (Schupp 2019). This limestone is thought to be a marine facies of the lower Catahoula Formation that becomes terrestrial/deltaic towards the Mississippi Embayment (J. Starnes, pers. comm., 2023). The Chickasawhay Limestone is known to be fossiliferous; however, it does not play an active role in modern geologic processes at the park. Nevertheless, this formation is included so as to provide a more complete picture of the underlying lithology at GUIS.

Fossils found within GUIS: None to date. This and other geologic units that are deeply buried in the GUIS area may be encountered in cores but are of limited concern for paleontological resource management.

Fossils found elsewhere: At least one tooth belonging to *Carcharodon angustidens* has been described from the Chickasawhay Limestone at an excavation site in Wayne County, Mississippi (Dockery and Thompson 2016). Additionally, manatee rib sections have been described from this limestone (Dockery and Thompson 2016). The ostracod *Pokornyella saginata* is noted as being distinctly present in the Chickasawhay Limestone (Poag 1974; Dockery and Thompson 2016). Bivalves (Mansfield 1940; Marsh 1966; Dockery and Thompson 2016), gastropods (Toulmin et al. 1951), echinoids (Cooke 1959; Osbourne and Ciampaglio 2014), and planktonic foraminifera (Marsh 1966; Poag 1972) have all been identified from the Chickasawhay Limestone. Coleoidea, a subclass of Cephalopoda, is also represented in this formation (Ciampaglio and Weaver 2008).

Catahoula Formation (Upper Oligocene–Lower Miocene) (28.5–14.8 Ma)

Description: The Catahoula Formation has been listed as an upper Oligocene–lower Miocene stratigraphic unit (Dockery and Thompson 2016; Stewart and Starnes 2019) but also previously as only Miocene (McNair et al. 2019; Schupp 2019). The Chickasawhay Limestone is the marine facies of the lower part of the Catahoula Formation; this facies becomes terrestrial/deltaic towards the Mississippi Embayment (J. Starnes, pers. comm., 2023). Recent work on mapping the Heterostegina Limestone in the upper Catahoula, along with vertebrate fossils in the Jones Branch Fossil Site in the lower Catahoula, may establish this formation as solely upper Oligocene (J. Starnes, pers. comm., 2023). It is a result of paralic water sequences in which fluvial, estuarine and marine environments combined and the sediment formed in sand beds (Otvos 1994, 1997). Core logs taken on the sound side of the Mississippi barrier islands have provided depth and compositional information. The upper extent of the Catahoula Formation is reported as being approximately 1,300 m (4,300 ft) beneath Ship Island and 760 m (250 ft) beneath Horn Island (Schupp 2019). The composition at the top of the formation at these depths consists of clay, shale and gravelly sands (Schupp 2019).

Fossils found within GUIS: None to date. This and other geologic units that are deeply buried in the GUIS area may be encountered in cores but are of limited concern for paleontological resource management.

Fossils found elsewhere: In recent years, a fossil assemblage rich in terrestrial mammals and nearshore marine fauna has been described from the Catahoula Formation near Waynesboro, Mississippi. Terrestrial vertebrates include small borophagine canids, the tapir *Protapirus*, horses such as *Miohippus* and *Anchippus*, and the anthracothere *Elomeryx*. Specimens from marine fauna include teleostean otoliths from *Aplodinotus gemma*, *Aplodinotus distortus*, and "*Sciaenida*" *radians* (Starnes and Phillips 2016). Silicified wood and palm trunks are common along streams that cut into the Catahoula Formation in Hinds, Simpson and Wayne Counties, Mississippi (Dockery and Thompson 2016). The Catahoula Formation is also known to contain a rich assemblage of pteridophyte spores, pollen, fungal debris, planktonic foraminifera, dinoflagellate cysts, and freshwater algae (Wren et al. 2003).

Arcadia Formation (Tampa Member) (Upper Oligocene–Lower Miocene) (27.9–18.9 Ma)

Note: Very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network indicate that the Arcadia Formation may not be present at or near GUIS (J. Starnes, pers. comm., 2023). However, a description of the Arcadia Formation is still provided below in keeping with prior reports such as Schupp (2019).

Description: Florida: The Tampa Member of the Arcadia Formation may be present under Santa Rosa Island and extends north to the mainland from GUIS (Schupp 2019). This formation was deposited during the late Oligocene Epoch (Marsh 1966). This formation is composed of a hard limestone, is a lighter gray than the Chickasawhay Limestone, and contains clay beds (Schupp 2019).

Fossils found within GUIS: None to date. This and other geologic units that are deeply buried in the GUIS area may be encountered in cores, but are of limited concern for paleontological resource management.

Fossils found elsewhere: Numerous mollusk species (including bivalves) have been identified in the Tampa Member of the Arcadia Formation (Mansfield 1937; Marsh 1966), as well as terrestrial snails (Auffenberg et al. 2015). Additionally, fossil teeth from the family Equidae have been found near Tampa, Florida (Morgan and Hulbert 1995). However, caution is advised in reviewing fossils noted elsewhere for this formation given that it is unclear if indeed the unit is at GUIS.

Hattiesburg Formation (Lower–Middle Miocene) (23.8–8.9 Ma)

Description: The Hattiesburg Formation is a Miocene deposit that formed about 23.8 to 8.9 million years ago (McNair et al. 2019; J. Starnes, pers. comm., 2023). It is a result of fluvial, deltaic, estuarine, and nearshore marine sequences (McNair et al. 2019). The Hattiesburg Formation is found 300–900 m (980–3,000 ft) below Horn Island (Schupp 2019). It is composed of a green to blue-green clay, sandy clay, and sand. Other deposits of the Hattiesburg Formation are composed of a gray siltstone and sand (Schupp 2019).

Fossils found within GUIS: None to date. This and other geologic units that are deeply buried in the GUIS area may be encountered in cores but are of limited concern for paleontological resource management.

Fossils found elsewhere: Locally fossiliferous, including mollusks (e.g., bivalves) (Schupp 2019). Brown et al. (1944) described a marine assemblage of the infaunal foram *Amphistegina* from the Hattiesburg Formation. Terrestrial mammal remains also have been described (Dockery and Phillips 2008), including a leg bone from *Teleoceras* and a toe bone of a llama (Dockery and Thompson 2016). Additionally, vast assemblages of flora (McNair et al. 2019) and petrified wood (Dockery and Thompson 2016) have been described.

Pensacola Formation (Clay) (Upper Miocene–Lower Pliocene) (8.9–3.6 Ma)

Note: Due to very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network, the Pensacola Formation (Clay) may no longer be considered a valid formation (J. Starnes, pers. comm., 2023). However, a description of the Pensacola Formation (Clay) is provided, in keeping with prior reports such as Schupp (2019).

Description: Florida: Present beneath Santa Rosa Island (Pensacola Beach east of the Fort Pickens area). Depending upon the literature cited (e.g., Marsh 1966; Otvos 1988, 1994), deposits of the Pensacola Clay may be broken up into what are described as different formations, the Pascagoula Formation and overlying (younger) Graham Ferry Formation.

Fossils found within GUIS: None to date.

Fossils found elsewhere: Contains fossil remains of carbonized plant fragments, abundant mollusks, and foraminifera (Marsh 1966). Raymond (1983) also describes mollusks and planktonic foraminifera. However, caution is to be advised in reviewing fossils noted elsewhere for this formation given that it is unclear if it is indeed a valid formation at GUIS.

Pascagoula Formation (Upper Miocene) (8.9–5.3 Ma)

Description: The Pascagoula Formation is an upper Miocene deposit that formed 8.9 to 5.3 million years ago (Dockery 2008; Schupp 2019). It is a result of paralic water sequences in which fluvial, estuarine and marine environments combined and the sediment formed in sand beds (Otvos 1994, 1997). The Pascagoula Formation is found at similar depths as the Hattiesburg Formation beneath Horn Island, and there is little to differentiate the two Miocene formations (Otvos 1994; Schupp 2019). The Pascagoula Formation is composed of green to blue-green clay, sandy clay, and sand, with gray siltstone and sand also present (Schupp 2019). Exposures of this formation are known to weather to a bright orange color (J. Ebersole, pers. comm., 2022), similar to what had previously been used to identify other units (e.g., such coloration is no longer appropriate to characterize as a marker for the former Citronelle Formation). Sediment sequences similar in age to the Pascagoula Formation were deposited in Florida as alluvial, estuarine and marine sands during the late Miocene–early Pliocene (Schupp 2019). Those similar deposits can be found under Santa Rosa Island (Otvos 1985a, 1988).

Fossils found within GUIS: None to date.

Fossils found elsewhere: Bivalve mollusk and ostracods are present in the Pascagoula Formation (Mincher 1941). The presence of *Rangia johnsoni*, an aquatic bivalve, is thought to be a marker fossil for the late Miocene Pascagoula Formation (Dockery and Thompson 2016; McNair et al. 2019;

Stewart and Starnes 2019; Stringer et al. 2020). Additionally, the remains of numerous vertebrates have been described, including *Mammut* (mastodon), *Teleoceras* (rhinoceros), three taxa of horses, a small llama-like artiodactyl, a pronghorn-like antilocaprid, and fishes, turtles, and alligators (Schiebout et al. 2006; Cannon et al. 2014). Fish otoliths belonging to *Micropogonias undulatus* are known (Stringer and Starnes 2020).

Graham Ferry Formation (Pliocene) (5.3–2.6 Ma)

Description: The Graham Ferry Formation, found beneath Pensacola Beach east of Fort Pickens (Otvos 1994; Schupp 2019), formed 5.3 to 2.6 million years ago (Stewart and Starnes 2019) as fluvial deposits collected (Marsh 1966). The Pliocene age of this formation is supported by pollen and dinocyst samples described by Otvos (1998). Described as sandy-clayey, it correlates with the Perdido Key Formation of Florida (Otvos 1994) and may correlate with fossiliferous Pliocene deposits in the shallow coastal waters of Alabama previously described by Raymond et al. (1993). It is a series of deltaic sediments overlying the older Pascagoula Formation (Brown et al. 1944). Due to high iron content, clays in the Graham Ferry Formation have been observed to weather to a reddish orange to tan color in outcrops (Stewart and Starnes 2019). This similar coloration in weathering had previously been used as a marker for the former Citronelle Formation (no longer an appropriate practice). The contact between the lower Graham Ferry Formation and older sediments is delineated by the absence of the bivalve *Rangia johnsoni* (Dockery and Thompson 2016). The upper contact of this formation is harder to determine; it is uncomfortably overlain by unconsolidated muddy Gulf sediments, deltaic sediment and longshore barrier sands offshore in the Mississippi coast (Stewart and Starnes 2019).

Fossils found within GUIS: None to date.

Fossils found elsewhere: Stringer et al. (2020) suggested an offshore deposit of the Graham Ferry Formation as the origin of Pliocene-aged shark teeth and fish otoliths recovered from a renourished beach on Dauphin Island. Taxa represented from the deposit include: *Hemipristis serra*, *Cosmopolitodus hastalis, Urophycis regia*, *Ophidion marginatum*, *Otophidium* sp., *Porichthys* sp., *Syacium* sp., *Citharichthys macrops*, *Paralichthys* sp., *Peprilus* sp., *Lopholatilus* chamaeleonticeps, *Orthopristis chrysoptera*, *Prionotus* aff. *P. carolinus*, *Micropogonias undulatus*, *Stellifer lanceolatus*, *Bairdiella chrysoura*, *Cynoscion arenarius*, *Cynoscion nothus*, *Leiostomus xanthurus*, and *Menticirrhus americanus*. Plant fossils, mollusks, and foraminifera have been previously documented (Marsh 1966). *Pterocarya* pollen and *Impagidinium fenestroseptatum* dinocysts confirm a Pliocene age in the uppermost part of sequence (GNU Staff 1995, as cited in Kenworthy et al. 2007). Otvos (1998) additionally described the Graham Ferry Formation as firmly Pliocene in age based upon the same pollen and dinocyst samples. Brown et al. (1944) noted 39 individual species of foraminifera from the Graham Ferry Formation; however, none of them were age-diagnostic.

Perdido Key Formation (Pliocene) (5.3–3.6 Ma)

Note: Due to very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network, the Perdido Key Formation may no longer be considered a valid formation (J. Starnes, pers. comm., 2023). However, a description of the Perdido Key Formation is provided, in keeping with prior reports such as Schupp (2019).

Description: Lying 15–30 m (49–98 ft) below Perdido Key, the Perdido Key Formation was formed as a muddy, thin layer of sediment in a nearshore environment (Otvos 1988, 1994). It is a lower Pliocene deposit, having formed 5.3 to 3.6 million years ago. The Perdido Key Formation is capped by an unfossiliferous sandy Neogene deposit, 5–15 m (16–49 ft) thick (Schupp 2019). It may correlate to the Graham Ferry Member (Otvos 2001).

Fossils found within GUIS: None to date.

Fossils found elsewhere: Described as "fossil-rich" in Schupp (2019). Described taxa include planktonic forams (*Globigerina riveroae*, *Globorotalia dutertrei*), ostracods (*Loxoconcha edentonensis*, *Malzella devexa*, and *Puriana mesocostalis*), and mollusks (*Nuculana trochilia*) (Otvos 1988). However, caution is advised reviewing fossils noted elsewhere for this formation given that it is unclear at this time if it is indeed a valid formation at GUIS.

Citronelle Terrace (Pliocene–Pleistocene) (3.6–1.8 Ma)

Description: The Citronelle Terrace, formerly known as the Citronelle Formation, is a Pliocene–Pleistocene terrace deposit. The type locality was first described from an outcrop in the town of Citronelle, Alabama (Matson 1916). The sediment at this type locality is comprised of "fine clayey sands that weather to a red brick color, with no apparent bedding" (Stewart and Starnes 2019: 7). The sediment layer that matches this description at the type locality occurs at 104–107 m (340–350 ft) in elevation and is approximately 15 m (50 ft) thick (Stewart and Starnes 2019). The Citronelle Terrace at the type locality is not fossiliferous and is comprised of non-marine deposits (Stewart and Starnes 2019).

Since its original description in 1916, the Citronelle Terrace has been a subject of confusion and controversy. Until recent years, the Citronelle had been generally described as a "formation" rather than a terrace deposit (Matson 1916; Isphording 1971; Otvos 1981a, 1998; Champlin et al. 1994; Schupp 2019). It has been previously attributed to multiple deposits both on the land surface and as a subsurface unit all along the northern Gulf Coastal Plain. In the case of GUIS, the "Citronelle Formation" has been referenced by Otvos (1998) and Schupp (2019) as being present either in the subsurface or immediately north and inland of GUIS land. The current understanding of the Citronelle now places it solely as a mainland terrace deposit, "restricted to the clayey sand interval at the type locality that generally occurs at an elevation above 300 feet [91 m]" (Stewart and Starnes 2019: 7). Furthermore, the Citronelle Terrace does not appear to dip into the subsurface at the type locality (Stewart and Starnes 2019); this observation conflicts with previous descriptions made by researchers proposing the Citronelle was present in core samples taken at Ship Island (Otvos 1981a; Champlin et al. 1994). Much of the confusion pertaining to previous interpretations of the Citronelle in the subsurface of GUIS barrier islands may be attributed to the type locality's distinctive red color. Per Jun Ebersole (pers. comm., 2022), any deposit with red-to-orange clayey quartz sands in the northern Gulf Coastal Plain may have been incorrectly attributed to the Citronelle Formation. Stewart and Starnes (2019) suspect that the "Citronelle Formation" deposits previously described in the subsurface may actually belong to erosional lags from other Miocene–Pliocene-aged formations known to be present in the northern Gulf Coastal Plain, such as the Hattiesburg, Pascagoula or Graham Ferry Formations. This idea is supported by observations that the upper Miocene Pascagoula

Formation and the Pliocene Graham Ferry Formation (both previously grouped in the Pensacola Clay) are known to weather to a bright orange color (J. Ebersole, pers. comm., 2022). More investigation is required to determine which formation(s) the deposits in the subsurface of GUIS barrier islands (such as Ship Island) belong now that it is no longer appropriate to classify these sediments as the Citronelle Formation. Regardless, it appears that the revised Citronelle Terrace deposit (formerly “Formation”) is not expected to be present on the surface or in the subsurface of any land managed by GUIS.

Fossils found within GUIS: None to date.

Fossils found elsewhere: The Citronelle “Formation”, as it was described before, had been documented as fossiliferous. All previous mentions of fossils described from the Citronelle should be scrutinized, however, as recent findings suggest that this terrace deposit is not, in fact, fossiliferous (J. Ebersole, pers. comm., 2022). Nonetheless, the following are fossils which were previously ascribed to the Citronelle (but may in fact be representative of several other deposits along the U.S. Gulf Coast). Several kinds of trace fossils such as ghost shrimp (*Ophiomorpha*) burrows and polychaete (annelid) worm tubes, and internal molds of shallow marine bivalves like Veneridae have been described (Otvos 1998). East of Mobile Bay in Mississippi, *Ophiomorpha* and molluscan molds were described in outcrops of estuarine deposits as well (Schupp 2019; Frey et al. 1978 as cited in Means 2009). Plant fossils are known, including species *Betula nigra* and *Carpinus caroliniana* (Stults and Axsmith 2009). Stults and Axsmith (2015) have also recently described 24 distinct plant fossil taxa attributed to what is now the former Citronelle Formation. It is unclear at this time if such fossils described elsewhere, now no longer categorized as part of the Citronelle Formation, pertain to deposits that correlate to the GUIS sediments previously classified as the Citronelle Formation.

Montgomery Terrace (Pleistocene) (216,000–176,000)

Note: Very recent and ongoing developments in our understanding of the geological framework in this area of the U.S. Gulf Coast indicate that the Montgomery Terrace may not being present at or near GUIS (J. Starnes, pers. comm., 2023). However, a description of the Montgomery Terrace is provided, in keeping with prior reports such as Schupp (2019).

Description: The Montgomery Terrace is the first named Pleistocene deposit present in the vicinity of GUIS; an end-Pliocene unconformity underlies this deposit in the vicinity of GUIS (Schupp 2019). This deposit consists of cross-laminated, poorly sorted, silty and muddy fine sands with sparse laminated clay beds and peaty clay lenses (Otvos 2001). The Montgomery Terrace deposits have so far only been described on the coastal mainland of Mississippi; no deposits have been described via core samples taken on GUIS barrier islands in Florida or Mississippi (Otvos 2001).

Fossils found within GUIS: None to date.

Fossils found elsewhere: Abundant fossil flora has been described from Montgomery Terrace deposits in Mississippi. These include yellow pine and lesser amounts of oak and other extant flora such as *Carya*, *Ilex*, *Liquidambar*, *Castanea*, and *Myrica* (Otvos 2001). Another locality on mainland Mississippi has produced carbonized remnants of *Pinus elliottii* (slash pine) and *Pinus glabra* (spruce pine) (Otvos 2001). However, caution is advised in reviewing fossils noted elsewhere for this formation, given that it is unclear if the unit is indeed present at GUIS.

Biloxi Formation (Pleistocene) (132,000–112,000 B.P.)

Note: Due to very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network, the Biloxi Formation may no longer be considered a valid formation. It may even be that there are no named Pleistocene formations present at GUIS (J. Starnes, pers. comm., 2023). However, a description of the Biloxi Formation is provided, in keeping with prior reports such as Schupp (2019).

Description: The Biloxi Formation formed amidst rising sea levels during the warm Sangamonian interglacial stage, 132,000 to 112,000 years ago. It is composed of both marine sands and muddier estuarine sediments, indicating variations in sediment sources. Transgressions and regressions in local sea level alternated during the Biloxi Formation's deposition, with phases of both inland brackish paralic and nearshore marine sedimentation (Schupp 2019).

The Biloxi Formation is reported as prevalent beneath the northern Gulf of Mexico (Schupp 2019). It is one of the formations noted in the Pleistocene core of Santa Rosa Island (Schupp 2019). Notably, the Biloxi Formation does not appear to be present beneath Horn Island in Mississippi. The Biloxi Formation appears much muddier in Alabama and Mississippi, as opposed to the sandier Florida deposits (Schupp 2019).

Fossils found within GUIS: None to date.

Fossils found elsewhere: The Biloxi Formation is reported as very fossiliferous. A study published by Ebersole et al. (2017) originally proposed this unit to be the likely source of shark tooth fossils recovered on Dauphin Island, Alabama. However, ongoing research in the region points to other Pliocene–Pleistocene units as the presumed source (Stringer et al. 2020). This formation is described as containing numerous species of foraminifera, as well as bivalves (Schupp 2019). Bivalves documented in the Biloxi Formation include *Rangia cuneata* and *Crassostrea virginica* (Otvos 2001). Common foraminifera species reported in the Biloxi Formation include *Ammonia beccarii*, *Elphidium galvestonensis*, *Hanzawaia strattoni, Rosalina columbiensis, Bigenerina irregularis,* and *Quinqueloculina miliolids* (Otvos 2001). For a list of more invertebrate species reported in the Biloxi Formation (and a complete list of all fossils reported from formations mentioned in this report), see "Fossil Taxa Known from Formations Outside of GUIS" in the NPS Paleontology Archives.

Gulfport Formation (Pleistocene) (132,000–112,000 B.P.)

Note: Due to very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network, the Gulfport Formation may no longer be considered a valid formation. It may even be that there are no named Pleistocene formations at GUIS (J. Starnes, pers. comm., 2023). However, a description of the Gulfport Formation is provided, in keeping with prior reports such as Schupp (2019).

Description: The Gulfport Formation is a Sangamonian interglacial stage deposit that is reported as overlying the Biloxi Formation (Schupp 2019). The Gulfport Formation is composed of marine sediments and was formed as a barrier strand plain which prograded seaward due to wave action (Otvos 2004a). It may also exhibit humate staining; humate is a dark brown–black organic, rich amorphous matter (Schmid and Otvos 2004). This formation grades upward (Schupp 2019). The Gulfport and Biloxi Formations are noted as present in sequence under much of the northwestern Florida coast, extending to Dauphin Island in Alabama (Otvos and Giardino 2004). The two formations tend to be less than 30 m (98 ft) in thickness combined (Schupp 2019). The Biloxi, Gulfport and Prairie Formations, which make up the entire upper Pleistocene sequence in this region, cover 10 km (6 mi) of sub-surficial area at some points (Otvos 2009).

The Gulfport Formation is listed as comprising the immediate area north of Santa Rosa Sound. It is noted as represented by 3–10 m (10–33 ft) of well-sorted sand under Santa Rosa Island's Pleistocene core (Schupp 2019). In Alabama, the eastern side of Dauphin Island is reported as the Gulfport Formation. The Gulfport Formation is not found under any of the Mississippi barrier island units. However, it is described as present on the mainland just north of the Mississippi Sound (Schupp 2019).

Fossils found within GUIS: None to date.

Fossils found elsewhere: Fossils are uncommon in the Gulfport Formation (Brown et al. 1944 as cited in Kenworthy et al. 2007; Schupp 2019). Otvos (1981c) noted *Callianassa* burrow tubes as the only fossils described from this formation. Additionally, Heinrich (2004) noted *Ophiomorpha* burrows and the molds of bivalves. However, caution is advised in reviewing fossils noted elsewhere for this formation, given that it is unclear if it is indeed a valid unit at GUIS.

Prairie Formation (Pleistocene) (130,000–80,000 B.P.)

Note: Due to very recent and ongoing developments in our understanding of the geological framework in this area of the Gulf Coast Network, the Prairie Formation may no longer be considered a valid formation. It may even be that there are no named Pleistocene formations present at GUIS (J. Starnes, pers. comm., 2023). However, a description of the Prairie Formation is provided, in keeping with prior reports such as Schupp (2019).

Description: The Prairie Formation is the youngest of the Pleistocene formations recorded for GUIS. The Prairie Formation was deposited on an alluvial floodplain (Schupp 2019). Its composition includes both muddy and clayey fine sands, as well as moderately silty, fine and very fine sands (Schupp 2019). The Prairie Formation may appear yellowish-gray yellowish-brown, greenish-gray, or brown (Schupp 2019).

The Prairie Formation is reported as present on the coast of mainland Mississippi and is 4.5–12 m (15–39 ft) thick, having formed as a narrow wedge (Schupp 2019). The Prairie Formation interpenetrates the Biloxi Formation according to Schupp (2019) and is stated to complete the Pleistocene sequence in this region of the Gulf of Mexico. In Florida, the Prairie Formation appears as yellowish-gray and yellowish-brown silty-sandy and sandy deposits (Schupp 2019). Otvos (2001) also describes it as "medium to coarse, gray, grayish orange silty, poorly sorted muddy very fine sand, fine silt and mud units". As reported in Schupp (2019), the Prairie Formation lies south (seaward) of the older Citronelle Formation (a unit now changed to a terrace deposit that is limited to the mainland; Stewart and Starnes 2019; Stringer et al. 2020). The Prairie Formation may exist as unfossiliferous silty-muddy sands beneath Santa Rosa Island (Schupp 2019).

<u>Fossils found within GUIS</u>: None to date.

<u>Fossils found elsewhere</u>: Brown et al. (1944) and Otvos (2001) noted that fossils are uncommon in the Prairie Formation. However, horse teeth, possibly belonging to *Equus fraternus* and *E. hemionus* (E. L. Lundelius, Jr., 1981, written comm., as cited in Otvos 1981b), have been described at shallow depths. An additional horse tooth, *Equus* cf. *occidentalis* or *Equus* cf. *complicatus*, has been found in the Prairie Formation along with sparse plant fossils and pine and oak pollens (Otvos 1973, 1995, 1997; Otvos and Howat 1992). However, caution is advised in reviewing fossils noted elsewhere for this formation, given that it is unclear if it is indeed a valid unit at GUIS.

Pamlico Terrace (Pleistocene) (130,000–70,000 B.P.)

<u>Description:</u> The Pamlico is the lowest (in elevation) terrace deposit mapped along the coastline of Mississippi. It evidently occurs as a series of three sub-terraces at approximately 6–8 m (20–25 ft), 3–4 m (10–13 ft), and 1.5–2.4 m (5–8 ft) elevation (Stewart and Starnes 2019). The Pamlico Terrace may be present as a surficial deposit at certain areas of the mainland units of GUIS in Mississippi, interspersed among low-lying Holocene alluvium and marshlands. It is not present on any of the barrier islands managed by GUIS. Based on well samples and geophysical well logs, the Pamlico terrace may be up to 43 m (140 ft) thick in some places along the Mississippi coast, thinning to the north (Stewart and Starnes 2019). It may appear yellowish-gray, buff, and/or white (Williams et al. 1967). Low terrace sands such as the Pamlico are described as mostly quartz and poorly sorted, varying from very fine-grained (1/16 mm) to very coarse-grained (2.0 mm) (Williams et al. 1967).

<u>Fossils found within GUIS:</u> None to date.

<u>Fossils found elsewhere:</u> None to date.

Taxonomy

See Appendices A and B for more information on taxa identified at GUIS.

The following (Kenworthy et al. 2007: 19) is a description and definition of what this inventory defines as "fossil material":

> *The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The "geologic context" phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, "Recent") specimens are usually considered modern and not fossils. Subsurface specimens collected at GUIS span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.*

In the case of shark teeth and other bony fossils, visual characteristics are also taken into account to identify them as "fossilized" and not modern specimens. As is observed with other fossils around the world, the process of fossilization will often alter the visual characteristics of specimens. Shark teeth are fossilized through a process called permineralization, in which the open pore spaces of bone are replaced by minerals. Although it varies by the locality, permineralized specimens generally take on the color of the minerals that replace their pore spaces. One would expect modern shark teeth to be the usual bone-white color observed in living organisms. A vast majority of the shark tooth and marine organism specimens collected during this inventory exhibited other coloration, indicating some degree of mineral alteration and fossilization.

Under research and collecting permit GUIS-2021-SCI-0037, an attempt was made to visually survey as many different beach areas at GUIS for paleontological resources as possible. In Florida, all three of the main coastal beach areas managed by GUIS (Santa Rosa, Fort Pickens area, and Perdido Key) were field-surveyed in some capacity. During the survey of Mississippi GUIS units in March of 2022, weather and other logistical hurdles prevented collection efforts at two of the five barrier island units: Petit Bois Island and Cat Island. It was determined through literature review, web searches and communication with park staff that these islands were less likely to have paleontological resources because of a combined historical absence of beach renourishment (a presumed source of fossil material) and no social media mentions of visitors to GUIS collecting fossils at these locations. Thus, these islands were not prioritized for sampling given constraints on getting into the field. West Petit Bois Island (Sand Island), Horn Island, and Ship Island were all field-surveyed for paleontological resources in some capacity. None of the mainland areas managed by GUIS (Naval Live Oaks, Fort Barrancas, and Davis Bayou) were physically surveyed for paleontological resources.

Fossil Plants

Pollen, as well as pulverized plant material, have been described from previous core samples taken at Horn Island; the samples are presumed to be Pliocene, based upon lithologic characteristics and similarity to Pliocene units in nearby Jackson County, Mississippi (Gohn et al. 1996, referencing Otvos 1994).

Fossil Invertebrates

All invertebrate fossils described in this section, unless otherwise noted, were identified from subsurface wells and vibracores. Historical subsurface wells and coring has yielded fossils from the subsurface of Santa Rosa Island (Florida), near the Naval Live Oaks area (Florida), and Mississippi's Horn and Ship Islands. See subsection "Coring History at GUIS" in "Geologic History" for more information about core samples taken at GUIS.

Macrofossil Invertebrates: Phyla Mollusca, Arthropoda, and Echinodermata

Mollusks have been described in core samples taken at Pensacola Beach in the mid-20th century, east of Fort Pickens (Marsh 1966).

Core samples were taken across Mississippi Sound from Beauvoir to Ship Island in the mid-20th century (Rainwater 1964). The cores provided evidence of fossiliferous sediments under the Sound, from the Pleistocene to Recent. Mollusks, ostracods, barnacles, and echinoderms were present among the core sediments (Kenworthy et al. 2007).

The U.S. Geological Survey took a core sample on Horn Island, Mississippi in 1991 which yielded mollusks and ostracods in the lower core (Gohn et al. 1994, 1996). The sediment from this core was interpreted as representing an estuarine, Pliocene-aged paleoenvironment. Mollusks, ostracods, and echinoderms were also found in the upper unit of the same core sample, up to 4.4 m (14 ft) below the surface (Gohn et al. 1996).

Crustacean claw fragments were collected during the 2021 and 2022 surveys conducted at numerous GUIS units. Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), crustacean material was only collected from Perdido Key. Among the three GUIS barrier island units in Mississippi surveyed for paleontological resources in 2022, crustacean material was collected on West Petit Bois Island and Ship Island. These specimens (primarily crab claws) are presumed to be from dredged fossil-bearing deposits.

A scaphopod (commonly called a tusk shell) specimen, GUIS-MSNC_007, is the only specimen from Phylum Mollusca represented among the fossil collections listed within this inventory. However, other pre-Holocene, Quaternary shell material (Mollusca) is likely present on beaches where beach renourishment has occurred at GUIS (and even older shell specimens may be intermixed with modern shells on beaches). The context of dredging and beach renourishment with presumed fossiliferous sediments (see the "History and Influence of Dredging/Beach Renourishment on Fossil Localities" section), as well as the confirmed presence of fossilized chondrichthyan specimens, indicates a high likelihood that at least part of the shell material in those renourished areas at GUIS is fossil as well. Assorted molluscan specimens were collected at Perdido Key, Ship

Island, and West Petit Bois Island. These were collected initially in the interest that they might be a mix of modern and fossil specimens, and could perhaps be studied in more depth at a later time to determine the likelihood of fossilization. Because it is unclear at this time if any are indeed fossil, no gastropod or bivalve shells are listed in the official collections noted in the Appendices of this report (although the scaphopod shell presumed to be fossil is included). Photographs of one cone snail shell found among fossil shark teeth at Ship Island were reviewed by Jonathan Hendricks from the Paleontological Research Institution, and a determination was made that it was more likely a subfossil or modern specimen (J. Hendricks, pers. comm., 2023). Fossilized mollusk shell has a similar appearance to modern mollusk shell, especially when it has been weathered and exposed. Thus, it is often difficult to distinguish a fossil from a modern specimen in the absence of geochemical analyses, especially since many (but not all) species represented by fossils in Neogene and younger deposits in the area still live along this coastline. The Fort Pickens and Perdido Key areas in Florida, as well as West Petit Bois, Ship, and Cat Islands in Mississippi, have been subjected to beach renourishment in recent years, and as a result specimens of mollusks on beaches could be from fossil deposits, but further analysis is needed.

Additionally, presumed fossil mollusks were observed within the construction of Fort Pickens proper. See the “Cultural Resource Connections” section for more information on these fossils.

Fossil Vertebrates

Class Chondrichthyes

Second-hand accounts of fossil shark teeth being found within GUIS extend back to at least 2012. However, it was not until recent fieldwork and collection efforts associated with this report in 2021 that the presence of fossil shark teeth at GUIS was confirmed. Multiple surveys at five of the seven barrier island units managed by GUIS during 2021 and 2022 have yielded a collection of more than 630 fossil shark teeth. Two orders, the Lamniformes and Carcharhiniformes, are represented among the specimens. All specimens identified appear to be attributed to extant (still living) taxa.

Order Lamniformes

Members of the order Lamniformes differ from other orders in that they possess eyes without nictitating membranes (protective inner eyelids), and a mouth extending behind the eyes. Of the 15 extant species of Lamniformes, one species is represented among the collections from GUIS: *Carcharias taurus* (Figure 18). *Carcharias taurus*, also known as the Sand Tiger Shark, possesses distinctive teeth with a slender, smooth crown and a very curved root. Additionally, the teeth of *Carcharias taurus* feature lateral cusplets on either side. Several teeth of *Carcharias taurus* were collected.

Figure 18. Specimen GUIS-MS_269. The specimen is a 2nd upper anterior tooth belonging to *Carcharias taurus* (NPS/MICHAEL CLINTON).

Order Carcharhiniformes

Carcharhiniformes is the most diverse extant order of sharks, with more than 250 species around the world represented by eight families (Froese and Pauly 2023). Unlike Lamniformes, members of the order Carcharhiniformes possess a nictitating membrane over the eye. Two families of Carcharhiniformes are represented among the collections thus far at GUIS: Carcharhinidae and Sphyrnidae.

Family Carcharhinidae

Carcharhinidae, also known as the requiem sharks, is a family of sharks that tend to live in warm environments in both salt and freshwater (Froese and Pauly 2023). Many carcharhinid species are found in the northern Gulf of Mexico, including *Carcharhinus leucas* (Bull Shark), *Carcharhinus obscurus* (Dusky Shark), *Galeocerdo cuvier* (Tiger Shark), *Negaprion brevirostris* (Lemon Shark), and *Rhizoprionodon terraenovae* (Atlantic Sharpnose Shark), to name a few. Among the collections at GUIS, four genera belonging to Carcharhinidae are represented: *Carcharhinus*, *Galeocerdo*, *Negaprion*, and *Rhizoprionodon*.

Carcharhinidae from Florida GUIS Units

Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), carcharhinid teeth were collected from the Fort Pickens area and Perdido Key. Two chondrichthyan teeth were collected at the Santa Rosa localities; however, those two specimens are both too worn to make any finer identification. *Carcharhinus* sp., *Galeocerdo*, and *Negaprion* are represented among collections from the Fort Pickens area of GUIS, and these three genera plus *Rhizoprionodon* are represented among collections from Perdido Key (Figure 19).

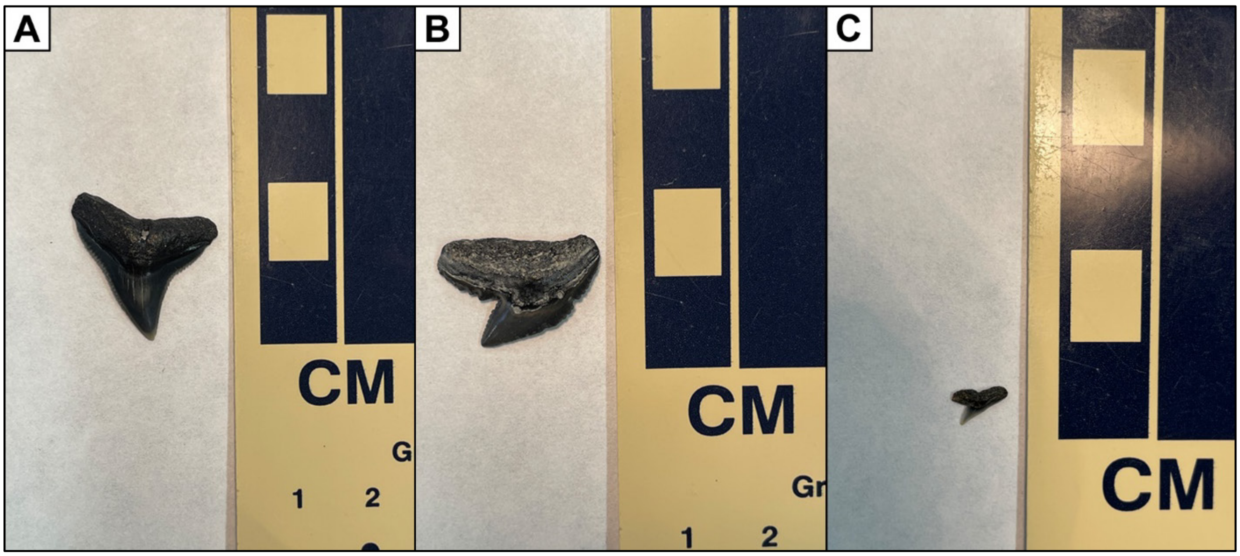

Figure 19. Specimens GUIS-FL_002 (**A**), GUIS-FL_145 (**B**), and GUIS-FL_087 (**C**). All three specimens were collected on Perdido Key. GUIS-FL_002 represents *Carcharhinus* sp., GUIS-FL_145 represents *Galeocerdo cuvier*, and GUIS-FL_087 represents *Rhizoprionodon* sp. (NPS/MICHAEL CLINTON).

Carcharhinidae from Mississippi GUIS Units

Carcharhinidae is represented at all three GUIS units in Mississippi surveyed for paleontological resources in 2022: West Petit Bois Island, Horn Island, and Ship Island. *Carcharhinus*, *Galeocerdo*, *Negaprion*, and *Rhizoprionodon* are represented among collections on West Petit Bois Island. Of the five shark teeth collected on Horn Island, three belong to *Carcharhinus* and two are too worn to make finer identification. *Carcharhinus*, *Galeocerdo*, *Negaprion*, and *Rhizoprionodon* are represented among collections on Ship Island.

Family Sphyrnidae

Sphyrnidae, also known as the hammerhead sharks, is a family of Carcharhiniformes which possess laterally elongated and flattened heads (cephalofoils) that visually resemble the head of a hammer (hence the name). Nine of the ten known species within Sphyrnidae belong to the genus *Sphyrna*.

Sphyrnidae from Florida GUIS Units

Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), teeth from *Sphyrna* were collected on Perdido Key.

Sphyrnidae from Mississippi GUIS Units

Among the three GUIS barrier island units in Mississippi surveyed for paleontological resources in 2022, teeth from *Sphyrna* were collected on Ship Island.

Division Batomorphi

Batomorphi, which includes rays, skates, and sawfish, is a division of cartilaginous fishes closely related to sharks (Division Selachii) under Class Chondrichthyes. Most fishes under Batomorphi possess flattened bodies, ventral (underside) gill slits, and large pectoral fins (Froese and Pauly 2023). There are four orders recognized under Batomorphi: Myliobatiformes, Rajiformes, Rhinopristiformes, and Torpediniformes. Fossils of myliobatiforms have been found at GUIS.

Order Myliobatiformes

Myliobatiformes is the order of flat-bodied, cartilaginous fish that includes most stingrays. Myliobatiformes is a very diverse order, with more than 200 species represented around the world (Froese and Pauly 2023).

Family Myliobatidae

Stingrays within Family Myliobatidae differ from other batoids (like skates) in that they possess venomous stinging barbs on their tails and ridged, plate-like teeth (Figure 20) used for crushing prey. All ray tooth and barb specimens collected at GUIS are presumed to belong to members of Myliobatidae (J. Ebersole, pers. comm., 2022).

Figure 20. Specimen GUIS-FL_297, a tooth from *Aetobatus* cf. *A. narinari*, a member of Myliobatidae. This specimen was collected on Perdido Key (NPS/MICHAEL CLINTON).

Myliobatidae from Florida GUIS Units

Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), multiple teeth as well as caudal barbs belonging to Myliobatidae were collected on Perdido Key.

Myliobatidae from Mississippi GUIS Units

Among the three GUIS barrier island units in Mississippi surveyed for paleontological resources in 2022, fossils belonging to Myliobatidae were collected on West Petit Bois Island and Ship Island. On West Petit Bois Island, a single tooth specimen was collected. On Ship Island, a single tooth specimen and two partial caudal barbs were collected. Myliobatids are not represented among the collections from Horn Island.

Subclass Actinopterygii

Actinopterygii, also known as the ray-finned fishes, is an extremely diverse and widespread group of bony fish with many thousands of species living today. The characteristic uniting certain fish under Actinopterygii is the presence of bones or spines connecting the thin flesh of their fins, as opposed to cartilaginous structures or lobes. Virtually all bony fish fossils found in the Gulf of Mexico, from both extant and extinct taxa, belong to Actinopterygii. Examples of living fish found in the Gulf of Mexico that belong to this class include catfish, flounder, grouper, mackerel, marlin, sailfish, tarpon, and tuna.

Fossilized remains of actinopterygians have been identified among the recent GUIS collections. A majority of the remains consist of disarticulated, and often fragmental, fin spines from bony fishes (Figure 21). Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), fin spines belonging to actinopterygians were collected on Perdido Key. Among the three GUIS barrier island units in Mississippi surveyed in 2022 (West Petit Bois Island, Horn Island, and Ship Island), two fin spines belonging to actinopterygians were collected on Ship Island. Initially, Clinton et al. (2022a, 2022b) identified these specimens at ratfish dorsal spines, but they are curved and not straight, and are instead representative of bony fishes (Victor Perez, St. Mary's College of Maryland, pers. comm., 2022).

Figure 21. Specimen GUIS-FLNC_003, a suspected fin spine of a bony fish. Several similar specimens were collected on Perdido Key in Florida and on Ship Island in Mississippi (NPS/MICHAEL CLINTON).

In addition to the actinopterygian fin spines, other bony fish remains were recovered at GUIS. Several bony fish otoliths were collected, including one specimen from the Fort Pickens area and two specimens from Perdido Key in Florida. The collected fish otoliths warrant further study and possible species identification; prior studies on fossil fish otolith assemblages from the northern Gulf of Mexico (Stringer et al. 2020) have shed light on paleoenvironments and can narrow down the ages of associated fossil material. Specimen GUIS-FLNC_011, collected at Perdido Key, is a fang belonging to *Trichiurus lepturus,* a species of cutlassfish (Bemis et al. 2019; J. Ebersole, pers. comm., 2023; V. Perez, pers. comm., 2023). Of note, this specimen is the only bony fish tooth recovered during the 2021–2022 survey. Specimen GUIS-FLNC_020, also collected at Perdido Key, has tentatively been identified as an element from a bony fish, such as part of the pre-operculum (V. Perez, pers. comm., 2023).

Family Diodontidae

Diodontidae, also known as the porcupinefish, is a family of bony fishes belonging to Actinopterygii. Porcupinefish are often confused with another closely related group of fish, the pufferfish (Family Tetraodontidae). Diodontids possess unique, fused platy teeth that aid them in crushing prey (Leis 2007). Among the three main coastal areas managed by GUIS in Florida (Santa Rosa, Fort Pickens, and Perdido Key), one fossilized dental plate from a diodontid was collected on Perdido Key (Figure 22). No diodontid remains were collected from the three GUIS barrier island units in Mississippi surveyed in 2022 (West Petit Bois Island, Horn Island, and Ship Island).

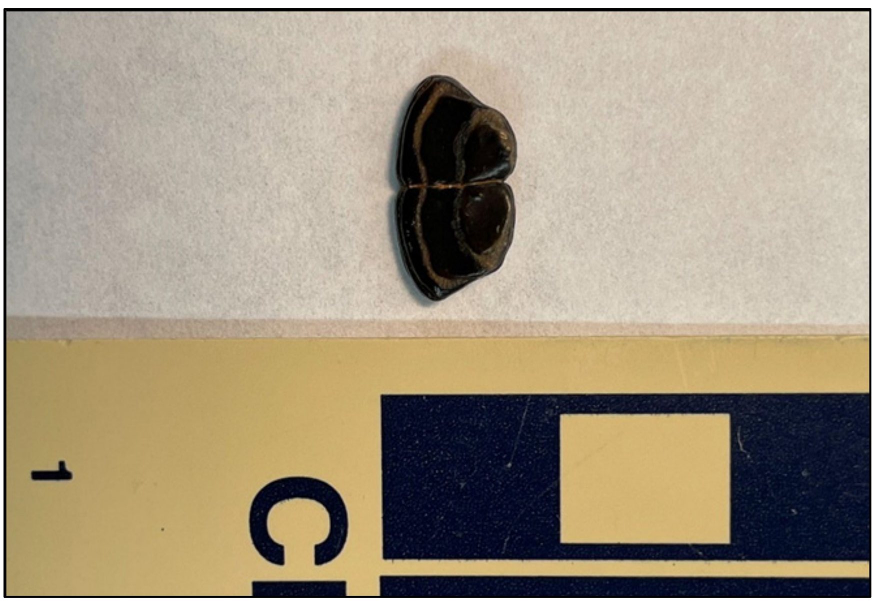

Figure 22. Specimen GUIS-FLNC_004, a lower mouth plate from family Diodontidae. This specimen was collected on Perdido Key (NPS/MICHAEL CLINTON).

Order Testudines

Testudines is an order of reptiles that encompasses all turtles. Turtles are differentiated from other reptiles in that they possess bony shells which grow out of their ribs. Having evolved for millions of years, testudines have diversified and filled many different niches. Different species within Testudines are terrestrial, aquatic, or a combination of both. One group of marine turtles, the sea turtles, are members of the superfamily Chelonioidea. There are seven extant species of marine turtles, and multiple extinct taxa. Six of the seven species of marine turtle are found in the Gulf of Mexico. These organisms have historically been known to lay eggs and make nests on the upper shores of beach areas managed by GUIS (Joe Burgess, NPS Biologist, pers. comm.).

Two fossils specimens were recovered by a GUIS ranger in January of 2022 on Petit Bois Island, GUIS-MSNC_030 (Figure 23) and GUIS-MSNC_031. The specimens are flat and square in shape. They are pieces of turtle shell, either from the carapace (top side of shell) or the plastron (underside of shell). Specimen GUIS-MSNC_030 is likely a peripheral scute from a freshwater or brackish turtle taxon (J. Ebersole, pers. comm., 2022). The specimens feature many linear grooves covering one face. The linear grooves initially led interpretive rangers at GUIS to associate the pieces with known historical Native American activity on the Mississippi barrier islands. However, preliminary research into turtle shells has revealed that the linear groove marks may have formed naturally when the organism was alive. More research needs to be conducted on this specimen and turtle morphology to determine its cultural significance, if any. See also “Cultural Resource Connections” below.

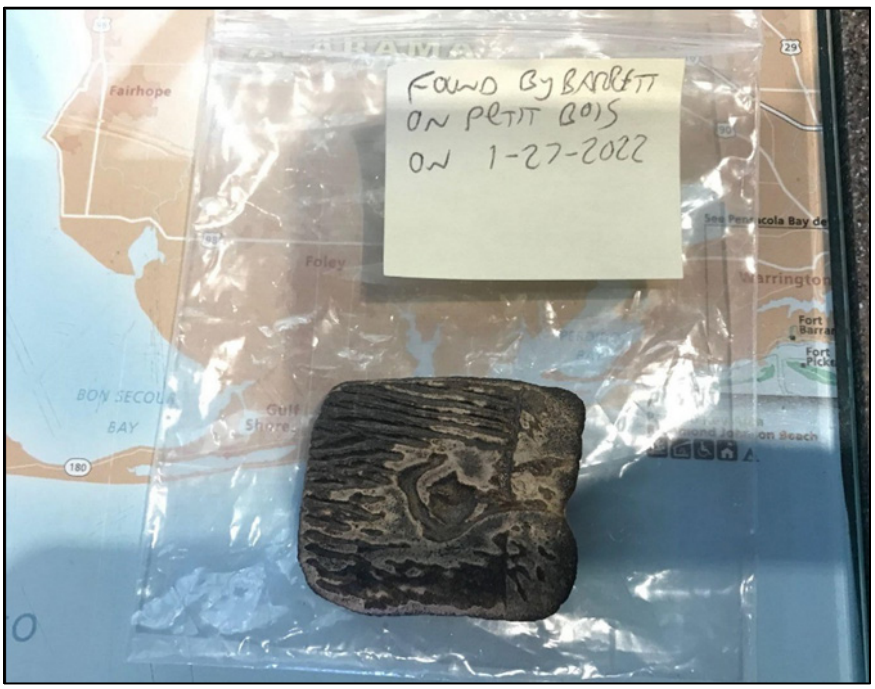

Figure 23. Photo of specimen GUIS-MSNC_030, a piece of fossilized turtle shell. This specimen, along with another of similar appearance, was collected by a GUIS ranger on the beaches of Petit Bois Island in January of 2022 (NPS).

Ichnofossils

Small burrows were noted in the middle lithologic unit of a core sample taken on Horn Island by the USGS in 1991.

Other Fossils

Dinoflagellata and Foraminifera

Dinoflagellates are single-celled "algae" noted for their two dissimilar flagella used for movement. They are represented in the fossil record by non-mineralized resting cysts (dinocysts). Foraminifera are single-celled marine "protists", now classified in the Kingdom Chromista (Ruggiero et al. 2015) with external shells or "tests" made up of calcite or other particles, resembling "amoebas with shells". Both types of microfossils have been found in core samples taken from GUIS.

Core samples were taken across Mississippi Sound from Beauvoir to Ship Island in the mid-20th century (Rainwater 1964). The cores revealed fossiliferous sediments under the Sound, from the Pleistocene to Recent. Foraminifera were present among core samples taken at Ship Island (Rainwater 1964).

The U.S. Geological Survey took a three-unit core sample on Horn Island, Mississippi in 1991 (Gohn et al. 1996). The sediment from this core was believed to represent a Pliocene-aged estuarine paleoenvironment. Dinoflagellates and foraminifera were described in the lower core (Gohn et al. 1994, 1996). Dinoflagellates and foraminifera were also found in the upper unit of the same core sample, up to 4.4 m (14 ft) below the surface (Gohn et al. 1996).

Foraminifera are some of the most abundant microfossils found in the formations beneath GUIS barrier island units. Sediment samples taken from the Pleistocene core of Santa Rosa Island are abundant in foraminifera (Kenworthy et al. 2007). Sub-surficial lithology studies have pointed to the estuarine clayey sands of the Pleistocene Biloxi Formation and the sandy barrier sediments of the upper Pleistocene Gulfport Formation as sources of the foraminifera under Santa Rosa Island (Otvos 1982). Lands managed by GUIS are due west of the Pleistocene core, which underlies the central areas of Santa Rosa Island. Otvos (1982) noted Pleistocene-aged sediments in core samples west of Santa Rosa Island, but they were unfossiliferous.

Fossil Localities

Paleontological Localities Within GUIS

Details on GUIS localities are available to qualified researchers. General information on locality definitions, fossil context, and beach nourishment is included below.

Locality Definitions

Because virtually all specimens collected during surveys at GUIS were "float" specimens resting on the beach surface, "locality" descriptions in the traditional sense (ex: an exposed fossiliferous formation on the side of a hill) are not utilized. Instead, new definitions specific to paleontological resources collected at GUIS are applied for localities, sub-localities, etc. These approaches were used also in considering how best to organize fossil collection both geographically and temporally.

A "GUIS Area" is defined as one of the main publicly accessible regions of the national seashore. GUIS areas include: the Santa Rosa area, the Fort Pickens area, and the Perdido Key area in Florida, and each individual barrier island managed by GUIS in Mississippi.

A "locality" is a spatially defined sub-area within individual GUIS areas. Localities are given spatial descriptions as their labels.

A "sub-locality" is a further sub-area within individual localities. Sub-localities are spatially arranged based upon clusters of where multiple specimens are collected within localities. Sub-localities are given individual numbered labels; the numbering system starts over between the Florida and Mississippi collections.

All confirmed paleontological specimens found within GUIS have been assigned unique labels. The numbering systems for specimens collected in Florida versus Mississippi are separate, so specimens from either state may possess the same number. However, additional signifiers are given to the specimen labels to differentiate Florida and Mississippi specimens, as well as chondrichthyan versus other organisms. All labels begin with "GUIS", followed by the state abbreviation, then "NC" if non-chondrichthyan, and finally the number. For example, a chondrichthyan fossil from Florida would be GUIS-FL_00[X], while a specimen of a non-chondrichthyan from Mississippi would be GUIS-MSNC_00[X]. Numbers are generally in the order in which the specimens were collected.

Context

The unique coastal setting of much of the land area within GUIS provides a different perspective to fossil localities than at most other NPS units. Fossil localities, as defined by Santucci et al. (2009), are "a spatially defined area that may include either in situ fossils or a site from which fossils have been previously collected and curated into a museum repository". After evaluation of the naturally occurring geologic formations and sediments found at all fossil localities described in this paleontological inventory, all described fossils recovered as part of sampling efforts in 2021 and 2022 should be considered "float" specimens. Float fossils are specimens which have been displaced from their in situ origin location. Considering the Holocene age of all of the surficial sandy beach units within GUIS, any fossils discovered on the beaches likely originated from pre-Holocene geologic formations either underlying these areas or otherwise in the near vicinity of GUIS.

It is presumed that the macrofossil surface localities documented at GUIS are the result of beach renourishment activities in which pre-Holocene sediments were dredged from the ocean floor and then placed on adjacent beaches. There is precedence for the scenario of fossiliferous dredged sediments being placed in this manner; a similar scenario was hypothesized and later confirmed to explain occurrences of fossil shark teeth and other specimens collected at Dauphin Island in Alabama (Ebersole et al. 2017, Stringer et al. 2020). Dredged sediment may contain a high abundance of shell material and potentially even fossilized specimens (Reilly and Bellis 1983; Boessenecker 2021).

Upon reviewing historical core samples, dredge source and placement locations, lithologic formation characteristics, and collected taxa assemblages, the presumed age of the fossil material at GUIS is Pliocene–Pleistocene. Depending upon the exact dredge locations and formation depths (which vary throughout GUIS), deposits classified presently as the Pliocene Graham Ferry or Perdido Key Formations or the Pleistocene Gulfport, Biloxi, or Prairie Formations may be sources of the fossiliferous sediments. This determination was made while keeping in mind the limited depth utilized by dredging equipment. Pliocene–Pleistocene sediments will naturally occur at shallower depths (usually within 30 m [98 ft] of the seafloor), which may be reached and exposed by dredging equipment.

Measures are normally taken to ensure that the sediment being dredged is compatible compositionally and visually to the existing beach sediment being renourished (Schupp 2019). This is the case with most renourished beach localities where fossils have been collected at GUIS. However, there are several localities with very distinctive renourished sediments that may indicate lithologic formations of origin. One such locality is PKMS5, on West Petit Bois Island. The sediment at this locality is composed of a unique reddish-orange quartz sand (Figure 24). The coloration of the material at this locality, not observed anywhere else, is presumed to be due to having originally been deposited in a limonitic (iron-rich) setting during prior Pleistocene sea-level lowstands. Limonitic deposits such as what was observed on West Petit Bois Island are indicative of a freshwater- or brackish-influenced nearshore paleoenvironment (J. Ebersole, pers. comm., 2022). Several different formations containing iron-rich/limonitic sediments, such as the upper Miocene Pascagoula Formation and the Pliocene Graham Ferry Formation, may exhibit this color. Further investigation is needed at this locality to see if any connections can be made to specific units. It is likely that different fossiliferous formations have been used as source sediments for beach renourishment in different areas of GUIS. See the “History and Influence of Dredging/Beach Renourishment on Fossil Localities” section for more information on historical dredge locations at GUIS.

Collecting of seashells (and to a lesser extent, shark teeth) is a popular recreational activity for many visitors to the beach areas in the vicinity of GUIS; it should be assumed that unauthorized fossil collecting has occurred at all localities. Cases of unauthorized fossil collection at GUIS are mentioned in the “Influence of Social Media on Paleontological Inventories” section.

Figure 24. The sands, shell hash, and fossils at sub-locality PKMS5 on West Petit Bois Island exhibit a distinctive reddish-orange color (NPS/MICHAEL CLINTON).

Dredging/Beach Renourishment and Fossil Localities at GUIS

A stretch of coastline on Perdido Key was renourished in late spring 2022 and was surveyed for fossil resources in August of the same year. The sediment used in the renourishment was dredged from the bottom of the Pensacola Pass shipping channel directly east of Perdido Key (B. Leutscher, pers. comm., 2022). Shark teeth were collected within the area of renourishment, along with one fossil fragment presumed to belong to a bony fish. The presence of fossils in dredged sediment which had been placed just several months prior (as well as a knowledge of underlying fossiliferous unit depths and locations) indicates a likelihood that pre-Holocene aged sediments have been dredged from the Pensacola Pass shipping channel. Although a definitive age cannot be assigned to the float specimens, proposed identifications and the context point to the fossils there being Pliocene–Pleistocene in age. There are several Pliocene–Pleistocene formations reported as underlying the Holocene sediment of Pensacola Pass, including (from oldest to youngest) the Pensacola, Biloxi, Gulfport, and Prairie Formations (Schupp 2019). For more information on lithologic formations, see "Geologic Formations" above. Regardless of the ages of these dredged sediments, there appears to be a positive correlation between identified fossil localities at GUIS and areas which have historically been renourished.

Paleontological Localities Near GUIS

There are multiple reports of fossilized shark teeth discovered on beaches immediately adjacent to GUIS units, primarily in Florida. Many of these reports and mentions can be found in the memos-to-file kept in the NPS Paleontology Archives.

Navarre Beach

Web searches on social media sites such as thefossilforum.com and Facebook.com have produced accounts of people finding fossils at Navarre Beach, Florida. Navarre is situated on Santa Rosa Island and is located immediately east of the Santa Rosa unit of GUIS. Keywords ("Navarre", "Navarre Beach", "fossils", "shark tooth", etc.) were used to search for accounts of fossil collecting. See the "Influence of Social Media on Paleontological Inventories" section for more information. The fossils in all accounts are shark teeth. While it is implied that the fossils were collected on the beaches at Navarre, the level of detail and useful information in the accounts varies.

Pensacola Beach

Occurrences of people finding fossils at Pensacola Beach, Florida, have also been identified during social media searches. Pensacola Beach is located on Santa Rosa Island, situated between the Santa Rosa unit (to the east) and the Fort Pickens unit (to the west) of GUIS. Keywords ("Pensacola", "Pensacola Beach", "fossils", "shark tooth", etc.) were used to search for accounts of fossil collecting. Similar to the accounts at Navarre Beach, all known fossil accounts at Pensacola Beach have been for shark teeth.

Marsh (1966) noted that a core sample from outside of GUIS at Pensacola Beach revealed both fossil mollusks and microfossils within the Pleistocene to Recent aged sediments.

West of Naval Live Oaks

While no fossils have yet been found exposed at the surface near Naval Live Oaks or Fort Barrancas, drilling west of the Naval Live Oaks area recovered Pleistocene mollusks from a depth of approximately 8 m (25 ft) in a well located on "Fairpoint Peninsula" (Kenworthy et al. 2007). The fossils from this well were believed to be from the Citronelle Formation (Schupp 2019), although recent findings dispute the idea that the Citronelle is present in this vicinity or that it is even fossiliferous (J. Ebersole, pers. comm., 2022).

Dredge Spoils: Sand (Dog) Island

There is a dredge spoils pile established immediately northwest of Fort McRee and the easternmost extent of the Perdido Key/Johnson Beach area; it is not managed by GUIS. The spoils pile is locally known as "Sand Island" or "Dog Island", and is only accessible by watercraft. The spoils pile is regularly replenished with sediment following routine dredging of the adjacent Pensacola Pass shipping channel. While no fossils have been documented from this spoils pile yet, it is likely that fossiliferous sediments dredged from the Pensacola Pass shipping channel have been placed there.

Dauphin Island: Ebersole et al. (2017) and Stringer et al. (2020)

Dauphin Island (and the smaller Sand/Pelican Island Complex immediately to the south) is Alabama's only barrier island unit. It is not managed by GUIS, but it is situated between the Florida and Mississippi units managed by GUIS. Dauphin Island and Petit Bois Island were once a single island unit, which was breached at some point in the early 18th century by a large storm (Otvos 1979, Otvos and Giardino 2004). Dauphin Island has historically been a site of marine research and education along the Gulf Coast. The primary marine research and outreach facility on the island is the Dauphin Island Sea Lab. Recent research has been conducted on fossil chondrichthyan teeth found at beaches on Dauphin Island and the Sand/Pelican Island Complex (Ebersole et al. 2017). Robert Dixon, the current aquarium manager at the Sea Lab and longtime resident of Dauphin Island, hand-collected all specimens used in that study. Ninety-one fossil chondrichthyan and bony fish specimens were studied as part of the paper (Ebersole et al. 2017). That report marks one of the first instances in the literature of fossil chondrichthyan teeth along the Mississippi–Alabama barrier islands. All specimens in that study were collected as "float" specimens. According to the paper, the teeth are suspected to be late Pliocene or early Pleistocene in age and originated from either the Citronelle or Biloxi Formations (Ebersole et al. 2017). However, it should be noted that the Citronelle Formation is no longer recognized as a valid formation in the Gulf Coast of Alabama (Stringer et al. 2020). Two primary localities were described in the Ebersole et al. (2017) paper: the western beaches of Dauphin Island, and the beaches of the Sand/Pelican Island Complex. Twelve taxa were identified: *Carcharias taurus*, *Carcharodon carcharias*, *Cosmopolitodus hastalis*, *Carcharhinus leucas*, *Carcharhinus obscurus*, *Carcharhinus* sp. cf. *C. longimanus*, *Carcharhinus* sp. cf. *C. plumbeus*, *Negaprion brevirostris*, *Galeocerdo cuvier*, *Hemipristis serra*, *Aetobatus* sp., and Diodontidae (Ebersole et al. 2017).

An additional paper relating to fossil assemblages from Dauphin Island was published in 2020. As part of that study, more than 200 individual otoliths as well as some shark and bony fish fossils were collected and examined from the southeast end of the island (Stringer et al. 2020). The locality of fossil collection was a documented beach renourishment placement location for dredged sands. The borrow location for the southeast beach sand was found to be approximately 8 km (5 mi) south of Dauphin Island (Stringer et al. 2020). That publication revised the then-current understanding of the underlying geology of the Alabama coast. Recent revisions included the omission of the Citronelle Formation from the underlying geology of the Gulf Coast of Mississippi (Stewart and Starnes 2019; Stringer et al. 2020). The Graham Ferry Formation is now the only named Pliocene-aged formation present in the vicinity of Dauphin Island. The dredged sediments on Dauphin Island were attributed to the Graham Ferry Formation due to the presence or absence of certain index taxa; teeth from *Hemipristis serra* collected at the new locality indicated a Miocene to Pliocene–Pleistocene range of ages for the sediment. The absence of the bivalve *Rangia johnsoni*, which disappears from the fossil record after the Miocene (and is a marker fossil for the upper Miocene Pascagoula Formation), confirmed a Pliocene age for the dredged sediments on Dauphin Island (Stringer et al. 2020).

While not all of the GUIS chondrichthyan taxa have been identified to species, a preliminary comparative study may be made with the taxa listed in Ebersole et al. (2017) and Stringer et al. (2020). The taxa that both GUIS and the Ebersole et al. (2017) study share include *Carcharias taurus, Carcharhinus leucas, Carcharhinus* sp., *Negaprion brevirostris, Galeocerdo cuvier*, and Diodontidae. Notable taxa represented from Dauphin Island but not represented by the collections at GUIS include *Hemipristis serra* and *Cosmopolitodus hastalis*. These two taxa, and all other new taxa identified at GUIS in the future, may prove helpful in giving a relative age or range of ages for their source formation(s), much like what was accomplished with the index fossils in Stringer et al. (2020).

History and Influence of Dredging/Beach Renourishment on Fossil Localities

Dredging/Beach Renourishment and Fossiliferous Sediments

Natural shoreline change and erosion affects virtually all coastal areas within GUIS. One of the methods this NPS unit uses to combat erosion and maintain sediment at beaches is beach nourishment. Beach nourishment is a popular method of erosion control because it expands beach width, which further protects infrastructure and promotes increased tourism (Schupp 2019). Several beaches and localities have been subject to nourishment efforts throughout the past century (Table 4).

There is reason to believe that much, if not all, of the fossil material present on sandy coastal surfaces at GUIS arrived there by some mechanism and did not occur in situ. The naturally occurring sediment on all beach units of the park is Holocene, and should generally be devoid of fossilized material. However, there is a mention of sub-fossil wood, humus, and peat on Santa Rosa Island as described in permit GUIS199914. Near GUIS, Holocene sub-fossil and limonitic wood, burrows, and invertebrates have also been described in a small zone on the west end beach at Dauphin Island; these specimens are likely ~6000 BP based upon similar deposits that were radiocarbon-dated in Mississippi (J. Ebersole, pers. comm., 2022). Holocene-aged microfossils have been described in underlying sediments at GUIS, but macrofossils have not (E. Otvos, University of Southern Mississippi, professor emeritus, GRI review comments, 15 September 2017). The two most likely scenarios for macrofossil placement are reworking of older (pre-Holocene) sediments during large storm events, or renourishment activity. There is precedent for both of these scenarios. Ebersole et al. (2017) expressed their opinions on various methods of fossil deposition on modern-day beaches in their report on Dauphin Island fossil specimens in Alabama. Fossilized teeth from chondrichthyans have been collected directly adjacent to island breaches on Dauphin Island that open up after hurricanes (Ebersole et al. 2017). One such island breach, locally known as the “Katrina Cut”, opened on the western end of Dauphin Island after the hurricane of the same name swept through the Southeast U.S. in 2005. Many fossil specimens were collected adjacent to the Katrina Cut following its formation (Ebersole et al. 2017). In the same report, the authors also suggested dredging/beach renourishment as a possible source of the fossil specimens. Various localities on Dauphin Island have been renourished over the last few decades, using sediments dredged from local shipping channels as well as deep-ocean sediments several kilometers or miles south of the island (Ebersole et al. 2017). Measures are normally taken to ensure that the sediment being dredged is compatible compositionally and visually to the beach sediment being renourished (Schupp 2019). However, dredged sediment may contain a high abundance of shell material and potentially even fossilized specimens (Reilly and Bellis 1983; Boessenecker 2021). For example, Stringer et al. (2020) found and studied numerous fossilized otoliths along with chondrichthyan and actinopterygian fossils on a 1.5 km (0.93 mi) stretch of beach on the southeastern end of Dauphin Island that had been renourished with sediment dredged from the Gulf.

Table 4. Statistics of beach nourishment events affecting Gulf Islands National Seashore, reproduced from Schupp (2019, Table 9). From original caption: "(1) Anderson et al. 2016a [2016b]; (2) Browder and Dean 1999; (3) Florida Department of Environmental Protection 2015; (4) Ford 2013; (5) Marsh 2016; (6) NPS 2011; (7) Otay and Dean 1993; (8) Pensacola News Journal 2016; (9) USACE 2013; (10) USACE 2016a; (11) Western Carolina University 2016; (12) Jolene Williams, Gulf Islands National Seashore, environmental protection specialist, GRI review comments, 5 September 2017; (13) Jolene Williams, Gulf Islands National Seashore, environmental protection specialist, MsCIP meeting notes, 28 September 2017; (14) Jolene Williams, Gulf Islands National Seashore, environmental protection specialist, written comm., 27 December 2017."

Placement Location	Year(s)	Length (m)	Length (ft)	Volume (m^3)	Volume (yd^3)	Source (see above)
Cat Island	2017	5,800	19,000	1.9 million	2.5 million	13
Sand Island/DA-10	1917–2010	Varied	Varied	5.3 million	6.9 million	10
	2009–2010	Unknown	Unknown	Unknown	400,000	1, 14
	2012	Unknown	Unknown	841,000	1.1 million	4
Fort Massachusetts	1974	Unknown	Unknown	383,277	500,000	11
	1980	Unknown	Unknown	76,000	100,000	11
	1984	Unknown	Unknown	160,000	210,000	11
	1991	206	676	44,000	58,000	11
	1996	Unknown	Unknown	42,000	55,000	11
	2002	Unknown	Unknown	Unknown	Unknown	5
	2012	3,155	10,350	432,000	565,000	11
Camille Cut	2017–2018	5,630	18,480	In process as of December 2017	In process as of December 2017	14
Perdido Key beach	1980	7,481	24,544	4.0 million	5.3 million	11
	1985	1,585	5,200	1.9 million	2.4 million	11
	1989–1990	7,481	24,544	4.1 million	5.4 million	7, 11
Perdido Key nearshore (6 m [20 ft] water depth)	1989–1991	7,500	24,600	3.0 million	3.9 million	2
	2011–2012	2,865	9,400	400,000	520,000	3, 6
	2016	2,865	9,400	Unknown	Unknown	12
Santa Rosa Island	1961	Unknown	Unknown	57,600	75,3000	11
Pensacola Beach	2003	13,036	42,768	3.2 million	4.2 million	11
	2006	8,047	26,400	2.2 million	2.9 million	3
	2016	13,036	42,768	1.3 million	1.7 million	11
Navarre Beach	2006	6,600	21,700	2.3 million	3.0 million	9
	2010	490	1,600	9,100	12,000	9
	2016	6,600	21,700	990,000	1.3 million	8, 9

Navarre Beach Renourishment

Navarre Beach, just east of the Santa Rosa units at GUIS (Figure 2), underwent beach renourishment in 2006 (Schupp 2019). The sediment used for the 2006 beach renourishment was dredged from an offshore borrow area approximately 6 km (4 mi) south (Schupp 2019). The western portion of Navarre Beach was renourished again in 2010 (Table 4), with sediment sourced upland (Schupp 2019). In spring 2016, Navarre Beach was renourished again with sediment from the same borrow site that was used in 2006 (McKeon 2016; Florida Department of Environmental Protection 2015). Following the devastation of Hurricane Sally (2020), the beaches at Navarre were once again heavily eroded. There are currently plans for additional renourishment efforts at Navarre Beach later in 2022 (Pensacola News Journal 2021).

Pensacola Beach

While it is not managed by GUIS, Pensacola Beach lies directly east of the Fort Pickens area and west of the Santa Rosa area. Pensacola Beach was renourished in 2003 with dredged sediment from an offshore borrow site approximately 5.6 km (3.5 mi) away. This renourishment expanded the width of Pensacola Beach to 58 m (190 ft) (Schupp 2019). Pensacola Beach was renourished twice since 2003, once in 2006, and most recently in 2016 (Schupp 2019).

Perdido Key

In the last decades of the 20th century, Perdido Key experienced increased erosion and sediment loss as Pensacola Pass was continually deepened (Schupp 2019). The NPS has elected to continually renourish sediment in this coastal area to help preserve its natural processes, including storm overwash and island migration (Kenworthy et al. 2007). Since 1980, Perdido Key has been renourished multiple times with dredged sediment from Pensacola Pass (Schupp 2019). Historically, two distinct methods of renourishment have been utilized at Perdido Key. The first method, utilized in most cases, is the placement of dredged sediment directly on the beach surface and swash zone; this method often will widen the beach area in the process. The second method involves placement of the dredged sediment directly offshore of the eroded beaches, forming swash-zone berms (Wang et al. 2013). There are certain benefits to utilizing the offshore berm method of beach renourishment versus the typical placement of sediments directly on the beach. The offshore berm method reduces erosive high-energy wave action on the beaches, and over time the berms will add sediment to both the littoral system and the beaches further downdrift (Wang et al. 2013).

Perdido Key was most recently renourished with dredged sediment placed directly on the beaches in the late spring of 2022 (Kelly Irick, pers. obs.). The sediment for the 2022 renourishment was dredged from the Pensacola Pass shipping channel. Prior to the 2022 renourishment, Perdido Key had not been renourished with dredge placement directly on its beaches since the early 1990s (Schupp 2019). Renourishment using the offshore berm method has been more frequently used at Perdido Key in recent decades. Nearshore berm renourishment has taken place at Perdido Key in 2011, and more recently in 2016 (Schupp 2019).

The area of Perdido Key renourished in late spring of 2022 was surveyed for fossil resources in August of the same year. The sediment used in the renourishment was dredged from the bottom of the Pensacola Pass shipping channel, directly east of Perdido Key (B. Leutscher, pers. comm., 2022).

Fossil specimens were collected within the area of renourishment (all shark teeth, all float specimens). The presence of fossil shark teeth in dredged sediment that had been placed just several months prior indicates a likelihood that pre-Holocene aged sediments have been dredged from the Pensacola Pass shipping channel.

West Petit Bois Island/Sand Island/DA-10

West Petit Bois Island (Sand Island) holds a unique position among the locations within GUIS that have been historically renourished. It was created entirely from dredged sediment, making West Petit Bois Island the only human-made island unit managed by GUIS. This island, also known as area DA-10, was established as a dredge placement area for the US Army Corps of Engineers (USACE) beginning in 1962 (Byrnes et al. 2012). The sediment source for West Petit Bois Island is dredge material from the Horn Island Pass stretch of the Pascagoula shipping channel. Approximately 300,000 cubic meters (392,000 cubic yards) is placed on West Petit Bois Island every 18 months from routine deepening of the Pascagoula channel (Jolene Williams, GUIS environmental protection specialist, email comm., 27 December 2017 as cited in Schupp 2019). Until 2009, dredge material was placed primarily on the north side of West Petit Bois Island. However, a sediment budget conducted in tandem with the Mississippi Coastal Improvements Project (MsCIP) revealed that littoral sand transport across Horn Island Pass was limited due to its usual placement location (Byrnes et al. 2012). A decision was made to place all future maintenance dredging material on the south and west portions of West Petit Bois Island in an effort to aid westward littoral sand movement to Horn Island (NPS 2016b). Routine maintenance dredging is still ongoing, and sediment from the Pascagoula channel has been placed at the new locations on West Petit Bois Island as recently as 2021 (C. Haynes, pers. comm., 17 March 2022).

Ship Island

The vast majority of Ship Island's area had been left relatively unaltered by humans until the 21st century. The only beach nourishment at this GUIS barrier island unit in the 20th century has been localized to the area surrounding Fort Massachusetts on the west end of the island. Fort Massachusetts, the only historically significant structure remaining at Ship Island, has been under continual threat of coastal erosion since the early 1900s. The USACE began protection efforts in 1917 by constructing a groin and seawall around the fort to minimize erosive processes (Schupp 2019). An additional circular rock jetty was built around the fort in the 1960s to serve as a breakwater (Kenworthy et al. 2007). Nourishment efforts around the fort did not begin until 1974, when the USACE placed sediment dredged from the original Ship Island Pass (Schupp 2019). As an onslaught of destructive storms hit Ship Island and eroded its beaches over the next two decades, additional renourishment efforts occurred multiple times (Chaney 1993; Stone et al. 1998). In 2002, the beach in front of Fort Massachusetts was again renourished with sediment dredged from the now-defunct old Ship Island Pass that was closed in 1993 (Toscano 2004). See subsection "Ship Island Pass/Gulfport Channel" under "Dredging of Passes" below for more information on the history of shipping channels within Ship Island Pass. Renourishment at Fort Massachusetts occurred in 2012, as part of the Mississippi Coastal Improvements Project (MsCIP). The 2012 renourishment at Fort Massachusetts used dredged sediment from the old Ship Island Pass (USACE 2016a). The 20th century concrete and rock barriers were also removed as part of the 2012 MsCIP phase (Schupp

2019). The most recent renourishment at Fort Massachusetts occurred in June of 2020; as part of a later phase of the MsCIP, approximately 229,000 cubic meters (300,000 cubic yards) of sediment was placed in front of the fort (Everitt 2020) (Table 5).

Table 5. Breakdown of sediment volumes used for each phase of the Ship Island Restoration component of the MsCIP (USACE 2016a; Erin Plitsch via C. Haynes, GUIS Biologist, email comm., 2022) (mcm = million cubic meters; mcy = million cubic yards).

Phase	**Description**	**Initiated/Completed**	**Volume of Sediment Used**
Early Operations	Reinforcement of beaches north of Fort Massachusetts	2010/2011	0.5 mcm (0.6 mcy)
I	Reconnection of East/West Ship Island at “Camille Cut”	Dec 2017/Nov 2019	5.7 mcm (7.5 mcy)
II	Reconnection of East/West Ship Island at “Camille Cut”	Dec 2017/Nov 2019	4.8 mcm (6.3 mcy)
III	Restoration of East Ship Island southeast beaches	Mar 2020/October 2020	1.8 mcm (2.3 mcy)
IV	Widening of reconnected “Camille Cut” section	Mar 2020/May 2020	1.1 mcm (1.4 mcy)
V	Installation of native vegetation on “Camille Cut” reconnection	Early 2019/Dec 2019	N/A
Additional north shore restoration	–	2020	0.2 mcm (0.3 mcy)
–	–	Total	14.1 mcm (18.4 mcy)

<u>The Mississippi Coastal Improvements Project</u>

The MsCIP was developed and approved in 2009 by the USACE, with support from other agencies such as the NPS, as a comprehensive plan to strengthen the Gulf Coast of Mississippi against erosional storm damage. One facet of the program’s “barrier island restoration” component involved restoration of Ship Island, which had experienced extensive storm damage throughout the previous century (USACE 2016b). The main goal of the Ship Island restoration was to rejoin East and West Ship Islands along the 5.6 km (3.5 mi)-wide Camille Cut, a breach created by Hurricane Camille in 1969 (NPS 2016b). The placement of millions of cubic meters of sediment on Ship Island was also intended to replenish the littoral transport of sediment and increase sedimentation in Ship Island Pass (Schupp 2019) and widened by Hurricane Katrina in 2005. Work began on the Camille Cut and Ship Island Restoration in December 2017, and concluded in December 2020 (Walker 2020). During this period, more than 16 million cubic meters (mcm) (21 million cubic yards; mcy) of sediment was placed on and adjacent to the Camille Cut to successfully reconnect Ship Island. Additionally, about 4.2 mcm (5.5 mcy) of sediment was placed along the southern beaches of East Ship Island (NPS 2016b).

The Ship Island segment of the MsCIP was split into five phases (USACE 2016a). Phases I and II involved reconnection of East and West Ship Islands via filling-in of the Camille Cut. Phase II was completed in November of 2019, and Ship Island was officially a single barrier island unit again. Phase IV was initiated and completed before Phase III. Phase IV widened the reconnected stretch of Ship Island, while Phase III added sediment to restore the southwest beaches of East Ship Island. Lastly, Phase V involved the introduction of more than 300,000 native plants to stabilize the reconnected Camille Cut area of Ship Island. In total, ~14.0 mcm (~18.4 mcy) of sediment were placed on Ship Island as a result of MsCIP efforts (C. Haynes, email comm., 2022).

MsCIP Dredging Activity

All sediment used to repair the Camille Cut and nourish the south beaches of East Ship Island as part of the MsCIP were sourced from borrow sites, some of them either outside or partially outside Mississippi state waters. The sediment used to renourish the Fort Massachusetts area in 2012 was dredged from the old Ship Island Pass (USACE 2016a), as was the 2020 sediment.

Hundreds of core samples were taken on and around the Mississippi–Alabama barrier islands from 2010–2011 to determine suitable borrow sediment for the MsCIP activities. Several borrow site options were proposed, and each option was weighed for its pros and cons. In the end, five primary borrow sites were chosen: Ship Island, Petit Bois Pass–Alabama (PBP-AL), Petit Bois Pass–Mississippi (PBP-MS), Petit Bois Pass–Outer Continental Shelf (PBP-OCS), and Horn Island Pass (USACE 2016a). The general locations of the five borrow sites are shown in Figure 25. The chosen borrow areas contain sub-areas; many sub-areas are located outside of the waters managed by GUIS. This includes Petit Bois-AL (PBP-AL East and PBP-AL West) and Petit Bois Pass-OCS (PBP-OCS East 1–5, PBP-OCS West 1, and PBP-OCS West 3–6). Various borrow sub-areas are found either in Alabama state waters or Outer Continental Shelf (OCS) waters (USACE 2016a).

Dredge material from a combination of the PBP-OCS East and West, Horn Island Pass, and PBP-MS borrow sites was chosen for Phase I of the Ship Island restoration to create the initial berm on the Camille Cut. Dredge material from the PBP-OCS West and PBP-AL borrow sites were chosen for Phase II to widen the berm on the Camille Cut. The PBP-OCS West and PBP-AL borrow sites were again chosen for the sediment used in Phase III, to restore the beaches at East Ship Island. Lastly, the Ship Island borrow site was chosen for sediment during Phase IV to be placed on top of the Camille Cut berm created in Phases I and II, because it exhibits a finer texture than the other borrow site sediments, and is more suitable for vegetation growth (USACE 2016a).

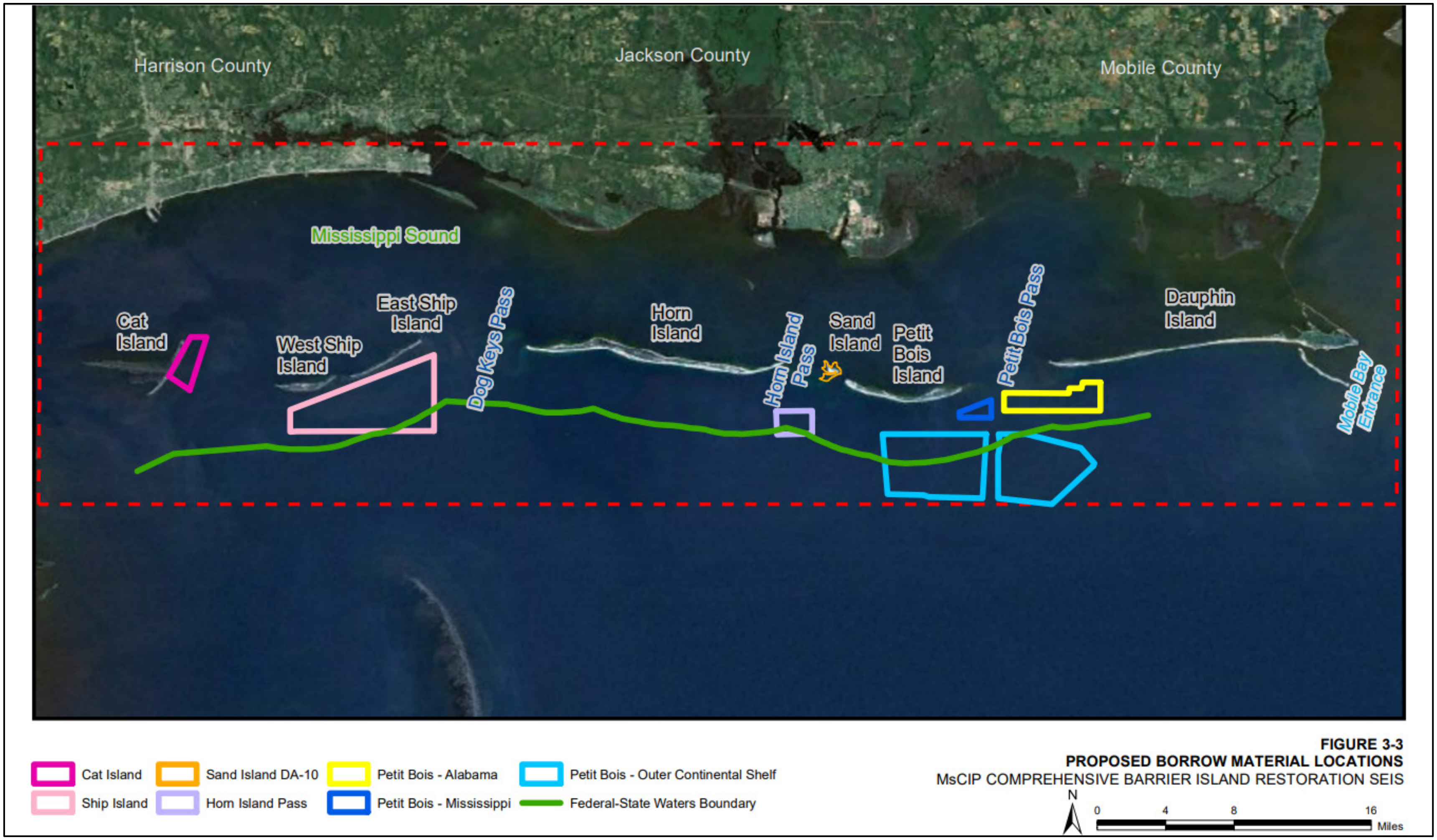

Figure 25. Map showing the boundaries of the five borrow areas chosen for the Ship Island Restoration Component of the MsCIP, as well as several other borrow areas considered but not taken forward. The five borrow areas chosen were: Ship Island, Petit Bois Pass–Alabama (PBP-AL), Petit Bois Pass–Mississippi (PBP-MS), Petit Bois Pass–Outer Continental Shelf (PBP-OCS), and Horn Island Pass. Reproduced from USACE (2016a, Figure 3-3). Image courtesy of the US Army Corps of Engineers.

Cat Island

There is no record of shoreline nourishment activities at Cat Island in the 19th or 20th centuries. Only the west side and southeast tip of Cat Island is owned by the NPS; the rest of the island is privately owned. The eastern beaches of Cat Island underwent sediment nourishment and dune planting as part of the MsCIP. Work associated with this nourishment was completed in November of 2017 (Schupp 2019).

Dredging of Passes

There are several inlets/passes near GUIS, including (east to west): East Pass (Florida), Pensacola Pass (Florida), Petit Bois Pass (Mississippi), Horn Island Pass (Mississippi), Dog Keys Pass (Mississippi), and Ship Island Pass (Mississippi). Routine dredging occurs in three of these passes: Pensacola Pass, Horn Island Pass, and Ship Island Pass.

Pensacola Pass

The shipping channel in Pensacola Pass (Figure 26) was created in 1883, and was originally excavated to 8 m (26 ft) in depth (Schupp 2019). Due to natural migration of Santa Rosa Island, the mouth of Pensacola Pass is also migrating westward (Browder and Dean 1999). Annual dredging took place in the Pensacola Channel from 1880 to 1960 to maintain its depth, with dredged sediments placed in a disposal site offshore (Florida Department of Environmental Protection 2015). In 1959, the channel depth was increased from 8 to 11 m (26 to 36 ft) with dredged sediment instead placed on Santa Rosa Island (Florida Department of Environmental Protection 2000). Pensacola Pass was drastically altered again in 1991, as it was dredged to 15 m (49 ft) deep and 240 m (790 ft) wide to allow passage of a naval aircraft carrier (Browder and Dean 1999). The continued maintenance dredging of Pensacola Pass over the 20th century has resulted in net sediment loss and increased erosion on Santa Rosa Island and Perdido Key (Browder and Dean 1999). It is estimated that only about 14 mcm (18 mcy) of the 35 mcm (46 mcy) of sediment dredged from Pensacola Pass between 1983 and 1991 was placed on nearby shorelines (Schupp 2019). In recent decades, much of the sediment dredged from Pensacola Pass has been used to renourish Perdido Key (Florida Department of Environmental Protection 2015).

Figure 26. Map of Pensacola Pass (bottom center of image) and nearby areas managed by GUIS in Florida. Pensacola Pass separates Santa Rosa Island (east) from Perdido Key (west). The Naval Air Station (NAS) area is directly north. The pass is routinely dredged by the US Army Corps of Engineers. NPS graphic available at the Harpers Ferry Center cartography website.

Horn Island Pass/Pascagoula Channel

Horn Island Pass is a 6 km (4 mi) stretch of shallow water located between Petit Bois Islands and Horn Island (Figure 27). The Pascagoula Port shipping channel cuts through Horn Island Pass and is situated between Petit Bois Island and Sand Island/West Petit Bois. The Pascagoula Channel is routinely dredged to a depth of more than 12 m (39 ft) (NPS 2007). Approximately 300,000 cubic meters (392,000 cubic yards) of sediment is placed on West Petit Bois Island every 18 months from routine deepening of the Pascagoula Channel (J. Williams, email comm., 27 December 2017 as cited in Schupp 2019).

Figure 27. Map of the Mississippi barrier islands with adjacent passes. East to west, the passes are Petit Bois Pass (easternmost, outside of image), Horn Island Pass, Dog Keys Pass, and Ship Island Pass. NPS graphic available at the Harpers Ferry Center cartography website.

Ship Island Pass/Gulfport Channel

Ship Island Pass is approximately 8 km (5 mi) wide and separates Ship Island and Cat Island (Figure 27). A 9 m (30 ft) deep, naturally occurring channel exists adjacent to the western end of Ship Island. This natural channel has historically moved westward due to longshore sediment transport (USACE 2015). The original Gulfport Channel was established here in 1899 for passage through Ship Island Pass (Schupp 2019). This channel was used until 1993, when it was abandoned. The new Gulfport Channel was established approximately 580 m (1,900 ft) west of the old channel to allow Ship Island to naturally migrate west (NPS 2007). The old Gulfport Channel was purposefully not backfilled (Chaney 1999) to serve as a sediment trap and limit sedimentation in the new channel (NPS 2007). However, the old Gulfport Channel has been dredged for renourishment of the Fort Massachusetts beaches in 1996, 2002 (Toscano 2004), and 2012 (USACE 2016a). More recently, the old Gulfport Channel was dredged for renourishment of the Fort Massachusetts beaches in 2020 as part of the MsCIP. The new Gulfport Channel is routinely maintained, with dredged sediment being placed in several different disposal sites along its length (Schupp 2019). Dredged material from one region of the new Gulfport Channel that contains sandier sediment is dumped in an offshore site south of Cat Island (USACE 2015).

History and Influence of Hurricanes and Storms on Fossil Localities

Hurricane Impacts and Human Responses

As a coastal NPS unit along the Gulf of Mexico, GUIS is highly susceptible to hurricanes and tropical storms. There has been an uptick in the impact of tropical storms around GUIS in the past several decades. Forty-eight hurricanes have made landfall on the Florida Panhandle in the hundred years between 1885 and 1985 (Wolfe et al. 1988). As for the Mississippi units of GUIS, 10 hurricanes and 21 tropical storms have occurred in the area surrounding Gulfport from 1901 to 2000 (Muller and Stone 2001). A list of tropical storms and hurricanes that have hit the Gulf of Mexico from 1917 to 2001 can be found in Deltares (2013). The Mississippi barrier islands have also been affected heavily by hurricanes; historical descriptions of hurricane impacts are reviewed by Morton (2007). Refer to Table 6 for descriptions of historically significant storms and hurricanes at GUIS.

Table 6. Major recent hurricanes affecting Gulf Islands National Seashore, adapted from Schupp (2019, Table 7). Sources: Browder and Dean (1999), Beavers and Selleck (2005), Houser et al. (2007), NPS (2007), Claudino-Sales et al. (2010), NPS (2014), Sankar (2015), Anderson et al. (2016b), and Florida Department of Environmental Protection (2020).

Hurricane	Date	Metrics (at time of landfall near park)	Affected area	Impacts
Frederic	9/12/1979	Category 3 Winds 233 kph (145 mph) Storm surge 3.7–4.6 m (12–15 ft) on Gulf Coast beaches	MS, FL	In MS, washover extended several hundred meters inland and reached the island centers and the sound shores, locally destroying tall foredunes. In FL, foredune retreat and 18 m (60 ft) of beach erosion along Perdido Key.
Erin	8/3/1995	Category 2 Winds 161 kph (100 mph) Storm surge 2 m (7 ft) at Navarre Beach, 1.2 m (4 ft) at Pensacola Beach	FL	Damaged Fort Pickens Road and J. Earle Bowden Way. Dune erosion. Caused 990,000 m^3 (129,000 yd^3) of erosion along a 12-km (8-mi) stretch of renourished beach on Perdido Key, with most of the sand being transported into the pass, and beach retreat of 18 m (60 ft). Nearly complete removal of foredunes along Perdido Key.
Opal	10/4/1995	Category 3 Maximum sustained winds 185 kph (115 mph) Maximum significant wave height 8.3 m (27 ft) off of Perdido Key Storm surge up to 5 m (15 ft) at Navarre Beach and 3–4 m (10–13 ft) at Pensacola	FL	Damaged Fort Pickens Road and J. Earle Bowden Way. Dune erosion. Caused 990,000 m3 (129,000 yd^3) of erosion along a 12-km (8-mi) stretch of renourished beach on Perdido Key, with most of the sand being transported into the pass, and beach retreat of 18 m (60 ft). Nearly complete removal of foredunes along Perdido Key.

Table 6 (continued). Major recent hurricanes affecting Gulf Islands National Seashore, adapted from Schupp (2019, Table 7). Sources: Browder and Dean (1999), Beavers and Selleck (2005), Houser et al. (2007), NPS (2007), Claudino-Sales et al. (2010), NPS (2014), Sankar (2015), Anderson et al. (2016b), and Florida Department of Environmental Protection (2020).

Hurricane	Date	Metrics (at time of landfall near park)	Affected area	Impacts
Georges	9/28/1998	Category 2 Winds 161 kph (100 mph) Storm surge 2–3 m (5–10 ft) at Pensacola	MS, FL	Damaged Fort Pickens Road and J. Earle Bowden Way. Beach erosion and overwash deposition.
Ivan	9/16/2004	Category 3 Winds up to 209 kph (130 mph) Sustained winds of 40 m (130 ft) per second Storm surge 0.9–1.4 m (3–4.5 ft) at Perdido Key	FL	Overwash, breaching, erosion of dunes and beaches. Covered Santa Rosa Island wetlands with washover sand. Net loss of sediment to the offshore region. Substantial damage to Fort Pickens Road, J. Earle Bowden Way, contemporary and historic structures, a campground, utilities, and landscapes. Perdido Key: Washover deposits extended over 140 m (450 ft) inland. Destruction of the berm, frontal dune, and substantial portions of secondary dunes. Foredune elevation decreased from approximately 4 m (12 ft) prior to the storm to 2 m (5 ft) after the storm. Shoreline retreat of 6 m (20 ft). In MS, washover extended several hundred meters inland and reached the island centers and the sound shores, locally destroying tall foredunes.
Tropical Storm Arlene	6/11/2005	Winds 97 kph (60 mph) Storm surge 0.4 m (1.3 ft) Storm tide (surge + tide) 1.2 m (3.9 ft)	FL	Damaged Fort Pickens Road and J. Earle Bowden Way. Beach erosion and breaching
Dennis	9/28/2005	Category 3 Winds 193 kph (120 mph) Storm surge 9 m (30 ft) Flow depth of the storm surge was at least 6 m (20 ft) on Cat Island, 7 m (23 ft) on West Ship Island, 8 m (25 ft) on East Ship Island, and 4 m (13 ft) on Horn Island. At Pensacola storm surge was 3–6 m (10–20 ft)	MS, FL	Caused pre-storm dunes and ridges on Petit Bois Island to migrate landward. Large pieces of shipwrecks carried far inland. Destroyed all NPS facilities on West Ship and Horn Islands except Fort Massachusetts. Severely damaged Davis Bayou unit (MS) and facilities in Florida. Damaged Fort Pickens Road and J. Earle Bowden Way.

Table 6 (continued). Major recent hurricanes affecting Gulf Islands National Seashore, adapted from Schupp (2019, Table 7). Sources: Browder and Dean (1999), Beavers and Selleck (2005), Houser et al. (2007), NPS (2007), Claudino-Sales et al. (2010), NPS (2014), Sankar (2015), Anderson et al. (2016b), and Florida Department of Environmental Protection (2020).

Hurricane	Date	Metrics (at time of landfall near park)	Affected area	Impacts
Gustav	9/1/2008	Storm tides 2 m (7 ft) at Pascagoula Wind gusts 30 m (100 ft) per second	FL, MS	Perdido Key dune lowering. East Ship Island: algal flat expansion, foredune blowout, conversion of vegetated habitat to bare sand, and land area expansion and overwash created intertidal zone extending from island core down length of the northeast spit. West Petit Bois Island: spit reworking and land growth on island's southeast flank.
Ike	2008	No data	FL	Perdido Key dune lowering
Tropical Storm Ida	2009	Storm surge 1.3 m (4.2 ft)	FL	Perdido Key dune lowering
Tropical Storm Lee	9/4/2011	Winds 72 kph (45 mph)	MS	Heavy rainfall and flooding. Ship Island: Damaged pier and eroded beach along southern side.
Tropical Storm Debby	7/2012	Waves 2.1 m (6.9 ft) Elevated water level of 0.15 m (0.49 ft) above normal tide level	FL	Erosion along Perdido Key.
Isaac	8/29/2012	Storm tides 2 m (7 ft) at Pascagoula Wind gusts 32 m (105 ft) per second	MS	East Ship Island: Growth of southeast spit, 23 ha (57 ac) added. West Petit Bois Island: southwest flank erosion, 11 ha (4.5 ac) lost.
Nate	10/7/17	Category 1	FL	Damage to Fort Pickens Road through the Fort Pickens area and Highway 399 through the Santa Rosa area. Road closures for nearly 2 months.
Sally	09/16/20	Category 2	MS, FL	Damage to Fort Pickens Road through the Fort Pickens area and Highway 399 through the Santa Rosa area. Damage to Johnson Beach Road at Perdido Key. Perdido Key dune lowering and formation of numerous washover fans. Three separate breaches were opened at the eastern end of Perdido Key near Fort McRee. In MS, the pier used by Ship Island Ferry Concessionaire was damaged. Pier was repaired before the summer 2022 season.

Hurricanes and tropical storms are some of the biggest contributors to geomorphologic change at GUIS. The high winds and storm surges very effectively transport sand across beaches and island units (Schupp 2019). The predicted storm surge at mean tide of a Category 4 hurricane hitting the coast is approximately 4 m (13 ft) (Caffrey and Beavers 2015). The effects a large storm event will have on barrier islands and beaches are primarily dependent on the bathymetry, relief and width of the island and beach units (Morton 2010). Shallower nearshore areas of the coast often receive increased storm surges compared to deeper areas (Sankar 2015). The path of a storm, as well as its wind speed, are additional factors that may affect its impact on coastal areas. Hurricanes that make landfall and travel west of a coastal area will generally be more destructive than hurricanes that travel east of an area (Schupp 2019). The orientation of barrier islands is another factor that may affect their response to large storms. In the Gulf of Mexico, hurricane waves generally approach the coast from the south-southeast to the south-southwest (Schupp 2019). While the Florida barrier island units of GUIS trend east-west, most of the Mississippi barrier islands trend east-northeast to west-southwest. Thus, the Mississippi barrier island units are more susceptible than the Florida barrier islands to erosion and alteration by hurricanes. Erosion rates are usually highest on the east ends of the barrier islands as a result (Otvos and Carter 2008).

After large tropical storms, barrier islands undergo gradual, natural recovery periods. The increasing frequency of destructive storms in the Gulf of Mexico over recent decades has inhibited barrier island recovery in several areas of GUIS. A recent example of disrupted barrier island recovery is Ship Island. Ship Island was breached by Hurricane Camille in 1969, effectively splitting the island into "east" and "west" sections (NPS 2016b). The breach, known locally as the "Camille Cut", slowly recovered over the next three decades until being widened again by Hurricane George in 1998 (Twichell et al. 2011). The Camille Cut then entered another recovery period, until rewidening after Hurricane Katrina in 2005 (Walker 2020). The Camille Cut was finally closed and East and West Ship Island rejoined in 2019 as part of the MsCIP (Walker 2020). In an effort to reinforce the sediment placed in the area of the old Camille Cut and prevent future breaches of Ship Island and erosion, the final phase of the MsCIP involved planting of dune vegetation in the area (NPS 2016b).

Overwash is a common phenomenon that occurs on barrier islands during large storms (Figure 28). High winds and waves allow storm surge to advance past the beaches and toward the interior of barrier islands. Sediment deposited by the water is known as washover. Recent hurricanes in the previous two decades, including hurricanes Frederic, Ivan and Katrina, caused major overwash on the Mississippi barrier islands, extending into their interiors and destroying tall foredunes (Otvos and Carter 2008). Historically, only the tallest dunes and highest relative elevations of barrier islands have been spared from the overwash of hurricanes (E. Otvos, University of Southern Mississippi, professor emeritus, written comm., 4 February 2007, as cited in NPS 2007). Overwash affects barrier islands in different ways depending on the local morphology of the island and the severity of the storm (Houser et al. 2007). There was minimal overwash along Santa Rosa Island during Hurricane Ivan (2004) in areas where the foredunes were taller than the storm surge and more highly concentrated. However, nearshore sediment erosion increased in those same areas where overwash was restricted (Houser et al. 2007). As for Perdido Key, substantial overwash and dune lowering from Hurricane Ivan left the area very susceptible to erosion. Perdido Key did not have time to recover before Hurricane Dennis hit the area one year later in 2005. The magnitudes of erosion and overwash at Perdido Key from Hurricane Dennis were increased due to the previous damage caused by Hurricane Ivan (Sankar 2015). Perdido Key, and its narrower eastern end in particular, has been prone to increased overwash and blowouts as a result of heightened hurricane frequency and inadequate recovery time.

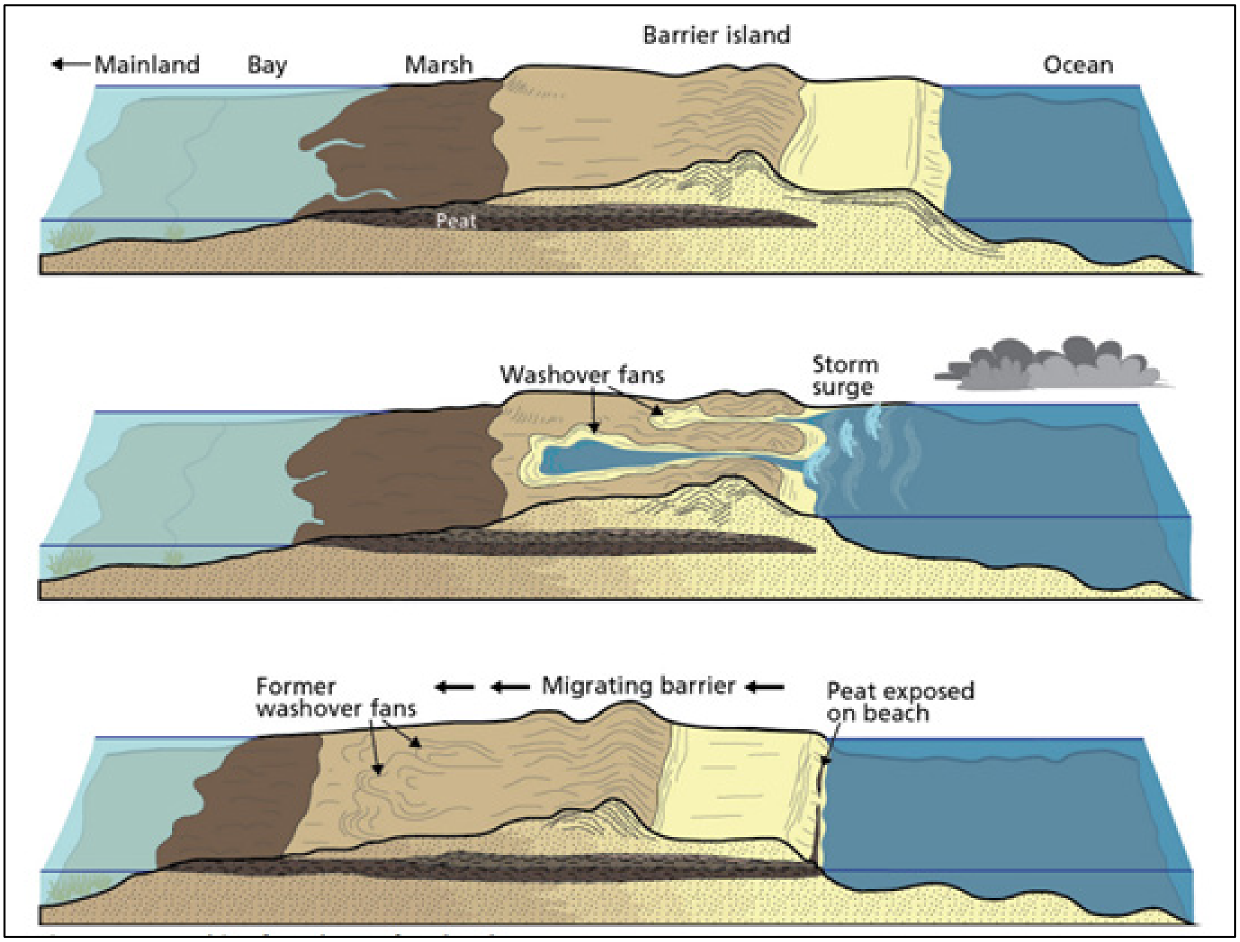

Figure 28. Graphic of washover fan development. Where waves carry sand across the beach, sediment is deposited as small washover fans in the island interior. Large storm events can drive meters of water across the island (in a process known as "overwash"), resulting in large washover ramps that bury the back-barrier marsh, as depicted here (such as Santa Rosa Island and Perdido Key) or beach (such as the Mississippi barrier islands, which do not have marshes on the sound side). Reproduced from Schupp (2019, Figure 20). Graphic by Trista Thornberry-Ehrlich (Colorado State University) after NPS and University of Maryland Center for Environmental Science.

Hurricane Katrina

The coastal landscape of the northern Gulf of Mexico was impacted heavily by the devastation of Hurricane Katrina in 2005. Katrina was only a Category 3 storm when it made landfall; however, its impact was heightened thanks to wave buildup caused when it was still a Category 5 storm on the

Gulf (Fritz et al. 2008). Hurricane Katrina was unusually large, with a 50 km (31 mi) radius and approximately 140 km (87 mi)-wide area of hurricane-force winds (Fritz et al. 2007).

In Mississippi, storm surge reached 4.9 m (16 ft) on Petit Bois Island, 5.7 m (19 ft) on Horn Island, 9.2 m (30 ft) on West Ship Island, 8.2 m (27 ft) on East Ship Island, and 6.9 m (23 ft) on Cat Island (Fritz et al. 2008). The eastern ends of Petit Bois, Horn, and Ship Islands were heavily eroded as a result of Katrina (Houser 2011). Extensive overwash occurred, with 20 to 80 cm (8 to 31 in) thick washover deposits extending 150 to 200 m (490 to 660 ft) into the barrier island interiors (Dalal 2006). Petit Bois Island experienced high storm surge and wave energy, causing dunes and beach ridges to migrate north. Despite the movement of dunes and beach ridges, there was negligible change in the elevation of Petit Bois Island due to erosion or other hurricane-related factors (Schupp 2019). The preservation of bathymetry and elevation is partially attributable to the extremely high storm surge that fully covered the island during the hurricane (Sallenger 2000; Schupp 2019). Horn Island was also heavily affected by Hurricane Katrina, despite its heavily vegetated island interior. Extreme wave activity removed the top 1 to 2 m (3 to 7 ft) of relict dunes on Horn Island, and a 700 m (2,300 ft) wide breach opened up at the western tip of the island (Otvos and Carter 2008). Washover deposits extended up to 430 m (1,410 ft) into the island's interior, with more washover fans found on the western side of the island (Morton 2010). The Camille Cut between East and West Ship Islands was widened due to erosion caused by Hurricane Katrina. The two separate Ship Islands both also experienced heavy erosion and reduction in land area due to their relatively low elevations and profiles when Hurricane Katrina struck (Houser 2011).

The Florida units of GUIS were also heavily affected by Hurricane Katrina and other strong hurricanes during the first years of the early 21st century. Overwash became so prevalent in certain areas that they eventually eroded both foreshore and back-barrier dunes. Natural overwash corridors were also established in areas between dunes; many of these overwash corridors extend into the island interior and even across to the Santa Rosa Sound (Houser et al. 2015). Geomorphologic impacts of Hurricane Katrina are captured in the GRI GIS data because source maps were developed using aerial orthophotographs taken approximately two years after the storm. It is worth noting that the geomorphology of coastal areas such as GUIS is subject to significant, unpredictable, and rapid changes. Areas of GUIS may look completely different from one season to the next because of shoreline erosion, storm activity, and so forth.

Impact of Climate Change on Hurricanes

Climate change and global warming will have an impact on both the intensity of large storms and how coastal areas and barrier islands will respond to these storms. The wind speed, rainfall intensity, and storm surge magnitude of hurricanes are all predicted to increase in the future (Carter et al. 2014). Additionally, rising mean sea levels will further exacerbate wave runup and storm surge during hurricanes (Tebaldi et al. 2012; Goldstein and Moore 2016). Studies taken on Santa Rosa Island and Perdido Key show that these particularly narrow barrier island areas will be predisposed to overwash and erosion during storm events (Houser et al. 2015; Sankar 2015). Sand retention and natural dune recovery are correlated to both the magnitude and frequency of large storms (Schupp

2019). See the above subsection “Hurricane Impacts and Human Responses” for more information on natural barrier island recovery after storms.

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Two fossils specimens were recovered by a GUIS ranger in January 2022 on Petit Bois Island. The specimens are likely pieces of turtle shell, flat and square in shape. The specimens feature many linear grooves covering one face. The linear grooves initially led interpretive rangers at GUIS to associate the pieces with known historical Native American activity on the Mississippi barrier islands. However, preliminary research into turtle shells has revealed that the linear groove marks may have formed naturally when the organism was still alive. More research needs to be conducted on this specimen and turtle morphology to determine its cultural significance, if any.

A mineralized fossil housed as part of the collections for GUIS, possibly a mollusk shell, was found associated with an apparent archeological site (R. Sellers, pers. comm., 2006, as cited in Kenworthy et al. 2007). This specimen is now housed at the NPS Southeast Archeological Center (SEAC). While this specimen is stored under GUIS collections, it was collected at a site in Carrabelle, Florida, which is outside of lands managed by GUIS. Thus, the archaeological significance of this specimen, if any, is not tied physically to GUIS.

Additional fossil resources may be tied to archeological sites. There are multiple archeological sites dispersed around GUIS units, on mainland areas as well as on the barrier islands (Toscano 2004). A majority of the sites identified in the park date to the Woodland period, spanning from 1000 BCE to 1000 CE (Schupp 2019). A common feature that signifies prehistoric human habitation in an area is the presence of middens. Middens are essentially ancient trash heaps that contain various human waste products and, in most coastal settings, mollusk shells. Middens have been identified in several areas of GUIS (Schupp 2019). Some younger settlements have also been identified within the park, dating to the Mississippian Period (550 CE–1500 CE). The inhabitants of both the Woodland and Mississippian settlements around GUIS were predominantly hunter-gatherers (NPS 2014).

Due to the established presence of early settlements at GUIS, it is plausible that paleontological resources may be found associated with archeological artifacts in the future. It is recommended that park personnel examine all known and future archeological artifacts to determine if said artifacts may be paleontological as well as archeological.

Several areas of GUIS are historical sites of military fortifications, most dating back to the early 19th century. One such fortification, Fort Pickens on Santa Rosa Island, may contain some fossil resources. There appears to be evidence of tabby shell/lime/concrete within the interior of the original fortification (Figure 29) (Michael Clinton, pers. obs., 2021). The shell material can be seen today in areas of the fort that have collapsed or were otherwise damaged, exposing the interior construction. Fossil mollusk shell was also observed within foundational blocks throughout the grounds of Fort Pickens (Christy Visaggi, pers. obs., 2021). Apart from visual observations made by the paleontological inventory team during a visit to Fort Pickens, the true composition of the shell construction on the fort (and whether or not it is fossilized) is undetermined. Further investigation is recommended to determine the composition of the apparent shell-based construction materials within Fort Pickens and other fortifications within GUIS.

Figure 29. Photo of a damaged and exposed section of the northwest corridor of historical Fort Pickens. White bivalve shells (potentially of fossil origin) are visible in the tabby/aggregate in this exposed section of the fort (NPS/MICHAEL CLINTON).

Museum Collections and Paleontological Archives

Museum Collections and Curation

Park Collections

GUIS does not currently have any paleontological resources in its collections from the park. Two specimens previously collected by GUIS rangers are currently being kept at the Davis Bayou Headquarters in Mississippi until a permanent repository is determined.

In total, 711 individual fossil specimens were collected under permit GUIS-2021-SCI-0037. The vast majority of the fossil specimens collected (661 or 93%) are from Class Chondrichthyes. Table 7 below shows total counts for all major taxa collected. Refer to Appendix B for a complete table of all specimens identified.

Table 7. Total specimens of all major taxa from 2021–2022 surveys. Taxa are listed top to bottom from greatest to smallest number. *Other collected shells of gastropods and bivalves may also include pre-Holocene specimens; however, only a single scaphopod specimen is included in the collections here for mollusks.

Taxa	# of specimens
Chondrichthyes (Sharks)	632
Chondrichthyes (Rays)	29
Actinopterygii (Bony Fishes)	27
Decapoda (Crabs, Lobsters, Crayfish, etc.)	20
Testudines (Turtles)	2
Mollusca* (Scaphopod)	1

Of the 661 chondrichthyan fossils recovered, 632 (96%) of the specimens belong to sharks. All shark fossils consist of teeth. The remaining 29 (4%) specimens belong to rays. A total of 292 shark teeth were recovered in Florida while 340 shark teeth were recovered in Mississippi. Of the 632 shark teeth, ~54% could be identified at least to genus level (and many more could be attributed to the family Carcharhinidae). Six genera have been identified among the specimens collected thus far: *Carcharias*, *Carcharhinus*, *Galeocerdo*, *Negaprion*, *Rhizoprionodon*, and *Sphyrna*. 73% of the shark teeth from Florida and 37% of the shark teeth in Mississippi were identifiable to genus level. Breakdowns of genera per state are given in Table 8 below.

Table 8. Breakdown of teeth identifiable to genus collected during the 2021 and 2022 surveys at GUIS, divided by state.

Genus	Florida GUIS Specimens	Mississippi GUIS Specimens
Carcharias	1	10
Carcharhinus	109	52
Galeocerdo	13	5
Negaprion	39	45
Rhizoprionodon	47	10
Sphyrna	5	3
Total identifiable teeth	214	125

In both Florida and Mississippi, genus *Carcharhinus* represents the largest number of shark teeth recovered. *Carcharhinus* is the most diverse genus in the family Carcharhinidae, with 34 species known (Nelson et al. 2016). In Florida, the genus with the second largest proportion of specimens recovered is *Rhizoprionodon*. There were markedly fewer teeth belonging to *Rhizoprionodon* recovered in Mississippi. Genus *Negaprion* was the third most abundant genus represented among Florida collections and the second most abundant genus represented among Mississippi collections. Chondrichthyan experts were consulted for assistance with identifying shark teeth to ensure proper identification. However, many shark teeth from different genera can look very similar. *Negaprion* teeth from the lower jaw and *Carcharhinus* teeth from the lower jaw may look extremely similar, even under a magnifying glass (V. Perez, pers. comm., 2022). If a determination could not be made regarding which genus a specimen belonged to, it was only identified to family level. The remaining three genera, *Carcharias*, *Galeocerdo*, and *Sphyrna*, comprised the fewest teeth represented among collections from both Florida and Mississippi. Notably, there were comparatively many more teeth from *Carcharias* collected in Mississippi (10) than there were in Florida (1).

Collections from this survey effort are presently at Georgia State University for study but will be moved to a final repository (to be determined) upon the conclusion of this report.

Collections in Other Repositories

There are several paleontological specimens currently housed at SEAC; one specimen is a mineralized fossil, possibly a mollusk shell. It was found associated with an apparent archeological site (R. Sellers, pers. comm., 2006, as cited in Kenworthy et al. 2007). More research and inquiry into this specimen is needed to determine its exact origins; there is little currently known about it. The mineralized mollusk specimen may be specimen GUIS 29237, housed at SEAC, based upon a similar description (J. Tweet, pers. obs., 2022). This mollusk specimen was collected in the Carrabelle, Florida area which is outside of GUIS.

Additionally, there are other specimens that may not have been collected on lands managed by GUIS. One of these specimens includes a small, 9.5-gram (0.33-ounce) fragment of what may be mastodon tusk, specimen GUIS 25726. GUIS 25726 was collected in 1940 by researchers from Columbia University, at the "Carrabelle Site" in Franklin County, Florida (H. Kratt, pers. comm., 2019). While

GUIS 25726 is attributed to the GUIS collections at SEAC and is labeled as such, it appears this specimen was collected outside of GUIS-administered lands. There may be other specimens associated with the 1940 survey attributed to the GUIS collection at SEAC; further information such as the collection locations of these specimens is not known (see Appendix C for SEAC contact information).

Archives

NPS Paleontology Archives

All data, references, images, maps and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at GUIS, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

Memos-to-File

Memos-to-file are useful methods of documenting notable pieces of information that merit preservation. This documentation format has been utilized throughout the creation of the Paleontological Resources Inventory, primarily as a means of aggregating instances of individuals supposedly collecting paleontological resources within GUIS (see section "The Influence of Social Media on Paleontological Resources Inventories" for more information). All memos-to-file created during the course of this report are stored within the NPS Paleontology Archives.

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). At this time, no E&R files have been located for GUIS.

Photographic Archives

All digital photographs associated with the Paleontological Resources Inventory have been compiled into named folders and will be stored within the NPS Paleontology Archives. Digital photographs include labeled photos of most of the fossil specimens collected at GUIS.

Park Paleontological Research

Current and Recent Research

Since the 1990s, five permits have been issued for research at GUIS that were either paleontological in focus, or a geological project with paleontological significance (omitting class field trips).

GUIS1994AKXB, principal investigator Stephen Oivanki of the Mississippi Office of Geology, project "*Geologic History, Geomorphology, and Geologic Process Analysis of the Barrier Islands, offshore Mississippi*", year issued uncertain from IRMA record.

GUIS1994AKXC, principal investigator Stephen Oivanki of the Mississippi Office of Geology, project "*Geologic History, Geomorphology, and Geologic Process Analysis of the Barrier Islands, offshore Mississippi: 1991–1995*", year issued uncertain from IRMA record.

GUIS199914, principal investigator Barbara A. Lewis of the Mississippi Office of Geology, project "*Santa Rosa Island Subfossil Wood, Humus, and Peat*", issued for 1999.

GUIS-2011-SCI-0008, principal investigator Dawn Lavoie of the U.S. Geological Survey Coastal and Marine Geology Program, project "*Cat Island Evolution and Mapping*", issued for 2010–2011.

GUIS-2021-SCI-0037, principal investigator John Michael Clinton of Georgia State University, project "*An Inventory of Fossil Shark Teeth and other Paleontological Resources within Gulf Islands National Seashore*", issued for 2021–2022. The research for the current inventory report was conducted under this permit.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/rprs/). Additional information on NPS law and policy can be found in Appendix D.

Interpretation

Current Long Range Interpretive Plan

As of 2022, no specific programming related to paleontological or geological resources is offered at GUIS. Both the Fort Pickens and Davis Bayou visitor centers feature small museums with various displays, generally relating to the human and natural history of GUIS, its association with the NPS, and local fauna/flora. Rangers at the visitor centers also occasionally conduct interpretive presentations, setting up a table with various interpretive objects; again, these presentations are normally associated with the history of GUIS, its association with the NPS, and local fauna/flora. One such interpretive item housed at the Davis Bayou visitor center was a jar of approximately 80 fossil shark teeth (M. Clinton, pers. obs., 2022). The origins of these shark teeth specimens are unknown, although they did not appear to be sourced from any areas within GUIS based on the specimens included. It is unclear what type of information was shared by interpretive rangers relating to the jar of shark teeth. The jar of shark teeth was observed at the Davis Bayou visitor center in March of 2022; it has since been moved to storage (B. Leutscher, pers. comm., 2022). The use of fossil shark teeth such as those previously housed at the Davis Bayou visitor center for interpretive reasons may need to be reconsidered in light of the new findings of fossil resources detailed within this inventory.

Interpretive strategies and resources at GUIS have traditionally focused upon the many historical coastal defense fortifications situated throughout park areas, the largest attraction being Fort Pickens in Florida. GUIS established its current long-range interpretive plan in 2020 (Casimer Rosiecki, GUIS Interpretive Ranger, pers. comm., 2022). There is currently no mention of paleontological resources in the current long-range plan. However, the current long-range interpretive plan may be amended in the future if GUIS chooses to include interpretive programming related to park paleontology. One avenue GUIS may choose to pursue would be to incorporate paleontological resources into the anthropogenic history of GUIS. Background research into historical channel dredging and beach nourishment (see the “History and Influence of Dredging/Beach Renourishment on Fossil Localities” section) appears to show that many of the fossil resources at GUIS arrived at the approximate areas of their identified localities as a result of anthropogenic sediment transport. An interpretive strategy could be to highlight the influence of humans on fossil resources at GUIS today. If future research sheds more light on the suspected fossil mollusk specimens used in the construction of Fort Pickens (see the “Cultural Resource Connections” section), a talking point could also be the use of fossils to build/reinforce GUIS forts.

There are some potential concerns and hurdles related to the creation of certain long-range interpretive programing related to paleontological resources at GUIS. The first concern involves potential resource management issues which may arise. Fossils have so far been identified at six of the seven barrier island units managed by GUIS: Santa Rosa Island, Perdido Key, Petit Bois Island, West Petit Bois Island, Horn Island, and Ship Island. While the creation of a long-range interpretive strategy for paleontological resources at GUIS would shed light on a historically underrepresented natural resource at the park, it could potentially also attract the attention of fossil collectors. The vast majority of the specimens identified at GUIS are “float specimens”, found resting on beaches. This fact raises even more concern, as float specimens by their very nature are much easier to remove from their point of origin than in situ specimens.

Additional concerns related to the interpretation of paleontological resources are the logistical hurdles involved with interpretive programming. One suggestion which has been raised in interpretive strategy discussions with park management is the creation of an exhibit or display highlighting the paleontological resources present at GUIS. GUIS currently features two primary interpretive exhibit spaces: the Fort Pickens Discovery Center at Fort Pickens, and the William M. Colmer Visitor Center at Davis Bayou. There is currently no exhibit on display in either space that mentions paleontological resources at GUIS. There are concerns with the feasibility of such an exhibit being created for paleontological resources at one or both of the exhibit spaces. Exhibit space is currently very limited in both the Fort Pickens Discovery Center and the visitor center at Davis Bayou, so GUIS may not have the facilities to house another exhibit. Additionally, the park may not be able to secure funding for the creation of such exhibits. One suggested solution to both of these concerns is for GUIS to collaborate with an organization specializing in paleontological outreach and education. This way, funding for programming such as a rotating exhibit at the park could be secured.

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the park. The ranger would provide the visitor with advice on why fossils are important, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected and not collected within park boundaries. As a general guideline, rangers and representatives of GUIS should err on the side of caution when discussing information related to park paleontological resources with the public. Rangers should attempt not to draw unwanted attention to fossil localities when discussing these resources with the public.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands and even hundreds of millions of years ago. The chondrichthyan fossils collected at GUIS possess additional significance, being only the second collection of their kind described from this area of the northern Gulf of Mexico.
- When paleontologists survey for paleontological resources, the most important tool for planning is often a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. In the case of GUIS, however, it is presumed that fossil resources have been displaced from sub-surficial geological formation(s) adjacent to GUIS units or under the continental shelf of the northern Gulf of Mexico via dredging/beach renourishment activities. The naturally occurring beach sediment at all barrier island and coastal units of GUIS is Holocene (modern) and will be reflected as such in typical geologic maps. Thus, a geologic map is less relevant for future paleontological resources surveys at GUIS, as fossils are not found in situ but as float specimens along the beaches. Tools that are more appropriate for paleontology at GUIS include a field notebook for recording data and observations, sample bags to collect

specimens, small brushes, consolidants to stabilize fossils, GPS, camera, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors if giving an interpretive talk.

- If fossils are found in the park by a visitor, the visitor should photograph it and notify a ranger, reporting to the best of their ability where exactly the resource was found. Under most circumstances they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved; however, GUIS is unusual in that fossils are found as float and have been transported there likely as a result of dredge materials, so contextual information is lacking. In addition, the beaches where fossil specimens are commonly found are very dynamic environments; the sands constantly shift, especially after storms. Thus, it may be that GUIS decides to encourage visitors to pick up fossil specimen they may encounter at the national seashore and turn them in to park staff so that the specimens aren't lost to the elements. This suggestion should be scrutinized thoroughly before implementation, however, as any advertisement of fossils at GUIS runs the risk of unauthorized fossil collection and removal from the national seashore lands. Visitors should be informed that NPS fossils are protected by law.

II. Fossils of GUIS

- A web page related to paleontological resources could be created within the official NPS website for GUIS. The goal of this web page would be to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of GUIS can be included. However, it is suggested that sensitive information such as the locations of fossil localities or specific areas not be disclosed in this web page as a measure to prevent illegal fossil collection. There is much that GUIS can do to promote knowledge of the unique fossils present at the park. One suggestion is to devote a section of the web page to fossil shark teeth. Facts about sharks and their teeth can be shared, as well as the useful scientific information which can be gained from studying them. Caution is advised however before more widespread communication about these resources given the risk of authorized collecting. While individuals may be able to collect shark teeth on beaches outside of the park, reminders about protections in place for specimens on park lands is important.

III. Further Interpretation Themes

GUIS may elect to promote NPS paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day, celebrated annually on Wednesday of the second full week in October (National Earth Science Week). However, GUIS should err on the side of caution when sharing information related to local park paleontological resources with the public. Again, any advertisement of the local fossils at GUIS runs the risk of unauthorized fossil collection and removal from the national seashore. For more information on National Fossil Day, visit: https://www.nps.gov/subjects/fossilday/index.htm. The NPS coordinates the National Fossil Day partnership and hosts fossil-focused events across the country. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide Junior Paleontologist Program supplies including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Additionally, the research team under permit GUIS-2021-SCI-0037 have created several pieces of educational material such as a "Shark Teeth of GUIS ID Guide". These materials were originally created to inform the staff at GUIS of the fossil resources found at the park. GUIS may elect to use these educational resources for future interpretive efforts when appropriate.

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 424 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 286 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these non-renewable paleontological specimens from federal lands. In March 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated Department of Interior (DOI) lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix D. Paleontological resource protection training is available for NPS staff through the NPS Paleontology Program. The Paleontology Program is also available to provide support in investigations involving paleontological resource theft or vandalism.

Between 2009 and 2022 an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) developed the DOI final regulations for PRPA. The draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team has reviewed public comments provided for the draft regulation and have incorporated these into the final regulation. The final regulation was surnamed by the DOI Solicitor's Office and each of the four bureau directors. On August 2, 2022 the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register. After 30 days the Office of Management and Budget approved the final DOI PRPA regulation, which is available at the following website: https://www.federalregister.gov/documents/2022/08/02/2022-16405/paleontological-resources-preservation. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *… Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

The chondrichthyan fossils collected at GUIS throughout 2021 and 2022 hold special significance. There is a noted gap in scholarly knowledge relating to chondrichthyan fossil assemblages of any age from the coastal units managed by GUIS, and in the greater northern Gulf Coast of Mexico. The gap in knowledge of chondrichthyan fossil assemblages in this region is noted by many in the scientific community including Victor Perez, former assistant curator of paleontology at the Calvert Marine Museum, now at St. Mary's College of Maryland (Perez 2022). The float fossil specimens at GUIS are presumed to have been placed on beaches through anthropogenic means, as the localities with greatest fossil abundance have been subject to beach renourishment using presumed pre-Holocene and fossiliferous dredged subsurface sediments. Thus, these GUIS specimens provide a rare chance for the scientific community to observe and analyze fossils which normally would be buried and underwater. While GUIS should take the necessary steps to ensure proper management of these newly discovered fossils, staff may also want to investigate avenues of preserving and sharing this resource's significance with the scientific community.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything that disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of associated paleontological resource data. Because of the rarity of fossil shark teeth along this part of the coastline, even though the specimens are found as removed from their original geological context, they are still of significant value in learning more about the history of sharks in this region.

Management strategies to address any of the conditions and factors that may put paleontological resources at risk could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish such a large task at GUIS. Active recruitment of paleontological research scientists should also be used as a management strategy.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on paleontological research done in and near GUIS, taxonomic groups that have been reported within GUIS boundaries, and reported localities. This effort can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and Monitoring report for the Gulf Coast I&M Network completed by Kenworthy et al. (2007) and the references cited within were important baseline paleontological resource data sources for this GUIS-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site which is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits (and perhaps specimen collection) than a less productive or less threatened site.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park which has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishing a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Ship Island Ferry Concessionaire

During the summer months, West Ship Island is the most visited of the Mississippi barrier islands. A concessionaire ferry boat, contracted by the NPS, routinely transports visitors to Ship Island from the mainland several times every day. According to Captain Pete Skrmetta, one of the concessionaire's managers, the concessionaire has never encountered visitors who have collected paleontological resources such as shark teeth from Ship Island (pers. comm., 2022). The concessionaire does not advertise or mention the presence of paleontological resources at Ship Island.

Kelly Irick (former Natural Resources Manager at GUIS) was made aware of a supposed incident regarding the Ship Island Ferry concessionaire. At some point prior to the 2021–2022 surveys, GUIS Law Enforcement Ranger Ronda Harper received a tip that raised concerns of a rumored organized operation for ferry passengers to collect fossils (presumed to be shark teeth) on Ship Island. It is unclear if the organizer of the supposed operation was an employee of the Ship Island Ferry concessionaire or a regular passenger. During a conversation in 2022, Captain Skrmetta did not have information regarding this rumored operation. At present time, it is unclear if this unauthorized fossil collecting operation had occurred. Nonetheless, a memo-to-file has been created for all correspondence related to this supposed incident and is stored in the NPS Paleontology Archives.

Considering the sensitive nature of paleontological resources at Ship Island, GUIS is encouraged to keep communication lines open with the Ship Island concessionaire (and any other contracted or chartered entities) regarding instances of unauthorized fossil collecting by passengers. GUIS may choose to share information on the fossil resources known on Ship Island with the concessionaire to inform them on what to look out for and how to communicate fossil resource management with ferry passengers. The concessionaire does announce to passengers that "seashell" collecting is allowed. It is suggested that the concessionaire continues to not advertise the presence of fossils at Ship Island or any of the other barrier islands within GUIS. Any advertisement given to fossil resources may draw unwanted attention from public fossil collectors. If they so choose, the concessionaire may elect to state instead that nothing other than seashells are allowed to be collected at Ship Island, without explicitly alluding to the presence of fossils such as shark teeth.

Influence of Social Media on Paleontological Inventories

Social media has proven to be an invaluable resource for gathering information during the synthesis of this inventory. The advancement of internet applications and the rise of social media platforms in recent years has provided a means for anybody to share their thoughts and experiences with the world. People with shared interests can communicate with each other, and with the public, in ways that hadn't been available before.

For the purpose of this inventory, social media applications were searched to identify instances of fossil collection within or near GUIS. Two primary social media sites were searched for this purpose: thefossilforum.com and Facebook.com. The former is a public online forum related to fossil enthusiasts both amateur and professional, while the latter is a more generalized social media platform. In the case of thefossilforum.com, keywords relating to GUIS units (Santa Rosa, Fort Pickens, Perdido Key, Mississippi Barrier Islands, etc.) were used to search for any mention of paleontological resources being discussed or collected. The keyword search method produced several results; there were instances of amateur fossil collectors allegedly discovering fossil shark teeth in areas within GUIS. All mentions of fossil resources within GUIS were documented in a memo-to-file, which can be accessed in the NPS Paleontology Archives.

In the case of Facebook.com, a similar method of searching was used. Instead of forums, Facebook features themed groups (both public and private). There are several active Facebook groups relating to seashell collecting in the approximate areas of some GUIS units, primarily in Florida. In each of the groups, keywords were used (fossil, shark tooth, etc.) to search for any mentions of paleontological resources being discussed or collected at GUIS. The keyword searches in Facebook groups produced more than 40 separate accounts of individuals either mentioning or collecting fossils (all shark teeth) at or adjacent to GUIS units. Areas of GUIS frequently mentioned in the Facebook groups were noted early on as potential areas of interest to conduct a survey for fossil resources.

Additional mentions of fossils at or near GUIS were discovered in other social media sites and web applications. Instagram, a popular mobile phone social media application, is one such source. Two mentions of fossils at or near GUIS were found while conducting keyword searches in the Instagram application. Airbnb, a web and mobile application that specializes in short term room rentals and experiences, is yet another source. A “Micro Shelling & Shark Tooth Hunting” experience is advertised in the Gulf Shores area of Alabama, approximately 30 km (19 mi) west of Perdido Key. While this experience is located outside of land managed by GUIS, it nonetheless advertises that fossil shark teeth may be found on the beaches in this area of the Gulf of Mexico.

More than 100 individual fossils, a vast majority being shark teeth, have been identified via social media mentions at or adjacent to GUIS areas. Thus far, all specimens identified via social media mentions belong to taxa represented in the 2021–2022 surveys at GUIS.

The GUIS Paleontological Resources Inventory serves as a case study of how social media can assist with future inventories for other NPS parks. The results of the social media searches also highlighted a management concern for the NPS. By posting the details and location of where they collected a fossil online, people are advertising sensitive information about paleontological resources. It is suggested that measures be taken to mitigate the occurrences of individuals sharing fossil collection information on the internet. More recommendations are listed under “Paleontological Resource Management Recommendations”.

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other important resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information, and are also useful as a preliminary assessment of what a park's staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for GUIS has been published (NPS 2016a).

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on current state of resources and planning, management priorities, and management goals over various time frames. An RSS for GUIS has not yet been published.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but it is recommended that GRI source files be downloaded from IRMA for use. The source files can be explored in much greater detail and incorporated into the park GIS database. Links to the maps digitized by the GRI for GUIS can be found in IRMA at https://irma.nps.gov/DataStore/Reference/Profile/2166537. In addition to a digital GIS geologic map, the GRI program also produces a park-specific report discussing the geologic setting, distinctive geologic features and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. A GRI report has been published for GUIS (Schupp 2019).

Note: In the case of fossil resources at GUIS, it is presumed that fossil resources have been displaced from sub-surficial geological formation(s) adjacent to GUIS units or under the continental shelf of the northern Gulf of Mexico via dredging/beach renourishment activities. The naturally occurring beach sediment at all barrier island and coastal units of GUIS is Holocene (modern) and will be reflected as such in typical geologic maps. Thus, a geologic map may be less helpful in any future paleontological resources surveys conducted at GUIS, as fossils are not found in situ but instead as float specimens along the beaches.

Paleontological Resource Management Recommendations

The paleontological resource inventory at GUIS has documented rich and previously unrecognized paleontological resources. A vast majority of the paleontological resources identified thus far are float specimens, many of which were found in areas of the park with heavy foot traffic. This report captures the scope, significance, and distribution of fossils at GUIS as well as provides recommendations to support the management and protection of the park's non-renewable paleontological resources.

- GUIS staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit.
- It is recommended that GUIS rangers (or other hired representatives) periodically survey certain localities identified in the restricted-access version of this report. At least one known fossiliferous locality/beach area should be chosen for monitoring from both the Florida and Mississippi units of GUIS. Levels of disturbance, fragility, abundance, and site access (all outlined in "Paleontological Resource Monitoring") are all factors which should be considered when choosing localities/beach areas to monitor. Background research appears to show that many of the fossil resources at GUIS were placed in the approximate areas of their identified localities as a result of beach nourishment activities. GUIS should monitor and record occurrences of future beach renourishment, as well as sediment borrow locations. Recommended survey periods are yearly, ideally after large storms impact those localities or after those localities are renourished with new sediment. Areas which have been recently renourished with dredge sediment should be surveyed as soon as possible after placement for the presence of fossil resources. GUIS may choose to collaborate with outside entities to assist with survey efforts after storms. One suggestion by the authors includes arranging for groups of students from Georgia State University (project lead for this paleontological resources inventory) to spend a day or more surveying certain fossiliferous localities at the park. These periodic surveys could additionally be conducted by future Scientist in Parks interns at GUIS if time and resources permit. See the "History and Influence of Dredging/Beach Renourishment on Fossil Localities" section for more information on historical dredging/beach renourishment activity at GUIS.
- GUIS staff should photo-document and monitor any occurrences of paleontological resources that may be observed either as float or in situ. Fossils and their associated geologic context, if any, should be documented, but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.

- It is recommended that individuals within GUIS staff gain a baseline knowledge of the known fossil taxa (and how to identify different taxa/specimens) and fossil localities at GUIS. This way, during future surveys, those individuals may be better able to identify and collect previously unknown taxa and inform others of the specimen's potential scientific significance.
- It is recommended that all employees and staff at GUIS be made aware of the park's paleontological resources and be educated accordingly about the significance of these resources and appropriate management strategies. One suggestion for GUIS is to add a section related to the National Seashore's paleontological resources during new hire orientation. For current staff, management can send a parkwide email explaining the paleontological resources at GUIS and management strategies. Park staff should be made aware of how to handle scenarios in which they discover a paleontological resource or locality, or scenarios in which a visitor makes them aware of a paleontological specimen or locality.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.
- GUIS rangers and/or law enforcement should monitor known localities for illegal fossil collecting. This is especially important after major storm events hit the area. The high winds and storm surge redistribute beach sediments, and may uncover more fossil float specimens. One visitor to GUIS that the field team interacted with reflected on an apparent abundance of shark teeth being present on the eastern beaches of Perdido Key following Hurricane Sally in 2020 (Perdido Key visitor, pers. comm., 2021) The same visitor also alluded to having collected shark teeth on numerous previous occasions (pers. comm., 2021).
- GUIS staff should periodically monitor online mentions of illegal fossil collection or shared information pertaining to fossil localities within areas managed by GUIS. As explained in subsection "Influence of Social Media on Paleontological Inventories", online social media websites and forums often become a means for GUIS visitors to share sensitive information regarding fossil resources/localities and their whereabouts with others.
- While it may not be feasible to completely stop the public from sharing information about fossils found at GUIS online, staff may want to further pursue preventative measures in extreme cases or with repeat offenders. GUIS staff may want to reach out to prolific individuals and encourage them to cease collecting on GUIS lands and/or sharing sensitive information online. See sub-section "Influence of Social Media on Paleontological Inventories" above for more information regarding online mentions of illegal fossil collection at GUIS.
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be

regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.

- The park may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks Program is an established program for recruitment of geology and paleontology interns. The Paleontology in the Parks Fellowships, a brand-new program co-sponsored by the NPS and the Paleontological Society, also recruits students to perform surveys, inventories and additional paleontological work at NPS units.
- It is recommended that the concessionaire continues to not advertise or even mention the presence of fossils at Ship Island or any of the other Mississippi barrier islands within GUIS to its passengers. Any advertisement given to fossil resources may draw unwanted attention from public fossil collectors.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by GUIS staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location, if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within GUIS and height within the outcrop, if applicable. If possible, revisit the site when a GPS unit is available. Most smartphones also have the ability to record coordinates; if no GPS unit is available, attempt to record the coordinates with a phone.
- Write down associated data, such as rock type, sediment characteristics, general description of the fossil, type of fossil if identifiable, general location in GUIS, sketch of the fossil, position within the outcrop or if it is loose on the ground, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes. Because GUIS has many culturally important sites, simply documenting the fossil and leaving it in place is the best course of action until natural resource staff is contacted.
- If fossil resources are found, alert staff at GUIS to allow for proper documentation.

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Appendix A: Paleontological Taxa

The 2021–2022 survey yielded the first surficial paleontological specimens ever described from GUIS. A vast majority of those specimens collected in 2021 and 2022 belong to the class Chondrichthyes. Teeth from genera including *Carcharias* (Odontaspididae), *Carcharhinus* (Carcharhinidae), *Galeocerdo* (Carcharhinidae), *Negaprion* (Carcharhinidae), *Rhizoprionodon* (Carcharhinidae), and *Sphyrna* (Sphyrnidae) are all represented among the specimens. Teeth and caudal barbs from the family Myliobatidae are also represented. The taxonomic distribution of these fossils is shown in Appendix Table A-1.

Among the non-chondrichthyan taxa, multiple fin spines, several otoliths, as well as one tooth and one crushing plate from the class Actinopterygii are represented. Numerous claw shells from the order Decapoda are also represented. On Petit Bois Island, two specimens attributed to the order Testudines were collected. The taxonomic distribution of these fossils is shown in Appendix Table A-2.

Pre-Holocene, shell material of phylum Mollusca is presumed to be present on beaches where beach renourishment has occurred at GUIS. The context of dredging and beach renourishment with presumed fossiliferous sediments (see "History and Influence of Dredging/Beach Renourishment on Fossil Localities" above), as well as the confirmed presence of fossilized chondrichthyan specimens, indicates a high likelihood that at least part of the organic shell material in those renourished areas at GUIS is fossilized as well. Apart from several molluscan shell specimens collected from the Perdido Key area, as well as several molluscan shells collected at West Petit Bois Island, relatively few (presumed) fossil mollusks were collected. Fossilized mollusk shell has a similar appearance to modern mollusk shell, especially when it has been weathered and exposed. Thus, it is often difficult to discern a fossil from a modern specimen. The Fort Pickens and Perdido Key areas in Florida, as well as surveyed localities on West Petit Bois and Ship Islands in Mississippi, have been subjected to beach renourishment in recent years.

Appendix Table A-1. Family-level chondrichthyan taxa represented among specimens collected during the 2021–2022 survey.

Taxon	Number
Family Carcharhinidae (Requiem Sharks)	474
Family Odontaspididae (Sand Sharks)	11
Family Sphyrnidae (Hammerhead Sharks)	8
Family Myliobatidae (Stingrays)	29
Unidentifiable Beyond Class Chondrichthyes	135
Total	661

Appendix Table A-2. Other (non-chondrichthyan) fossil taxa represented among specimens collected during 2021–2022 survey at GUIS.

Taxon	Number
Phylum Mollusca: Class Scaphopoda (Tusk Shells)*	1
Phylum Arthropoda: Order Decapoda (Crabs, Crayfish, Lobsters)	21
Phylum Chordata: Class Actinopterygii (Ray-Finned Fish)	25
Phylum Chordata: Order Testudines (Turtles)	2
Unidentifiable Taxa	1
Total	50

* *Note*: Other bivalve and gastropod shells collected may include pre-Holocene specimens but due to uncertainty are not included above.

Appendix B: Specimens Collected During 2021–2022 Inventory

Below are a series of tables providing information on specimens collected during the 2021–2022 inventory. The information is divided between chondrichthyan specimens and non-chondrichthyan specimens from Florida sites (Appendix Tables B-1 and B-2), and chondrichthyan and non-chondrichthyan specimens from Mississippi sites (Appendix Tables B-3 and B-4). Chondrichthyans are identified to the genus level where possible.

Specimens GUIS-FL_027, GUIS-FL_144, and GUIS-FL_268 were initially classified as chondrichthyan fossils, but have been reevaluated and the numbers not included in the appendix tables. Specimen GUIS-FL_027 is now presumed to be a piece of modern shell material. As it is presumed modern, this specimen is no longer counted among the 2021–2022 survey collections. Specimen GUIS-FL_144 is now classified as *Trichiurus lepturus*, also known as a hairtail or cutlassfish. As it is now determined to be non-chondrichthyan, this specimen was given a new label (GUIS-FLNC_011) and is now counted among the non-chondrichthyan specimens from Florida. Specimen GUIS-FL_268 is now presumed to be a pre-operculum from a bony fish. As it is now presumed non-chondrichthyan, this specimen was given a new label (GUIS-FLNC_020) and is now counted among the non-chondrichthyan specimens from Florida. See Appendix Table B-2 for the new listings for specimens GUIS-FLNC_011 and GUIS-FLNC_020.

Appendix Table B-1. Chondrichthyan specimens from Florida sites.

Specimen #	**Order**	**Family**	**Genus**
GUIS-FL_001	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_002	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_003	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_004	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_005	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_006	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_007	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_008	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_009	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_010	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_011	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_012	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_013	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_014	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_015	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_016	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_017	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_018	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_019	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_020	–	–	–
GUIS-FL_021	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_022	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_023	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_024	–	–	–
GUIS-FL_025	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_026	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_028	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_029	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_030	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_031	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_032	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_033	–	–	–
GUIS-FL_034	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_035	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-FL_036	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_037	–	–	–
GUIS-FL_038	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_039	–	–	–
GUIS-FL_040	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_041	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_042	Lamniformes	Odontaspididae	*Carcharias*
GUIS-FL_043	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_044	–	–	–
GUIS-FL_045	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_046	–	–	–
GUIS-FL_047	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_048	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_049	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_050	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_051	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_052	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_053	–	–	–
GUIS-FL_054	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_055	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_056	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_057	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_058	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_059	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_060	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_061	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_062	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_063	–	–	–
GUIS-FL_064	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_065	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_066	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_067	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_068	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_069	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_070	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_071	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_072	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_073	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_074	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_075	Carcharhiniformes	Carcharhinidae	*Negaprion*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_076	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_077	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_078	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_079	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_080	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_081	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_082	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_083	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_084	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_085	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_086	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_087	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_088	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_089	–	–	–
GUIS-FL_090	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_091	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_092	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_093	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_094	–	–	Missing tip
GUIS-FL_095	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_096	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_097	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_098	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_099	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_100	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_101	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_102	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_103	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_104	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_105	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_106	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_107	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_108	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_109	–	–	–
GUIS-FL_110	–	–	–
GUIS-FL_111	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_112	Carcharhiniformes	Carcharhinidae	*Negaprion*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_113	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_114	Carcharhiniformes	Sphyrnidae	*Sphyrna*?
GUIS-FL_115	–	–	–
GUIS-FL_116	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_117	–	–	–
GUIS-FL_118	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_119	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_120	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_121	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_122	–	–	–
GUIS-FL_123	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_124	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_125	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_126	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_127	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_128	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_129	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_130	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_131	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_132	–	–	–
GUIS-FL_133	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_134	Carcharhiniformes	Carcharhinidae	*Galeocerdo*?
GUIS-FL_135	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_136	–	–	–
GUIS-FL_137	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_138	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_139	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_140	–	–	–
GUIS-FL_141	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_142	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_143	–	–	–
GUIS-FL_145	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_146	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_147	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_148	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_149	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_150	Carcharhiniformes	Carcharhinidae	*Negaprion*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_151	–	–	–
GUIS-FL_152	–	–	–
GUIS-FL_153	–	–	–
GUIS-FL_154	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_155	–	–	–
GUIS-FL_156	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_157	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_158	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_159	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_160	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_161	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_162	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_163	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_164	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_165	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_166	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_167	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_168	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_169	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_170	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_171	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_172	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_173	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_174	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_175	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_176	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_177	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_178	–	–	–
GUIS-FL_179	–	–	–
GUIS-FL_180	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_181	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_182	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_183	–	–	–
GUIS-FL_184	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-FL_185	–	–	–
GUIS-FL_186	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_187	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	**Order**	**Family**	**Genus**
GUIS-FL_188	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_189	–	–	–
GUIS-FL_190	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_191	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-FL_192	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_193	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_194	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_195	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_196	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_197	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_198	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_199	–	–	–
GUIS-FL_200	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_201	–	–	–
GUIS-FL_202	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_203	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_204	–	–	–
GUIS-FL_205	–	–	–
GUIS-FL_206	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_207	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_208	–	–	–
GUIS-FL_209	–	–	–
GUIS-FL_210	–	–	–
GUIS-FL_211	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_212	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_213	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_214	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_215	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_216	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-FL_217	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_218	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_219	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_220	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_221	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_222	–	–	–
GUIS-FL_223	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_224	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_225	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_226	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_227	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_228	–	–	–
GUIS-FL_229	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_230	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_231	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_232	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_233	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_234	–	–	–
GUIS-FL_235	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_236	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-FL_237	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_238	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_239	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_240	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_241	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_242	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_243	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_244	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_245	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_246	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_247	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_248	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_249	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_250	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_251	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_252	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_253	–	–	–
GUIS-FL_254	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-FL_255	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_256	–	–	–
GUIS-FL_257	–	–	–
GUIS-FL_258	–	–	–
GUIS-FL_259	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_260	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_261	Carcharhiniformes	Carcharhinidae	–

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_262	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_263	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_264	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_265	–	–	–
GUIS-FL_266	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_267	–	–	–
GUIS-FL_269	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_270	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_271	–	–	–
GUIS-FL_272	–	–	–
GUIS-FL_273	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_274	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_275	–	–	–
GUIS-FL_276	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_277	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_278	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_279	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_280	–	–	–
GUIS-FL_281	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_282	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_283	–	–	–
GUIS-FL_284	–	–	–
GUIS-FL_285	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_286	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_287	–	–	–
GUIS-FL_288	Carcharhiniformes	Carcharhinidae	–
GUIS-FL_289	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-FL_290	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_291	–	–	–
GUIS-FL_292	–	–	–
GUIS-FL_293	–	–	–
GUIS-FL_294	–	–	–
GUIS-FL_295	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-FL_296	Myliobatiformes	Myliobatidae	–
GUIS-FL_297	Myliobatiformes	Myliobatidae	*Aetobatus*
GUIS-FL_298	Myliobatiformes	–	–
GUIS-FL_299	Myliobatiformes	–	–

Appendix Table B-1 (continued). Chondrichthyan specimens from Florida sites.

Specimen #	Order	Family	Genus
GUIS-FL_300	Myliobatiformes	–	–
GUIS-FL_301	Myliobatiformes	–	–
GUIS-FL_302	Myliobatiformes	–	–
GUIS-FL_303	Myliobatiformes	–	–
GUIS-FL_304	Myliobatiformes	–	–
GUIS-FL_305	Myliobatiformes	–	–
GUIS-FL_306	Myliobatiformes	–	–
GUIS-FL_307	Myliobatiformes	–	–
GUIS-FL_308	Myliobatiformes	–	–
GUIS-FL_309	Myliobatiformes	–	–
GUIS-FL_310	Myliobatiformes	–	–
GUIS-FL_311	Myliobatiformes	–	–
GUIS-FL_312	Myliobatiformes	–	–
GUIS-FL_313	Myliobatiformes	–	–
GUIS-FL_314	Myliobatiformes	–	–
GUIS-FL_315	Myliobatiformes	–	–
GUIS-FL_316	Myliobatiformes	–	–
GUIS-FL_317	Myliobatiformes	–	–

Appendix Table B-2. Non-chondrichthyan specimens from Florida sites.

Specimen #	**Phylum**	**Subphylum**	**Class**
GUIS-FLNC_001	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_002	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_003	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_004	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_005	Arthropoda	Crustacea	Malacostraca
GUIS-FLNC_006	Arthropoda	Crustacea	Malacostraca
GUIS-FLNC_007	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_008	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_009	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_010	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_011	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_012	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_013	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_014	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_015	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_016	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_017	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_018	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_019	Chordata	Vertebrata	Actinopterygii
GUIS-FLNC_020	Chordata	Vertebrata	Actinopterygii

Appendix Table B-3. Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_001	Carcharhiniformes	Carcharhinidae	Too weathered
GUIS-MS_002	Carcharhiniformes	Carcharhinidae	Too weathered
GUIS-MS_003	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_004	Carcharhiniformes	Carcharhinidae	Too weathered
GUIS-MS_005	Carcharhiniformes	Carcharhinidae	Too weathered
GUIS-MS_006	Carcharhiniformes	Carcharhinidae	Too weathered
GUIS-MS_007	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_008	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_009	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_010	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_011	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_012	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-MS_013	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_014	–	–	–
GUIS-MS_015	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_016	–	–	–
GUIS-MS_017	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_018	–	–	–
GUIS-MS_019	–	–	–
GUIS-MS_020	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_021	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_022	–	–	–
GUIS-MS_023	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_024	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_025	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_026	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_027	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_028	–	–	–
GUIS-MS_029	–	–	–
GUIS-MS_030	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_031	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_032	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_033	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_034	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_035	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_036	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_037	–	–	–

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	**Order**	**Family**	**Genus**
GUIS-MS_038	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_039	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_040	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_041	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_042	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_043	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_044	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_045	Carcharhiniformes	Carcharhinidae	*Negaprion*? weathered
GUIS-MS_046	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_047	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_048	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_049	–	–	–
GUIS-MS_050	–	–	–
GUIS-MS_051	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_052	–	–	–
GUIS-MS_053	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_054	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_055	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_056	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_057	–	–	–
GUIS-MS_058	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_059	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_060	–	–	–
GUIS-MS_061	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_062	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_063	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_064	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_065	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_066	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_067	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_068	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_069	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_070	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_071	–	–	–
GUIS-MS_072	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_073	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_074	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_075	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_076	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_077	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_078	–	–	–
GUIS-MS_079	–	–	–
GUIS-MS_080	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_081	–	–	–
GUIS-MS_082	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_083	–	–	–
GUIS-MS_084	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_085	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_086	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_087	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_088	–	–	–
GUIS-MS_089	–	–	–
GUIS-MS_090	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_091	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_092	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_093	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_094	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_095	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_096	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_097	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_098	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_099	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_100	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_101	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_102	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_103	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_104	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_105	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_106	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_107	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_108	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_109	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-MS_110	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_111	Carcharhiniformes	Carcharhinidae	–

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_112	Carcharhiniformes	–	Too weathered
GUIS-MS_113	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_114	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_115	Carcharhiniformes	–	Too weathered
GUIS-MS_116	Carcharhiniformes	–	Too weathered
GUIS-MS_117	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_118	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_119	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_120	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_121	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_122	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_123	–	–	Too weathered
GUIS-MS_124	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_125	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_126	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_127	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_128	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_129	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_130	–	–	Too weathered
GUIS-MS_131	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_132	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_133	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_134	–	–	Too weathered
GUIS-MS_135	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_136	–	–	Too weathered
GUIS-MS_137	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_138	–	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_139	–	–	Too weathered
GUIS-MS_140	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_141	–	–	Too weathered
GUIS-MS_142	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_143	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_144	–	–	Too weathered
GUIS-MS_145	–	–	Too weathered
GUIS-MS_146	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_147	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_148	Carcharhiniformes	Carcharhinidae	–

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_149	–	–	Too weathered
GUIS-MS_150	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_151	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_152	–	–	Too weathered
GUIS-MS_153	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_154	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_155	–	–	Too weathered
GUIS-MS_156	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_157	–	–	Too weathered
GUIS-MS_158	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_159	–	–	Too weathered
GUIS-MS_160	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_161	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_162	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_163	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_164	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_165	–	–	Too weathered
GUIS-MS_166	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_167	–	–	Too weathered
GUIS-MS_168	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_169	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_170	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_171	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_172	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_173	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_174	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_175	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_176	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_177	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_178	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_179	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_180	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_181	–	–	Too weathered
GUIS-MS_182	–	–	Too weathered
GUIS-MS_183	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_184	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_185	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_186	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_187	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_188	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_189	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_190	–	–	Too weathered
GUIS-MS_191	–	–	Too weathered
GUIS-MS_192	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_193	–	–	Too weathered
GUIS-MS_194	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_195	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_196	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_197	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_198	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_199	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-MS_200	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_201	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_202	–	–	Too weathered
GUIS-MS_203	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_204	–	–	Too weathered
GUIS-MS_205	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_206	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_207	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_208	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-MS_209	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_210	–	–	Too weathered
GUIS-MS_211	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_212	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_213	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_214	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_215	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_216	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_217	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_218	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_219	–	–	Too weathered
GUIS-MS_220	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_221	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_222	–	–	Too weathered

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_223	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_224	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_225	–	–	Too weathered
GUIS-MS_226	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_227	–	–	Too weathered
GUIS-MS_228	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_229	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_230	–	–	Too weathered
GUIS-MS_231	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_232	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_233	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_234	–	–	Too weathered
GUIS-MS_235	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_236	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_237	–	–	Too weathered
GUIS-MS_238	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_239	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_240	–	–	Too weathered
GUIS-MS_241	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_242	–	–	Too weathered
GUIS-MS_243	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_244	–	–	Too weathered
GUIS-MS_245	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_246	–	–	Too weathered
GUIS-MS_247	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_248	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_249	–	–	Too weathered
GUIS-MS_250	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_251	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_252	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_253	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_254	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_255	–	–	Too weathered
GUIS-MS_256	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_257	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_258	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_259	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_260	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_261	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_262	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_263	–	–	Too weathered
GUIS-MS_264	–	–	Too weathered
GUIS-MS_265	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-MS_266	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_267	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_268	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_269	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_270	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_271	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_272	–	–	Too weathered
GUIS-MS_273	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_274	–	–	Too weathered
GUIS-MS_275	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_276	–	–	Too weathered
GUIS-MS_277	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_278	–	–	Too weathered
GUIS-MS_279	–	–	Too weathered
GUIS-MS_280	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_281	–	–	Too weathered
GUIS-MS_282	–	–	Too weathered
GUIS-MS_283	–	–	Too weathered
GUIS-MS_284	–	–	Too weathered
GUIS-MS_285	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_286	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_287	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_288	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_289	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_290	–	–	Too weathered
GUIS-MS_291	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_292	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_293	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_294	–	–	Too weathered
GUIS-MS_295	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_296	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_297	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_298	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_299	–	–	Too weathered
GUIS-MS_300	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_301	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_302	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_303	–	–	Too weathered
GUIS-MS_304	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_305	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_306	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_307	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_308	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_309	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_310	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_311	–	–	Too weathered
GUIS-MS_312	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_313	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_314	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_315	–	–	Too weathered
GUIS-MS_316	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*
GUIS-MS_317	Carcharhiniformes	Sphyrnidae	*Sphyrna*
GUIS-MS_318	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_319	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_320	–	–	Too weathered
GUIS-MS_321	Carcharhiniformes	Carcharhinidae	*Negaprion*
GUIS-MS_322	–	–	Too weathered
GUIS-MS_323	–	–	Too weathered
GUIS-MS_324	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_325	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_326	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_327	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_328	Lamniformes	Odontaspididae	*Carcharias*
GUIS-MS_329	–	–	Too weathered
GUIS-MS_330	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-MS_331	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_332	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_333	Carcharhiniformes	Carcharhinidae	*Carcharhinus*

Appendix Table B-3 (continued). Chondrichthyan specimens from Mississippi sites.

Specimen #	Order	Family	Genus
GUIS-MS_334	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_335	Carcharhiniformes	Carcharhinidae	*Carcharhinus*
GUIS-MS_336	–	–	Too weathered
GUIS-MS_337	–	–	Too weathered
GUIS-MS_338	Carcharhiniformes	Carcharhinidae	*Galeocerdo*
GUIS-MS_339	–	–	Too weathered
GUIS-MS_340	Carcharhiniformes	Carcharhinidae	–
GUIS-MS_341	Myliobatiformes	–	–
GUIS-MS_342	Myliobatiformes	–	–
GUIS-MS_343	Myliobatiformes	–	–
GUIS-MS_344	Myliobatiformes	–	–
GUIS-MS_345	Myliobatiformes	–	–
GUIS-MS_346	Myliobatiformes	–	–
GUIS-MS_347	Myliobatiformes	–	–

Appendix Table B-4. Non-chondrichthyan specimens from Mississippi sites.

Specimen #	Phylum	Subphylum	Class
GUIS-MSNC_001	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_002	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_003	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_004	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_005	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_006	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_007	Mollusca	Conchifera	Scaphopoda
GUIS-MSNC_008	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_009	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_010	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_011	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_012	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_013	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_014	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_015	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_016	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_017*	–	–	–
GUIS-MSNC_018	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_019	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_020	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_021	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_022	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_023	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_024	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_025	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_026	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_027	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_028	Chordata	Vertebrata	Actinopterygii
GUIS-MSNC_029	Arthropoda	Crustacea	Malacostraca
GUIS-MSNC_030	Chordata	Vertebrata	Reptilia
GUIS-MSNC_031	Chordata	Vertebrata	Reptilia

* *Note:* Upon further study, specimen GUIS-MSNC_017 was determined to be a modern mollusk shell, and as such, is no longer retained in the fossil collections or included among the counts in this inventory.

Appendix C: Repository Contact Information

Contact information for institutions known to have collections affiliated with GUIS are included below. Addresses, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks.

Southeast Archeological Center
National Park Service
2035 E. Paul Dirac Drive
Johnson Building, Suite 120
Tallahassee, FL 32310
phone (850) 580-3011
fax (850) 580-8479
https://www.nps.gov/orgs/1539/index.htm

Appendix D: Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020).

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *…any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *…inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park's enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations.* (16 U.S.C. § 1).

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *…derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress.* (16 U.S.C. § 1 a-1).

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *…harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values.* (Management Policies 2006 1.4.3).

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

> *The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for "Cave Resource" in Section 4302 states

> *Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.*

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

> *Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of the collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.*
>
> *The sale of original paleontological specimens is prohibited in parks.*
>
> *The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that*

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; Artifacts and Specimens 10.2.4.6. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012):

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

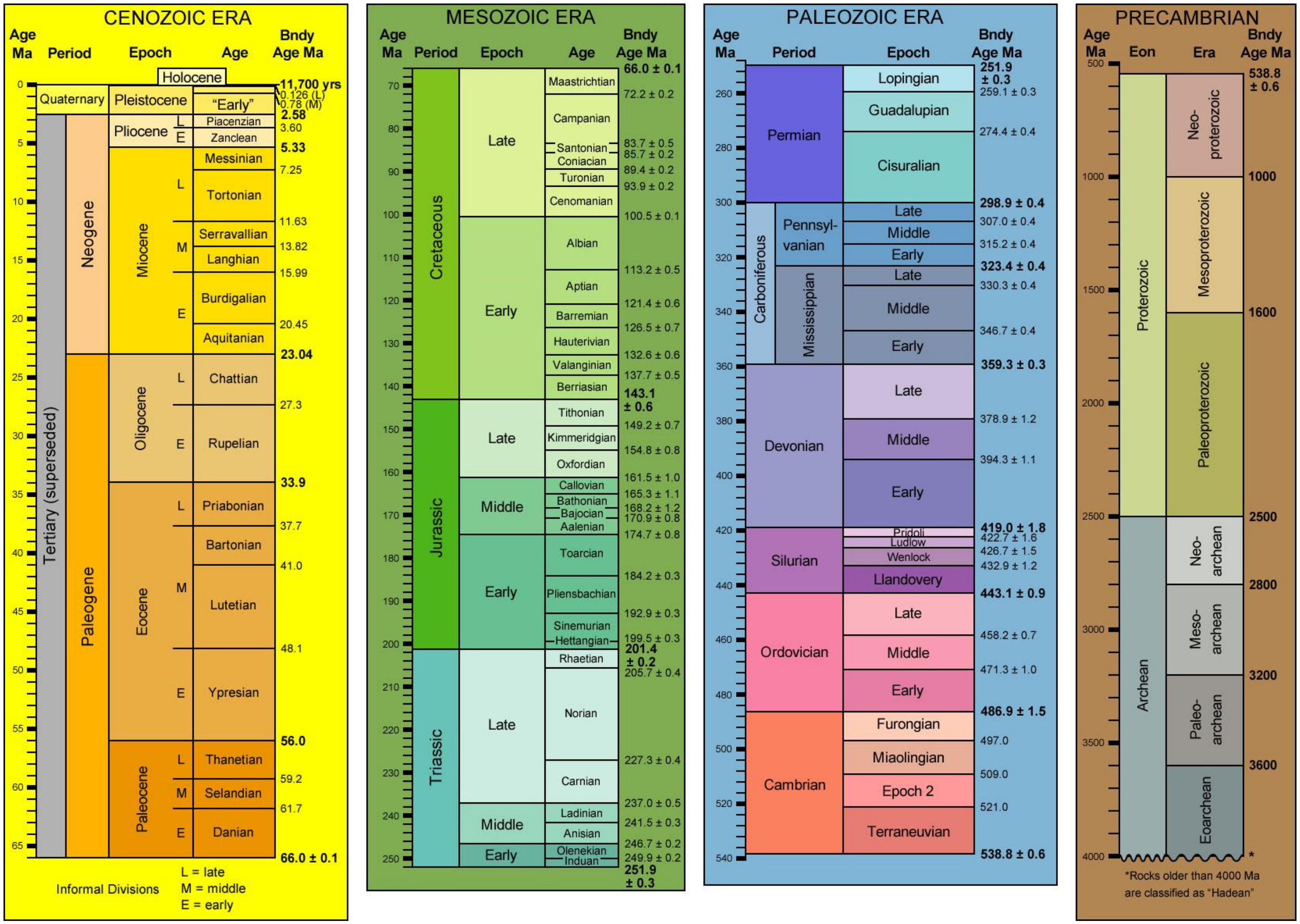
Condition Assessment and Cyclic Prospecting

These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix E: Geologic Time Scale



Ma=Millions of years old. Bndy Age=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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