Marine Seawater Desalination Diversion and Discharge Zones Study

HB 2031 | 84TH TEXAS LEGISLATURE

SEPTEMBER 1, 2018

TEXAS PARKS AND WILDLIFE DEPARTMENT
TEXAS GENERAL LAND OFFICE

August 27, 2018

Mr. Toby Baker, Executive Director
Texas Commission on Environmental Quality
P.O. Box 13087
Austin, Texas 78711-3087

RE: Texas General Land Office and Texas Parks and Wildlife Department Joint Marine Seawater Desalination Study as Required by House Bill 2031 of the 84th Texas Legislature

Dear Mr. Baker:

Pursuant to the requirements of House Bill (HB) 2031 (84th Legislature), the Texas General Land Office (GLO) and the Texas Parks and Wildlife Department (TPWD) have prepared the attached report to identify zones in the Gulf of Mexico that are appropriate for the diversion of marine seawater and for the discharge of marine seawater desalination waste while taking into account the need to protect marine organisms. Results from the study are intended to inform the new optional expedited permit application program authorized by HB 2031 under development at the Texas Commission on Environmental Quality (TCEQ).

The study is based on a geospatial approach and incorporates the framework of state submerged land tract boundaries, the best available information on natural resource concerns associated with state land tracts, information from TPWD coastal fisheries programs, literature research, and best professional judgement. An interagency work group, which included expertise on coastal ecosystems, marine fisheries, water resources and water quality, natural resources management, geographic information science, water quality permitting, and legal perspectives, was convened by the GLO and TPWD to support development of the study. The printed maps of zones provided in the report are available from the agencies in electronic format for use with ArcGIS mapping software and will soon be accessible online through the GLO's Resource Management Code Viewer.

The GLO and TPWD look forward to working with TCEQ to further develop the state's capacity to use marine seawater desalination as a water supply strategy while safeguarding important coastal infrastructure and natural and cultural resources.

Sincerely,

George P. Bush, Commissioner
Texas General Land Office

Carter Smith, Executive Director
Texas Parks and Wildlife Department

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EXECUTIVE SUMMARY

This report contains results of a joint agency study concerning marine seawater desalination required by House Bill (HB) 2031 (84th Legislature). HB 2031 directed the Texas Parks and Wildlife Department (TPWD) and the Texas General Land Office (GLO) to identify zones in the Gulf of Mexico that are appropriate for the diversion of marine seawater, and for the discharge of marine seawater desalination brine concentrate, while taking into account the need to protect marine organisms. Results from the study will inform a new expedited permit application program currently under development at the Texas Commission on Environmental Quality (TCEQ).

A geospatial approach was used to conduct the study and incorporates the framework of state submerged land tract boundaries, the best available information on natural resource concerns associated with state land tracts, information from TPWD coastal fisheries programs, literature research, and best professional judgement. An interagency work group was convened by TPWD and GLO to support development of the study which included expertise on coastal ecosystems, marine fisheries, water resources and water quality, natural resources management, geographic information science, water quality permitting, and legal perspectives. Input from others who have developed marine desalination projects was also sought.

The approach consists of 1) creating a baseline data layer of submerged land tracts from the GLO's Resource Management Code (RMC) database focusing on areas not assigned any special recommendations relating to sensitive areas other than cultural resources, 2) applying overlays for marine habitat and migratory passes, and 3) developing a web-based viewer to facilitate work group review and discussion. To assist TCEQ and facility applicants, TPWD and GLO intend to develop a unique code in the GLO Resource Management Code Viewer to enable viewing of zones.

The study includes desalination zone maps required by HB 2031. Based on available information and known concerns the recommended diversion and discharge zones are identical. Included are recommendations that should be considered during planning and design phases since the protection of marine organisms can be accomplished by giving appropriate attention to site-specific factors, the chemical properties of the waste being discharged, and the physical design of diversion intake and discharge facilities.

For diversions the recommendations include:

- diversions of marine seawater should not exceed flow-through velocities of 0.5 feet per second (fps), nor be co-located such that combined impacts in the surrounding approach area exceeds 0.5 fps;
- intake structure design should adjust or adaptively manage with varying flows and water quality that may occur at the intake site;
- intake structures should be designed to reduce the flow velocity so that marine organisms may escape being drawn into the intake;
- screens or booms, or both, should be used to exclude organisms from the intake; and
- a site-specific study of conditions at proposed intake locations be conducted to identify marine organisms at risk from intake operations and to inform the design planning process.

When feasible, directional drilling to install piping below the seabed and drawing water down through a sandy bottom will prevent impingement of marine organisms on intake screens exposed to open water and prevent entrainment of other organisms carried with the feedwater through the intake screen.

For brine concentrate waste discharges, the study recommends the following evaluations. The first three are important to aquatic organisms because a shift in the salt ratio and type of salt can cause osmotic imbalance and toxicity. At a minimum, evaluations should address:

- the total salt content as compared with receiving waters;
- the source of the salts (in the case of mixed or comingled waste discharges);
- the ratio of the type of salts compared with those in the receiving waters;
- whether there is adequate circulation to prevent the salt from building up over time to a point where it is toxic to the ecological community;
- the potential for depressed oxygen levels due to poorly dispersed brine discharges at a particular location;
- the contaminants discharged with the brine that resulted from natural sources (such as fluoride and copper), and from chemicals used in the operation and maintenance of the desalination facility such as conditioning reagents, antiscalant chemicals, and metals from corrosion of piping (iron, chromium, and nickel); and
- a site-specific analysis is recommended to determine if there is toxicity and, if so, the steps needed to minimize the impact.

The study summarizes key recommendations from published literature concerning discharge plume regulations and modeling approaches, and these include:

- using a mixing zone approach to regulate discharges;
- regulating toxicity and water quality objectives at the edge of a mixing zone boundary that is conservatively recommended to be 100 meters from the discharge and includes the entire water column;
- limiting salinity increases at the mixing zone boundary to no more than 5% (or an absolute increment of 2 practical salinity units (psu), whichever is less) of that occurring naturally in the waters around the discharge;
- accounting for effluent density and flow rates on plume behavior; and
- applying conservative assumptions when evaluating dilution and overall flushing of the discharge site to ensure the dilution requirement at the edge of the mixing zone is still met, examples of conservative assumptions are: i) ocean currents do not increase dilution beyond the zone of initial dilution, and ii) the seabed is flat and horizontal.

The study also discusses limitations of the analyses, including: 1) an incomplete understanding of the complex life histories and habitat requirements for all marine organisms that may be present within the project study area, or those that may enter the study area as part of a larger home range, 2) an incomplete inventory of submerged habitats and important migratory corridors, and 3) a limited understanding of coast-wide migratory and habitat requirements for nesting and inter-nesting sea turtles. Considering these limitations and the dynamic nature of the Gulf of Mexico, the agencies identify a need for periodic updating of zone maps used in permitting decisions. The study proposes that TPWD in consultation with the GLO will monitor changes in the nearshore and offshore submerged tracts and determine whether areas should be added or removed from the identified zones.

A JOINT STUDY BY THE TEXAS PARKS AND WILDLIFE DEPARTMENT AND THE TEXAS GENERAL LAND OFFICE REQUIRED BY HB 2031 (84TH TEXAS LEGISLATURE) CONCERNING MARINE SEAWATER DESALINATION DIVERSION AND DISCHARGE ZONES

A. INTRODUCTION

In 2015, the 84th Texas Legislature passed House Bill (HB) 2031 relating to the diversion, treatment, and use of marine seawater. In HB 2031, the Legislature created new Texas Water Code (TWC) Chapter 18 to address marine seawater desalination projects (Figure 1). TWC §18.003(a) requires a person to obtain a permit to divert and use state water that consists of marine seawater if: 1) the point of diversion is located less than three miles seaward of any point located on the coast of this state; or 2) the seawater contains a total dissolved solids (TDS) concentration based on a yearly average of samples taken monthly at the water source of less than 20,000 milligrams per liter (mg/L). TWC §18.003(b) creates an exemption from permitting to divert and use marine seawater if TWC §18.003(a) does not apply. In addition, TWC §18.005(c) requires a person to obtain a permit to discharge: 1) treated marine seawater into a natural stream in this state or a lake, reservoir, or other impoundment in this state; or 2) wastewater resulting from the desalination of treated marine seawater into the Gulf of Mexico.

HB 2031 also directs the Texas Commission on Environmental Quality (TCEQ) to adopt rules to expedite permitting and related processes for the diversion of marine seawater and the discharge of both treated marine seawater and wastewater resulting from the desalination process, in accordance with TWC Chapter 18. HB 2031 prohibits the diversion of marine seawater and the discharge of wastewater resulting from the desalination of marine seawater in a bay and estuary under the expedited permit process as allowed by TWC Chapter 18. A person has the option to submit an application under TWC Chapter 11 or 26 to seek a permit to divert or discharge in a bay or estuary.

HB 2031 requires that the Texas Parks and Wildlife Department and the Texas General Land Office conduct a study to identify zones in the Gulf of Mexico that are appropriate for the diversion of marine seawater and for the discharge of wastewater resulting from the desalination of marine seawater and for the commission to adopt rules designating these zones by September 1, 2020. Under TWC §§18.003(j) and 18.005(g), an applicant for a permit to divert marine seawater must consult with TPWD and GLO regarding the point(s) of diversion or discharge until such time as the commission adopts rules designating diversion or discharge zones.

For more information about the desalination legislation readers may refer to Texas Water Code (TWC) Chapter 18 and the guiding legislation Texas House Bills 2031 and 4097 (84th Legislature, 2015). HB 4097 addresses desalination projects solely for industrial use and does not require a study to identify zones appropriate for diversions and discharges. The purpose of this document, therefore, is to fulfill HB 2031 study requirements. The following paragraphs in this section summarize TPWD's role in the protection of marine organisms, the study approach and methods, and supporting data and resources.

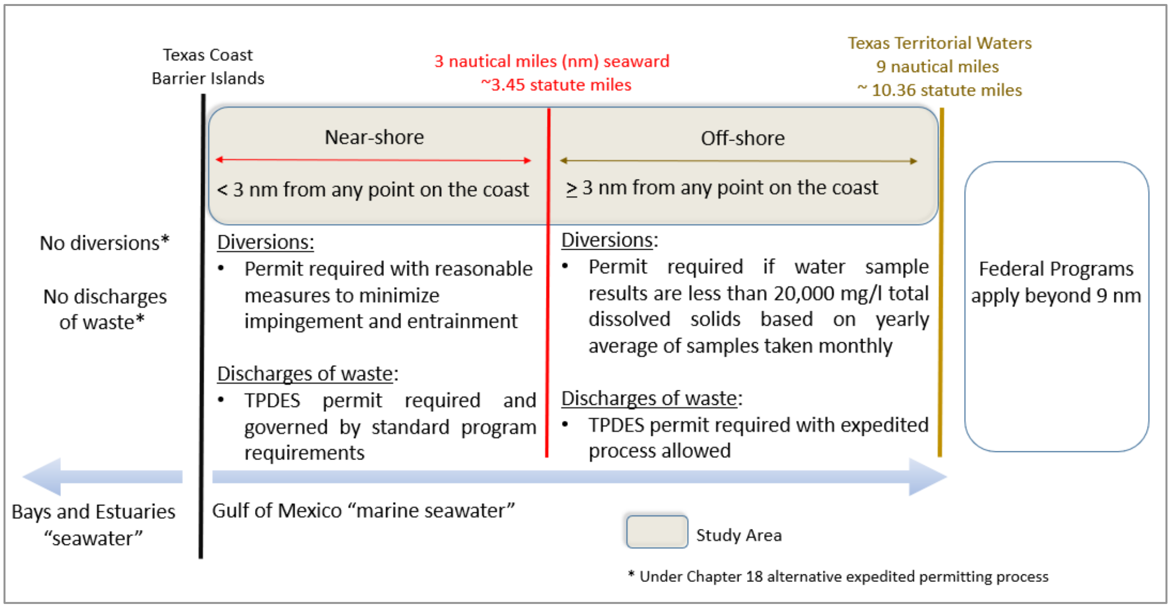

Figure 1. Illustration of the study area and authorizations needed under TWC Chapter 18 Marine Seawater Desalination Projects. Note that requirements can vary by applicant and TCEQ should be consulted to evaluate any particular project.

The TPWD Coastal Fisheries Division manages the marine fishery resources of Texas' estimated four million acres of saltwater, including the bays and estuaries and out to nine nautical miles (nm) in the Gulf of Mexico. Coastal Fisheries management strategies are directed toward optimizing the long-term utilization and sustainability of fisheries populations at levels that are necessary to ensure replenishable stocks of commercially and recreationally important species. In support of these strategies, the Division established a marine resource monitoring program in coastal bays and estuaries, and seaward surrounding five major passes in the Gulf of Mexico. In addition to being important transportation corridors that serve a variety of human needs, both large and small coastal passes function as migratory corridors between shallow, low salinity estuarine habitats and oceanic Gulf habitat. The importance or relevance of coastal passes to marine organisms varies by species. While some species spend their entire lives in an estuarine environment, others require migrating between estuarine and marine environments for a variety of reasons such as access to 1) suitable spawning and nursery habitats, 2) habitat conditions required during older life stages, and 3) shelter and abundant food sources located in an estuarine environment.

For over forty years the Division's resource monitoring program has collected samples of fish, shellfish, and water chemistry using leading scientific principles and a randomized sampling strategy. Data from the program is used to assess populations and trends and to develop regulations for the protection of those resources. The Division also focuses on habitat conservation and restoration and leads the agency in coastal research and management. The Water Resources Branch is responsible for inter-agency coordination on all water-related issues, including assuring adequate instream flows for Texas' rivers and sufficient freshwater inflows for bays and estuaries. These priority goals and strategies contribute to our marine waters' health and productivity and protect fish, wildlife and plant resources from degradation or depletion.

TPWD and GLO have determined that a geospatial approach would be most suitable for identifying geographic zones within the Gulf of Mexico that would be appropriate for diversions of marine seawater and the discharge of waste resulting from the desalination of marine seawater. The approach consists of applying data overlays and analyses within a geographic information system (GIS) and developing a web-based viewer to support decisions on the location of diversions and discharges. The next section provides an overview of data sources for the study.

B. DATA RESOURCES AND OVERVIEW OF THE TEXAS MARINE GULF COAST

Geospatial information and selected literature references for the study are organized into six thematic topics: 1) administrative programs and boundaries, 2) currents and bathymetry, 3) submerged structures, 4) marine organisms and protected areas, 5) stressors, and 6) other resources. Background discussion about the Gulf of Mexico is intended to provide context about why certain data were considered in the study and to provide general information for project staff with diverse academic backgrounds. Geospatial information sources include ArcGIS online (AGO) authoritative publishers, federal and state data portals and mapping services, published and unpublished data for the Gulf of Mexico compiled by TPWD or GLO, and scientific publications. Although scientists have strived to catalogue what is known about living marine resources, there remains gaps in knowledge about the complex life histories of marine organisms, their habitat-use patterns and migratory requirements, and the Gulf's oceanographic system (NMFS 2015, National Academies 2018). However, the outlook for addressing these gaps is hopeful due to recent technological advances in autonomous underwater vehicles, multibeam sonar, and satellite-based observation (NMFS 2015).

1. Administrative Programs and Boundaries

Administrative boundaries referenced in this study include 1) a cadastral map of state-owned submerged land tracts developed by the GLO with Resource Management Codes (RMC) that were developed in partnership with state and federal resource agencies, 2) the state seaward boundary for Texas, and 3) a three nm offshore delineation. Resource Management Codes provide environmental guidelines for submerged land tracts and are published in an online web application named the RMC Viewer.

The RMC Viewer is available through the GLO website at http://cgis.glo.texas.gov/rmc/index.html. The viewer and codes assist individuals by providing the best available information on natural resource concerns associated with state land tracts and assist them with project planning efforts. The RMC's are intended to enhance protection of sensitive natural resources by providing recommendations that promote best management practices to minimize impacts to sensitive areas from development, and oil and gas related activities. The RMC's are based on recommendations from the following resource agencies: U.S. Fish and Wildlife Service, National Marine Fisheries Service, Texas Parks and Wildlife Department, Texas Historical Commission, and U.S. Army Corps of Engineers.

2. Currents and Bathymetry

a. Gulf of Mexico Loop Current and separation of eddies

A dominant feature in the Gulf of Mexico (Gulf) is the Loop Current that moves large volumes of warm, saline water along with biota northward into the Gulf. The Loop Current enters from the Yucatan Channel near Mexico where it pushes north into the Gulf and then turns south forming a wide loop. At the end of the loop the current then flows through the Florida Straits around the tip of Florida where it merges into the Gulf Stream current (Figure 2). The loop has been described as somewhat like a river through the Gulf of Mexico that enables migration of warmer water reef fishes, eggs and larvae from the Caribbean Sea in to the Gulf. Once in the Gulf, some of the biota traveling in the current will be carried to new locations within eddies that spin off from the larger current; and these eddies can last from a few months to as long as a year (Walker 2001). As eddies are shed and drift westward toward the Texas and Louisiana coast they create prime spawning habitat for many commercially and recreationally important species due to their warmer temperatures, and increased nutrient and salinity levels. The Environmental Studies Program at the U.S. Bureau of Ocean and Energy Management oversees an extensive program of research about the Loop Current and hydrodynamics in the Gulf of Mexico, and their website has links to many of the completed research reports (U.S. BOEM website https://www.boem.gov/Studies/).

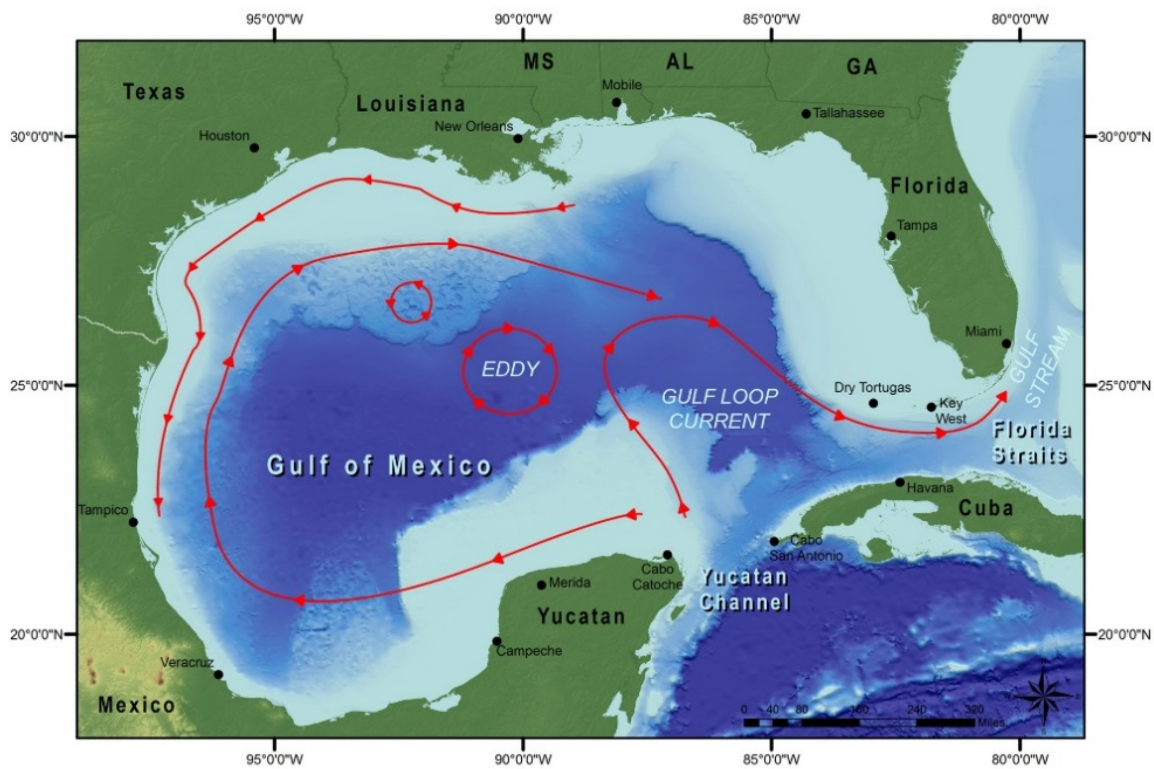

Figure 2. Illustration of the Gulf of Mexico Loop Current. **Credit: Flower Garden Banks National Marine Sanctuary**

Shallow-water reef fishes in the snapper and grouper families are examples of marine species carried by the Loop Current into the Gulf, and during certain life stages these commercially and recreationally important fish are found around reefs on the relatively shallow continental shelf (NOAA 2015). Vibrant reef communities develop on and around hard surfaces entrenched on the shelf seafloor which include shipwrecks (accidentally or intentionally sunk), submerged petroleum industry platforms, and other materials specifically repurposed for use as an artificial reef. Other submerged hard features on the continental shelf are fossilized remains of natural coral reefs and the remnants of past coastal shorelines and barrier islands collectively referred to as relict reefs and banks. Many of the relict reefs and banks are found in a region known as the South Texas Banks which extends from Matagorda Bay southward to the Texas border (Nash 2013, Streich et al. 2017). Research is ongoing by NOAA and others to document the relict features and advance our existing knowledge about their use as habitat by marine organisms. More information about the South Texas Banks is provided in the Natural Features section of this report.

b. Texas coastline currents – longshore current, seasonal trends

In general, the currents on the continental shelf are dynamic and influenced by many factors including surface winds and large weather patterns that are difficult to predict, tidal forces, and spin-off eddies from the Loop Current that sometimes crash into the edge of the shelf (Lugo-Fernandez 2001, Lugo-Fernandez and Green 2011, Johnson 2008). The shelf also receives large outflows from rivers with watersheds that cover a surprisingly large portion of the U.S. and Mexico as seen in Figure 3. The largest is the Mississippi River drainage shown in brown. River outflows have the potential to impact water quality on the continental shelf and predicting the location and magnitude of impacts is imperfect due to the variability of forces influencing weather patterns and localized currents. For example, hypoxia or depressed dissolved oxygen associated with river outflows has been a reoccurring water quality concern in the northwest Gulf of Mexico (Jewett et al. 2010, Love et al. 2013). Hypoxic conditions have been characterized over the years with variable levels of intensity and spatial extent (see Appendix 1 NOAA Hypoxia Watch Program maps for 2007 through 2017).

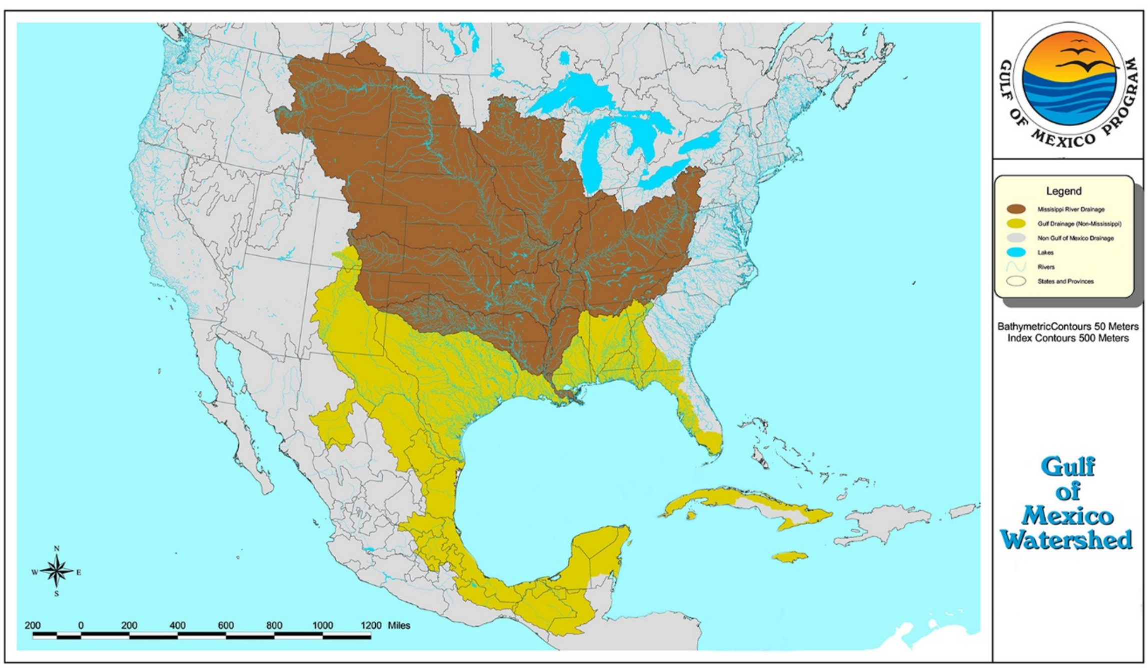

Figure 3. Gulf of Mexico Watershed. Credit: Gulf of Mexico Program

Although currents in the Gulf are dynamic, a circulation climatology for the continental shelf of the Gulf of Mexico has been developed using surface water current data collected over two decades (Johnson 2008). The Johnson study sponsored by NOAA National Marine Fisheries was targeted especially for fishery researchers and managers to understand the effects of ocean currents on fisheries. Among the products of this study are maps depicting monthly average wind and surface water currents, average summer season currents (June through August), and average non-summer season currents (September through May) (Figure 4 & 5). Walker (2001) describes the up-coast movement along the Texas coast during summer months as relatively short-lived compared with the predominant down-coast flow during the fall, winter, and spring months.

There are online data sources for near real-time and forecasted conditions for surface winds and ocean currents. The Gulf of Mexico Coastal Ocean Observing System (GCOOS) provides near real-time data, and a cooperative project between the GLO and Texas A&M University publishes forecasts. Website links are provided in the References section.

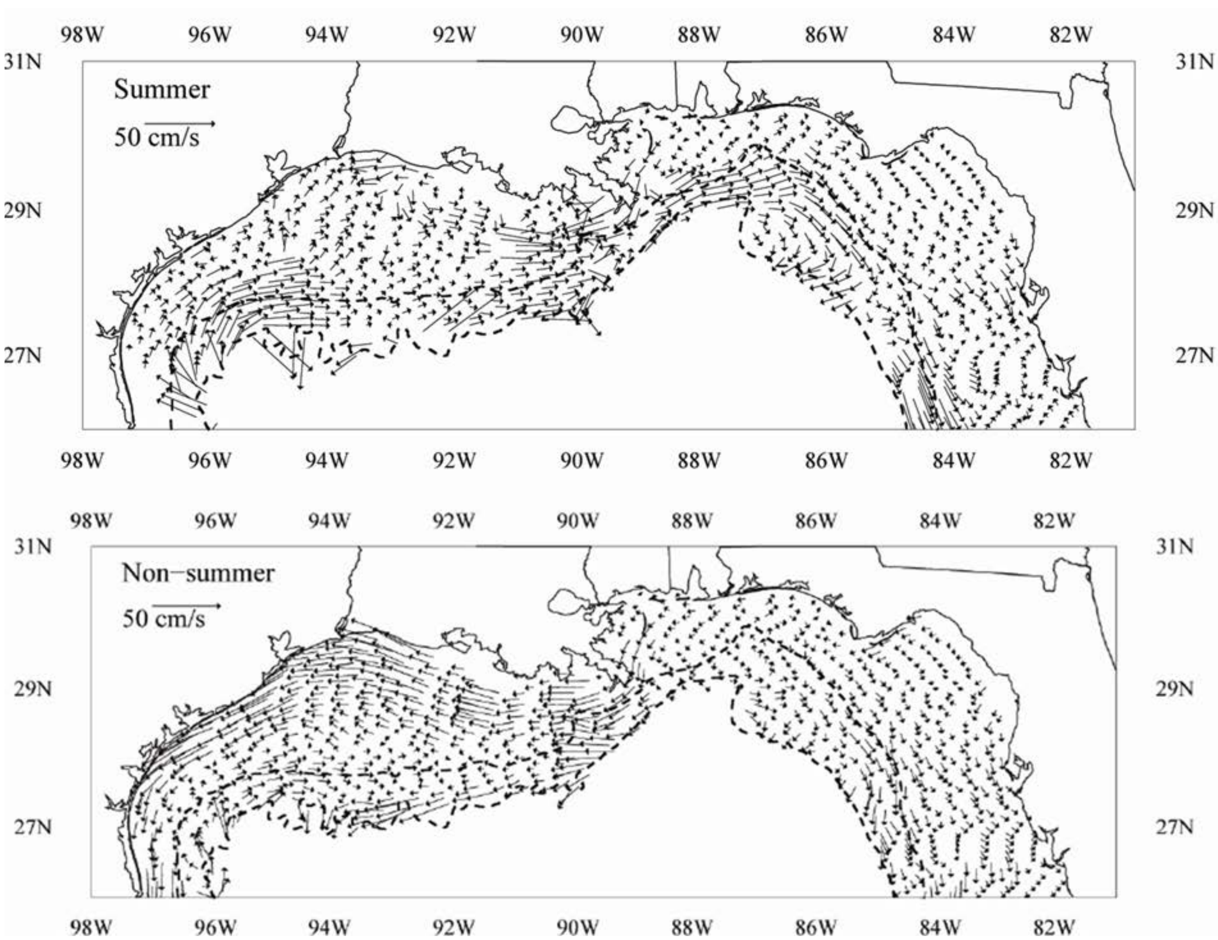

Figure 4. Average circulation patterns on the continental shelf region during summer, June to August (top), and the more predominant non-summer season, September to May This figure illustrates the seasonal variability of currents (Johnson 2008)

c. Bathymetry for the Texas portion of the continental shelf

Bathymetry for the Texas portion of the continental shelf is available from several sources including the Texas Natural Resource Information System (TNRIS), the AGO web mapping platform, and the Marine Cadastre National Viewer website. AGO hosts NOAA bathymetry products including a digital elevation model (DEM) color shaded relief imagery layer, which is also available directly from NOAA. Websites for coast-wide bathymetry data for the continental shelf are provided in the References section. It is not unusual to discover differences between bathymetric map products since the source data can be collected and processed using a variety of methods. For this study, the NOAA National Centers for Environmental Information (NOAA NCEI) bathymetric data viewer was used to screen for bathymetric features within the study area and with the understanding that not all features can be effectively captured by the DEM. This task was performed in response to staff who were particularly interested in identifying canyons and depressions in the seabed that could potentially affect proper circulation and dilution of brine waste discharges. During a scan of the study area two features were observed that appeared to be depressions approximately one half-mile in diameter (measured using GIS tools) and a couple of meters deep: one was located approximately four miles seaward from the San Antonio Bay area, and another approximately four miles seaward and just south of the Brazos River delta.

d. Passes connecting the Gulf of Mexico with Texas coastal bays and estuaries

TPWD's Coastal Fisheries Division conducts a resource monitoring program in the areas surrounding five coastal passes connecting the Gulf of Mexico with Texas' bays and estuaries. Coastal passes function as migratory corridors connecting shallow, lower salinity habitats with oceanic Gulf waters, and as important transportation corridors serving a variety of human needs. From north to south along the coast they are Sabine Pass, Bolivar Pass, the Matagorda Ship Channel, Aransas Pass, and Brazos-Santiago Pass, and TPWD identifies these as major passes (Figure 5). A footprint of TPWD's resource monitoring program is available online through NOAA's Environmental Response Management Application (ERMA) under the Restoration layer, and then sublayer Ocean Conservancy Gap Analysis for marine fish (www.erma.noaa.gov).

Figure 5. Red stars show the locations of five major passes connecting the Gulf of Mexico with Texas bays and estuaries. Credit: TPWD/Lynne Hamlin

Because marine organisms have complex life cycles and habitat requirements, this study highlights the importance of passes connecting Texas estuaries with the Gulf of Mexico. Estuaries are among the most productive natural systems and are important nursery areas that provide specific salinities to complete development phases, refuge from predation, and are sources of food for many species (Patillo et al. 1997). Many aquatic species including Gulf Menhaden, flounder, redfish, shrimp, blue crab, and green sea turtles utilize major and minor coastal passes to reach habitats or food sources required during their various life stages (Nelson 1992, Patillo et al. 1997, Renaud et al. 1995). Significant minor coastal passes identified by TPWD Coastal Fisheries biologists include Cedar Bayou, Packery Channel, Port Mansfield Channel, and San Luis Pass.

As direct connections to the Gulf, coastal passes influence bay and estuary salinity levels, circulation, water quality, and ultimately ecosystem dynamics. Protection of water chemistry within passes is important since water quality and salinity levels within bays and estuaries directly influence marine life and the habitats upon which they depend for food and shelter.

3. Submerged structures off the Texas coast

a. Artificial Reefs

TPWD's Artificial Reef Program develops, maintains, monitors and enhances the artificial reef potential of offshore waters. TPWD, NOAA, and BOEM maintain artificial reef geospatial data which are available from TPWD's website, ArcGIS Online, and MarineCadastre.gov. TPWD Artificial Reef Program data can be accessed online at http://tpwd.texas.gov/gis/ris/artificialreefs.

b. Hard substrate

TPWD has compiled information about submerged structures as part of a vertical longline survey program conducted on the Texas portion of the continental shelf. The purpose of vertical longline surveys is to collect information about commercially and recreationally important reef fish species in Gulf of Mexico coastal waters and in the adjoining Exclusive Economic Zone. Information collected will help to fulfill the program objectives of developing life histories for reef fish, quantifying and characterizing habitats and creation of a Gulf-wide habitat map, and characterizing reef fish assemblages by depth and habitat type. The Texas vertical longline survey program began recently, in 2015, and the survey data is submitted to the Southeast Area Monitoring and Assessment Program, a program administered by the Gulf States Marine Fisheries Commission.

Included in TPWD's vertical longline survey database are shipwrecks and obstructions, natural and artificial reefs, and other offshore man-made structures. Many of these locations duplicate data found in other sources such as NOAA's Automated Wreck and Obstruction Information System and Raster Navigational Charts. TPWD's longline survey program data is available from TPWD upon request and may also be available through contacts and links provided on the Gulf States Marine Fisheries Commission website (www.gsmfc.org/seamap.php).

There are several online sources for downloading or viewing locations of submerged structures that are opportunities for marine habitat. NOAA Coast Survey publishes the Automated Wreck and Obstruction Information System or AWOIS at noaacoastsurvey.wordpress.com/tag/awois/. This website provides links to explore the data in an online viewer and provides links to a REST service for use in GIS software. The AWOIS program catalogs and stores a substantial volume of wrecks and obstructions but acknowledges that it is not a comprehensive record of wrecks for any particular area. Updates are ongoing as sites are investigated and confirmed. AWOIS program data can also be found using other online viewers such as the Marine Cadastre National Viewer.

NOAA's Raster Navigational Charts (RNC's) is another online source for information about substrate on the continental shelf. GIS-compatible data and a guide to map symbology are available from https://nauticalcharts.noaa.gov/.

Features identified in the RNC's were compared with data from TPWD's vertical longline survey and the artificial reef program databases. The comparison resulted in several locations being added to the submerged structures data and they consisted of eight submerged wrecks, three fish havens, and three obstructions located near the fish havens.

c. Natural features

Ocean Conservancy compiled spatial data from 173 different sources to produce an atlas for the entire Gulf of Mexico Ecosystem. The online atlas contains maps and narratives for a variety of physical features and processes that define and drive the Gulf's ecosystem (Love et al. 2013).

Within the project study area, relict reefs and banks are important natural features for marine life (Nash et al. 2013, NOAA 2018, Texas A&M 1983, Streich et al. 2017). A group of these features known as the South Texas Banks are in a large area offshore extending roughly from Matagorda Bay southward to the Texas border. As explained in Nash (2013) the number of features in the South Texas Banks is debatable since it depends in part on how a bank is defined (minimum size, relief, etc). Currently, more than twenty locations have been documented in published literature and student theses, and it is likely more locations will be discovered during future explorations. While most of the documented South Texas relict reefs and banks appear to be located beyond Texas territorial waters, there are two relatively near-shore features named 7.5 Fathom Reef and 9 Fathom Rocks located roughly 1.6 and 5.5 nautical miles offshore from the Laguna Madre bay system. The References section provides resources for information about their geological and physical setting, and importance for marine life.

Although large complex coral reefs are not known to exist within the project study area, they are present in other Gulf locations where water quality, temperature, and salinity are favorable (see the NOAA Deep Sea Coral online viewer website in References). The shallower nearshore region of the continental shelf is, however, favorable habitat for sea pens which are a relative of corals and sea anemones. Briefly, sea pens (*Virgularia presbytes*) are suspension-feeding marine organisms that anchor in nearshore sandy or muddy sediments creating stands or "beds" analogous to beds of seagrass; and they have been associated with the feeding ecology of loggerhead sea turtles (Plotkin et al. 1993). In the late 1980's researchers from the University of Texas Marine Science Institute conducted a stomach content analysis from loggerhead turtles recovered off the Texas coast and concluded that sea pens provided significant forage for these turtles, and particularly during the spring months. The team estimated where sea pen beds were located within the study area and the results are presented in Figure 3 of the Plotkin report. The survey map was accurate for that time period and local experts do not know of anything more recent (personal communication with Donna Shaver, Chief of the Division of Sea Turtle Science and Recovery, National Park Service, Padre Island National Seashore).

4. Marine Organisms and Protected Areas – information sources for marine organisms, ranges, and habitats

A variety of marine vertebrates and invertebrates populate the Gulf of Mexico as permanent or temporary residents. Permanent populations in the study area include the commercially important species Gulf Menhaden, and several species of shrimp and crabs, among others. Some species enter the Gulf temporarily during seasonal migration or as part of a large home range; and others such as tropical reef fishes and larvae migrate by swimming or drifting in oceanic currents and join existing populations. It is a challenging endeavor to track the movements and identify all marine organisms in the Gulf, and unfortunately our understanding of the Gulf's complex oceanographic systems is not yet complete (National Academies 2018). However, two helpful references that summarize our current knowledge about species movements and habitats are: 1) Ocean Conservancy's coastal and marine atlas for the Gulf of Mexico (Love et al. 2013), and 2) The Nature Conservancy's migratory species mapping project www.migratoryblueways.org.

Coastal passes provide connections between the Gulf's oceanic habitat and less saline bays and estuaries. Passes are used by a variety of marine species as documented in the NOAA reports "Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries" Volume I Data Summaries, and Volume II: Species life history summaries (Nelson et. al. 1992, Patillo et al. 1997). As described in these reports, many species only use estuaries for specific parts of their life histories and spend the rest offshore. Most of these species fall into four general categories: 1) diadromous species which use estuaries as migratory corridors and, in some instances, nursery areas; 2) species that use estuaries for spawning; 3) species that spawn in marine Gulf waters and depend on tidal- and wind-driven currents to carry eggs, larvae, or early juveniles into estuarine nursery areas; or 4) species that enter estuaries during certain times of year to feed on abundant prey.

The References section provides sources of geospatial information about marine organisms in the Gulf of Mexico, their known or estimated species ranges and habitats, and conservation and protection zones. Marine organisms include commercially and recreationally important species, and species that are at-risk, among others. At-risk species include the state and federally listed endangered Kemp's ridley (KR) sea turtle found in Texas waters and other regions in the Gulf. During nesting season, female KR sea turtles migrate from the waters of the Gulf to sandy beaches where they create nests and lay their eggs, and may nest multiple times during the season (Seney et al. 2008). Satellite tracking studies indicate that during these inter-nesting periods female sea turtles remain in Gulf waters offshore from the nesting beaches (Hays et al. 1999, Seney et al. 2008, Hart et al. 2010). Recent studies have revealed that nearshore Gulf waters contain important foraging areas as well as critical migratory habitat for KR sea turtles; although it is acknowledged there is a gap in our understanding of how these migratory pathways are used by KR's and other species to return from their foraging grounds to nesting beaches (Shaver 2013, Shaver 2016). Based on a recent satellite tracking study, the KR's migratory pathway was identified as extending a mean distance of 20 kilometers (apx. 12 miles) from the nearest mainland coast and having a mean water depth of 26 meters (apx. 85 feet) (Shaver 2016). In summary, there is a limited understanding of sea turtle nesting and inter-nesting habitat requirements due to relatively few published studies which focused on particular species of sea turtles; however, our knowledge will improve as more studies are completed.

Several other at-risk species of turtles are found in the Gulf of Mexico: green sea turtles, loggerheads, leatherbacks, and hawksbills. In Texas waters, juvenile and adult green sea turtles populate the nearshore zone throughout the year and travel back and forth through coastal passes connecting the Gulf of Mexico with bays and estuaries (personal communication with Donna Shaver, Chief of the Division of Sea Turtle Science and Recovery, National Park Service, Padre Island National Seashore). A summary of research and published literature about sea turtles in the Gulf of Mexico is available from Valverde and Holzwart (2017).

An overview of fishery management plans (FMPs) for the Gulf of Mexico is available in a National Marine Fisheries Service (NMFS) publication titled "Our Living Oceans: Habitat" (NMFS 2015). The Southeast Region includes a chapter about the Gulf of Mexico, and a discussion of habitat use begins on page 160. The report has a summary table (Table 9) of FMP species groups that utilize shallow marine habitat typical of the continental shelf near the Texas coast. The report states that it is important to recognize that there are many species included in a FMP species group, and all have unique habitat requirements by life stage. Furthermore, habitat information is lacking for many species, particularly in the earlier life stages, and such critical information gaps are not captured. Protected species groups that are reported to frequently or occasionally use shallow marine habitat are cetaceans, sea turtles, and pinnipeds. Other species and species groups covered in an FMP for the Gulf of Mexico include, but are not limited to, reef fish resources, red drum, shrimp, and coastal migratory pelagics of the Gulf of Mexico and South Atlantic. Please see the NMFS report for more information about Gulf of Mexico's fishery management plans, or the NMFS Southeast Regional Office website provided under Section 6 Other Resources.

5. Stressors

Contour maps of hypoxic zones in the Gulf are accessible through the NOAA Gulf of Mexico Hypoxia Watch website (www.ncddc.noaa.gov/hypoxia/) and GIS REST service (service.ncddc.noaa.gov/arcgis/rest/services/EnvironmentalMonitoring/Hypoxia/MapServer). Hypoxic zones have such low concentrations of dissolved oxygen that marine life leaves the area, if possible, or dies. Dissolved oxygen is influenced by salinity and temperature. The ability of oxygen to dissolve in water decreases as salinity and temperature increase. For reference, Appendix 1 contains hypoxic zone maps for 2007 through 2017 downloaded from the NOAA website, and an assessment of hypoxic conditions and effects on aquatic life in the Gulf of Mexico can be found in a 2010 report "Scientific Assessment of Hypoxia in U.S. Coastal Waters" by a U.S. Joint Subcommittee on Ocean Science and Technology (Jewett et al. 2010).

A list of Gulf ecosystem stressors and supporting maps are presented in the Ocean Conservancy's coastal and marine atlas. The maps include a tropical cyclone density map, low oxygen areas, hazardous materials spills, and areas where changes in ocean acidification and temperatures may be occurring. Available online: oceanconservancy.org/wp-content/uploads/2017/05/gulf-atlas.pdf.

Due to the variability of hypoxic regions, climate, spills, and other stressors along the Texas coast, this information was not applied as an overlay when selecting zones appropriate for the diversion of marine seawater or discharge of waste from desalination facilities. However, these stressors including climatic events should be considered during site-specific planning due to their potential impact on water quality and discharge plume behavior.

6. Other Resources

a. NOAA National Marine Fisheries Southeast Regional Office

Gulf of Mexico fishery management plans, GIS data, and rulemaking documents: sero.nmfs.noaa.gov/sustainable_fisheries/gulf_fisheries/index.html.

Information about protected marine resources in the Gulf of Mexico is available from NOAA's Protected Resources Division website: sero.nmfs.noaa.gov/protected_resources/index.html. Accessed January 2018.

b. Gulf of Mexico Alliance (GOMA)

The Gulf of Mexico Alliance (gulfofmexicoalliance.org) promotes an ecosystem approach to managing the Gulf of Mexico's resources. Established in 2004 in response to the U.S. Ocean Action Plan, GOMA is non-profit regional ocean partnership led by leadership from the five U.S. Gulf States.

c. Selected desalination-related publications from other states

California

The California State Water Resources Control Board's Ocean Unit is responsible for the development and updating of plans, policies, and standards involving marine waters, and for providing scientific support to various agencies regarding marine pollution and resource management. The most recent version of the California Ocean Plan with Desalination Amendment (2015) is available on their website as well as other desalination-related environmental reports (www.waterboards.ca.gov/water_issues/programs/ocean/). The Desalination Amendment specifically addresses effects associated with the construction and operation of seawater desalination facilities. Included in the amendment are requirements for monitoring and reporting, and requirements to use best available site, design, technology, and mitigation measures feasible to minimize intake and mortality of all forms of marine life. Furthermore, mitigation measures are required to address harmful impacts on marine life that occur after a desalination facility uses the best available site, design, and technology feasible. When considering feasibility, planners consider economic, environmental, social, and technological factors and whether something is capable of being accomplished in a successful manner within a reasonable period of time.

During development of California's 2015 Ocean Plan, a Science Advisory Panel was convened to advise the state on best practices for brine disposal to coastal waters (Roberts et. al. 2012). The members represented expertise in physical oceanography, modeling, ecology, and toxicology. Panelists reviewed extensive material about desalination discharges including peer-reviewed publications, gray literature and technical memorandums, National Pollutant Discharge Elimination System (NPDES) permits that have been issued, discharge regulations from around the world, and results from monitoring studies. No specific mathematical discharge models were endorsed by the Panel, however they provided criteria for evaluating proposed models and recommended that a monitoring program should be employed that includes pre-discharge conditions and that continues after discharge has begun so that changes in the ecosystem can be evaluated.

The panel recommended:

1) using a mixing zone approach to regulate discharges;

2) limiting salinity increases at the mixing zone boundary to no more than 5% (or an absolute increment of 2 psu, whichever is less) of that occurring naturally in the waters around the discharge;

3) regulating toxicity and water quality objectives at the edge of a mixing zone boundary which is conservatively recommended to be 100 meters from the discharge and includes the entire water column;

4) accounting for effluent density and flow rates on plume behavior; and

5) applying conservative assumptions when evaluating dilution and overall flushing of the discharge site to ensure the dilution requirement at the edge of the mixing zone is still met. Examples of conservative assumptions are:

i) ocean currents do not increase dilution beyond the zone of initial dilution, and ii) the seabed is flat and horizontal.

The Panel researched brine discharge regulations from around the world and the information is repeated here due to interest about this topic from this study's interagency work group. The Science Advisory Panel reported that there are few actual regulations, standards, or guidelines for brine discharges. For brine waste discharges, the main water quality concern is elevated salinity in the receiving waters and secondarily the discharge of various chemicals used in the treatment process. Some regulations that have been established and their compliance points for various desalination facilities are presented in Table 2-1 of the Panel report; and for reference the table is copied below as Table 1. As explained in the report there is substantial variation in the specifics of the regulations, but almost all share two key elements: a salinity limit and a point of compliance expressed as a distance from the discharge. The salinity limit is usually stated as an increment of no more than 1 to 4 ppt relative to ambient, and less frequently stated as an absolute salinity or minimum level of dilution. The point of compliance for the salinity limit is usually specified in terms of a fixed distance from the discharge ranging from tens to hundreds of meters. Ultimately, the Panel recommended promulgation of a regulatory mixing zone that generally encompasses the near field mixing zone which is where the rapid mixing of the concentrated brine discharge and reduction in salinity occur.

Table 1. International brine discharge regulations (Roberts et al. Science Advisory Panel report 2012).

Region/Authority	Salinity Limit	Compliance Point (relative to discharge)
US EPA	Increment ≤ 4 ppt	-
Carlsbad, CA	Absolute ≤ 40 ppt	1,000 ft (304.8 m)
Huntington Beach, CA	Absolute ≤ 40 ppt salinity (expressed as discharge dilution ratio of 7.5:1)	1,000 ft (304.8 m)
Western Australia guidelines	Increment < 5%	-
Oakajee Port, Western Australia	Increment ≤ 1 ppt	-
Perth, Australia/Western Australia EPA	Increment ≤ 1.2 ppt at 50 m and ≤ 0.8 ppt at 1,000 m	50 m and 1,000 m
Sydney, Australia	Increment ≤ 1 ppt	50-75 m
Gold Coast, Australia	Increment ≤ 2 ppt	120 m
Okinawa, Japan	Increment ≤ 1 ppt	Mixing zone boundary
Abu Dhabi	Increment ≤ 5 %	Mixing zone boundary
Oman	Increment ≤ 2 ppt	300 m

Florida

In 2010 the Florida Department of Environmental Protection (FDEP) Division of Water Resources published the following report in response to interest in desalination development in the state. The report "Desalination in Florida: Technology, Implementation, and Environmental Issues" is available online as of February 2018 (ufdcimages.uflib.ufl.edu/UF/00/10/03/82/00001/desalination-in-florida-report.pdf). Section Four addresses desalination concentrate management, water quality concerns, and potential impacts of desalination intakes and discharges on the aquatic environment.

According to the FDEP report, the following considerations are recommended for analysis of brine discharges. The first three are important for aquatic species because a shift in the salt ratio and type of salt can cause osmotic imbalance and toxicity.

1) the total salt content as compared with receiving waters;

2) the source of the salts (groundwater or surface water);

3) the ratio of the type of salts compared with those in the receiving waters;

4) whether there is adequate circulation to prevent the salt from building up over time to a point where it is toxic to the ecological community;

5) the potential for depressed oxygen levels due to poorly dispersed brine discharges at a particular location;

6) the contaminants discharged with the brine that resulted from natural sources (such as fluoride and copper), and from chemicals used in the operation and maintenance of the desalination facility such as conditioning reagents, antiscalant chemicals, and metals from corrosion of piping (iron, chromium, and nickel); and

7) a site-specific analysis is recommended to determine if there is toxicity and, if so, what steps would need to be taken to minimize the impact.

FDEP recommendations for desalination intakes:

1) designing intake structures to cope with varying flows and water quality that may occur at the intake site;

2) designing intake structures to reduce the flow velocity so that organisms may escape being drawn into the intake;

3) using screens or booms or both to exclude organisms from the intake; and

4) when feasible, use of directional drilling to install piping below the seabed and drawing water down through a sandy bottom to prevent impingement of marine organisms on intake screens exposed to open water, and entrainment of other organisms carried with the feedwater through the intake screen.

C. CREATION OF ZONE MAPS

a) Methodology

The purpose of this study is to identify zones in the Gulf of Mexico that are appropriate for the diversion of marine seawater and for the discharge of waste resulting from the desalination of marine seawater, while taking into account the need to protect marine organisms. The zones are based on the framework of submerged tract boundaries developed for the GLO RMC program, and the following paragraphs describe development of the zones.

An initial base layer of submerged land tracts was derived from the GLO RMC database by applying a filter that identified and selected tracts not assigned any special recommendations relating to sensitive areas, other than cultural resources (RMC code MA). The result forms the initial base layer of appropriate zones for diversions and discharges of marine seawater.

Next, a second filter was applied to the base layer to identify and remove tracts with activity-related time restrictions that are intended to avoid disturbance to certain species and habitats (RMC codes TA through TF). The result is a selection of tracts from the RMC database with no specific concerns at this point in time, and tracts that are not identified as sensitive areas or habitats. For reference, the RMC program identifies sensitive areas and habitats as including but not limited to the following: hard substrate reefs, endangered species habitat, private oyster leases, submerged aquatic vegetation, dredge material placement areas, bird rookeries, and tidal sand and mud flats.

Additional geospatial data were then applied as overlays. These data include: TPWD's Coastal Fisheries Resource Monitoring Program sampling footprint around major passes in the Gulf of Mexico; minor coastal passes identified as important fish passes by TPWD Coastal Fisheries biologists; additional locations of artificial reefs and hard substrate information recorded in TPWD Coastal Fisheries datasets or from NOAA online Raster Navigational Charts; and locations of nesting beaches and inter-nesting habitat for sea turtles.

Data Overlays

The overlay for major coastal passes consists of the TPWD's Coastal Fisheries Resource Monitoring Program sampling footprint surrounding five major coastal passes: Sabine Pass, Bolivar Pass, Matagorda Ship Channel, Aransas Pass, and the Brazos-Santiago Pass. A description is provided below (TPWD 2015 Marine Resource Monitoring Operations Manual, available from TPWD upon request).

- Gulf area off Sabine Lake. All waters located 13 nautical miles (15 statute miles) on either side of Sabine Pass from the gulf beach shoreline to 9 nautical miles (10 statute miles) offshore (includes Louisiana waters).

- Gulf area off Galveston Bay. All waters located 13 nautical miles (15 statute miles) on either side of Bolivar Pass from the gulf beach shoreline to 9 nautical miles (10 statute miles) offshore.

- Gulf area off Matagorda and San Antonio bays. All waters located 13 nautical miles (15 statute miles) on either side of Matagorda Ship Channel from the gulf beach shoreline to 9 nautical miles (10 statute miles) offshore.

- Gulf area off Aransas and Corpus Christi bays. All waters located 13 nautical miles (15 statute miles) on either side of Aransas Pass from the gulf beach shoreline to 9 nautical miles (10 statute miles) offshore.

- Gulf area off Lower Laguna Madre. All waters located 26 nautical miles (30 statute miles) north of the Texas-Mexico border from the gulf beach shoreline to 9 nautical miles (10 statute miles) offshore.

The overlay for minor coastal passes consists of a three-mile buffer around the mouth of four minor coastal passes identified by TPWD Coastal Fisheries biologists. The passes are San Luis Pass, Cedar

Bayou, Packery Channel, and Port Mansfield Channel. The three-mile buffer is based on guidelines from the TPWD's Kills and Spills Program concerning the use of dispersants.

The overlay for points of interest consists of the locations of natural features and hard substrate recorded in TPWD's Vertical Longline Program database and filtered to exclude features that no longer exist, and features identified as platforms, rigs, or communication towers.

The overlay for sea turtle nesting beaches consists of a 5-mile buffer around six nesting beaches. Because of the other overlays and use of the RMC database there are relatively few tracts affected by this overlay. Sea turtle nesting beach locations are obtained from the Nature Conservancy's Conservation Blueways project.

b) Discharge Zones

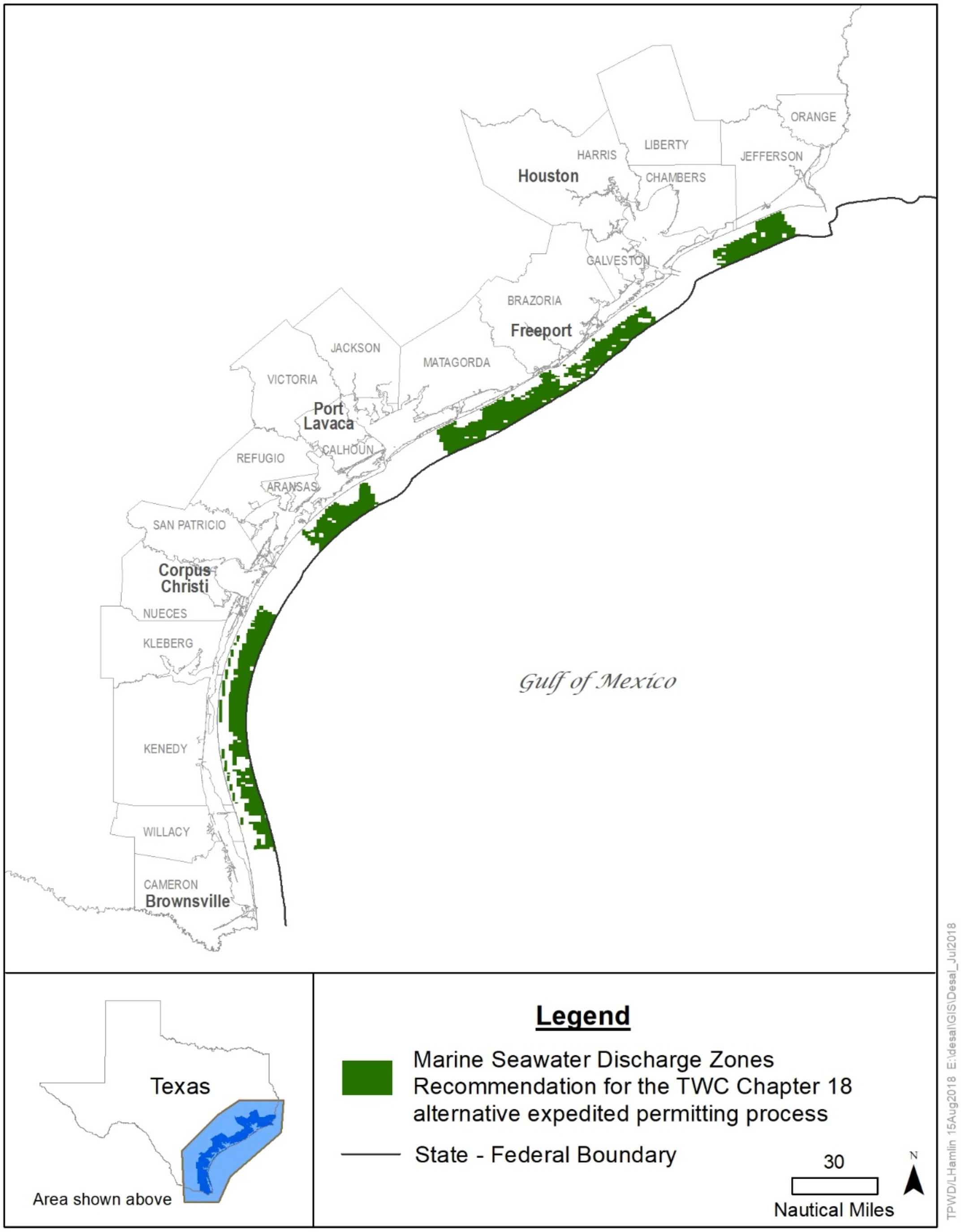

Figure 6. Coastwide map of zones within Texas territorial waters (highlighted in green) recommended by TPWD and GLO as appropriate for the discharge of desalination waste into the Gulf of Mexico as required by HB 2031 (84th Legislature).

Recommendations when locating discharges:

In addition to the review and analysis of mapping data provided here, the list below identifies other general considerations for brine concentrate discharges that apply to Texas and elsewhere. The first three are important for aquatic species because a shift in the salt ratio and type of salt can cause osmotic imbalance and toxicity to aquatic organisms. Evaluations of brine concentrate discharges should include:

1) the total salt content as compared with receiving waters;

2) the source of the salts (groundwater or surface water);

3) the ratio of the type of salts compared with those in the receiving water;

4) whether there is adequate circulation to prevent the salt from building up over time to a point where it is toxic to the ecological community;

5) the potential for depressed oxygen levels due to poorly dispersed brine discharges at a particular location;

6) the contaminants discharged with the brine that resulted from natural sources (such as fluoride and copper), and from chemicals used in the operation and maintenance of the desalination facility such as conditioning reagents, antiscalant chemicals, and metals from corrosion of piping (iron, chromium, and nickel); and

7) a site-specific analysis is recommended to determine if there is toxicity and, if so, the steps needed to minimize the impact.

c) Diversion Zones

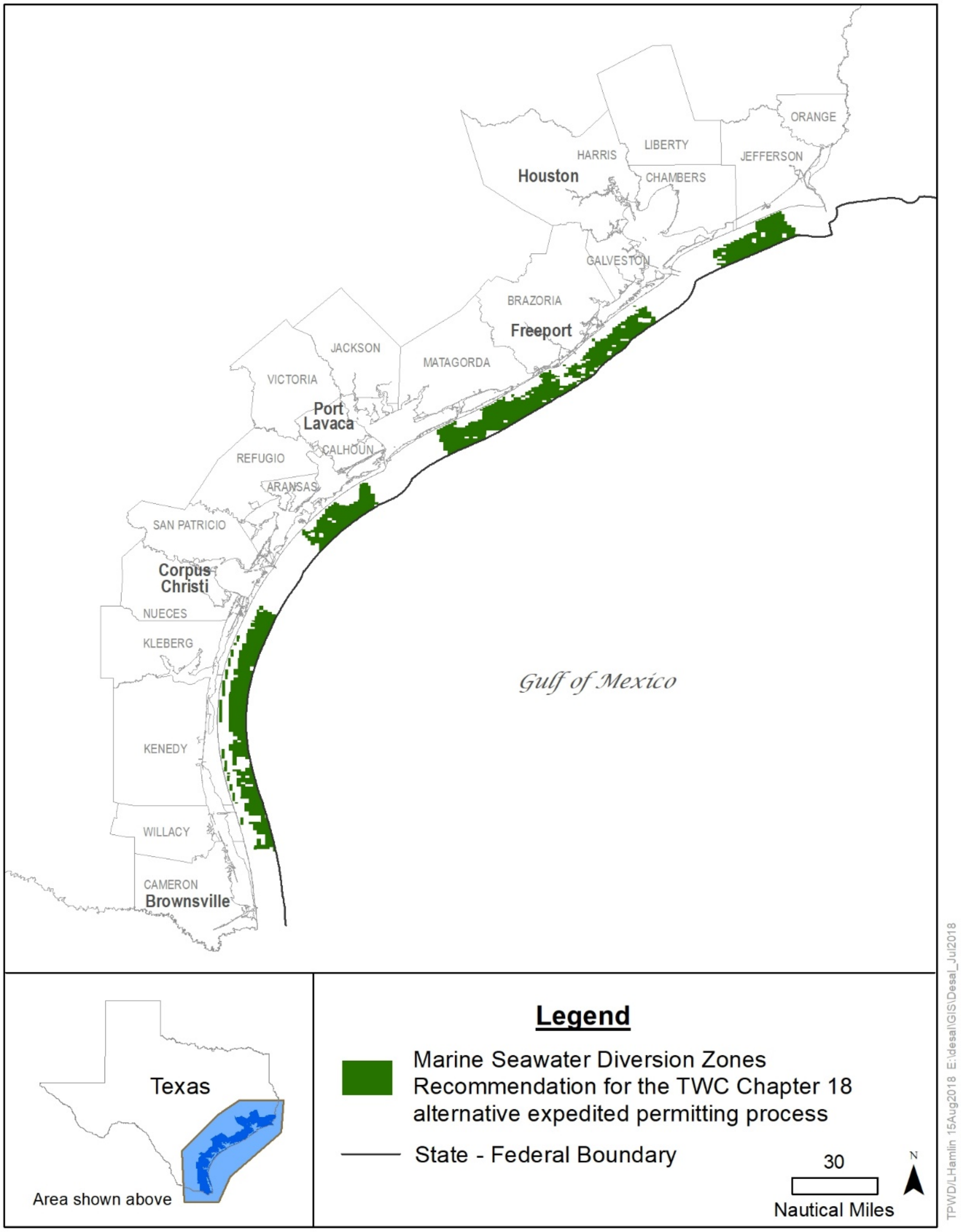

Figure 7. Coastwide map of zones within Texas territorial waters (highlighted in green) recommended by TPWD and GLO as appropriate for the diversion of marine seawater from the Gulf of Mexico as required by HB 2031 (84th Legislature).

The guiding legislation (HB 2031) requires this study to recommend the number of points from which, and the rate at which, a facility may divert marine seawater. Recognizing that it is beyond the scope of this study to prescribe detailed design specifications for any particular desalination facility, a series of general recommendations are as follows based on previous TPWD consultations and results from the literature review performed for the study:

1) diversion points should not exceed flow-through velocities of 0.5 feet per second (fps), nor be co-located such that combined impacts in the surrounding approach area exceeds 0.5 fps;

2) intake structure design should adjust or adaptively manage with varying flows and water quality that may occur at the intake site;

3) intake structures should be designed to reduce the flow velocity so that marine organisms may escape being drawn into the intake;

4) screens or booms, or both, should be used to exclude organisms from the intake; and

5) it is recommended that a site-specific study of conditions at proposed intake locations be conducted to identify marine organisms at risk from intake operations, and to inform the design planning process.

When feasible, directional drilling to install piping below the seabed and drawing water down through a sandy bottom will prevent impingement of marine organisms on intake screens exposed to open water, and entrainment of other organisms carried with the feedwater through the intake screen.

D) CONCLUDING REMARKS

This report fulfills the joint study requirements of HB2031 (84^{th} Legislature) to identify zones in the Gulf of Mexico appropriate for the diversion of marine seawater and for the discharge of waste resulting from the desalination of marine seawater, while taking into account the need to protect marine organisms.

Periodic updating of zones, and the resulting zone maps used in permitting decisions, is required due to the dynamic nature of the Gulf of Mexico and as more information becomes available about marine organisms and habitats that are important for sustaining a healthy and productive marine ecosystem. Periodically, the TPWD in consultation with the GLO will monitor changes in nearshore and offshore submerged tracts to determine if areas should be added or removed from the identified zones. The GLO will make the geospatial information available through the Internet using online web applications including the GLO Resource Management Code Viewer. A unique RMC code will be assigned to enable viewing of tracts recommended as appropriate for desalination diversion and/or discharges of waste.

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Alex Sanders	Tony Williams	Alec Robbins	

F) LIST OF ACRONYMS

AGO - ArcGIS online

AWOIS - the Automated Wreck and Obstruction Information System

BOEM - U.S. Bureau of Ocean and Energy Management

DEM - digital elevation model

FDEP - Florida Department of Environmental Protection

FMPs - fishery management plans

fps - feet per second

GCOOS - Gulf of Mexico Coastal Ocean Observing System

GIS - geographic information system

GLO - Texas General Land Office

GOMA - Gulf of Mexico Alliance

GSMFC - Gulf States Marine Fisheries Commission

HB - House Bill

mg/L - milligrams per liter

nm - nautical mile

NMFS - National Marine Fisheries Service

NOAA ERMA - National Oceanographic and Atmospheric Administration Environmental Response Management Application

NOAA NCEI – National Oceanographic and Atmospheric Administration National Centers for Environmental Information

NPDES - National Pollutant Discharge Elimination System

psu – practical salinity units

REST – Representational State Transfer

RMC - Resource Management Code

SEAMAP - Southeast Area Monitoring and Assessment Program

TCEQ - Texas Commission on Environmental Quality

TDS - total dissolved solids

TNRIS - Texas Natural Resource Information System NOAA

TPDES – Texas Pollutant Discharge Elimination System

TPWD - Texas Parks and Wildlife Department

TWC - Texas Water Code

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APPENDIX 1: NOAA HYPOXIA WATCH PROGRAM MAPS

Maps reprinted from www.ncddc.noaa.gov/hypoxia/products/ , Jan. 2018

Year: 2017

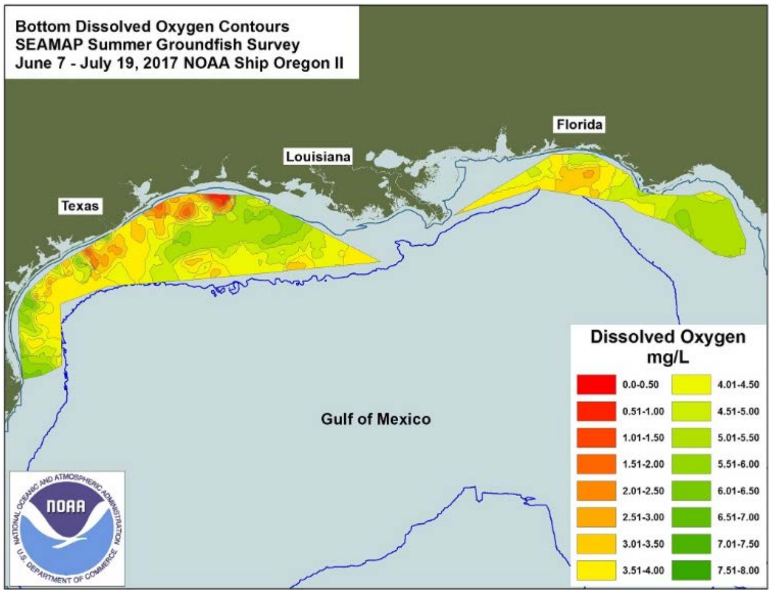

Figure 8. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – July 19, 2017 NOAA Ship Oregon II

Year: 2016

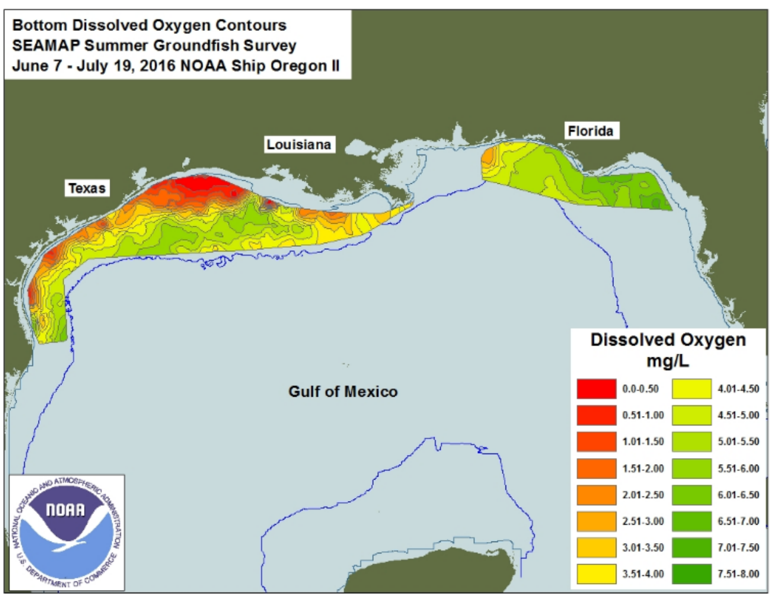

Figure 9. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – July 19, 2016 NOAA Ship Oregon II

Year: 2015

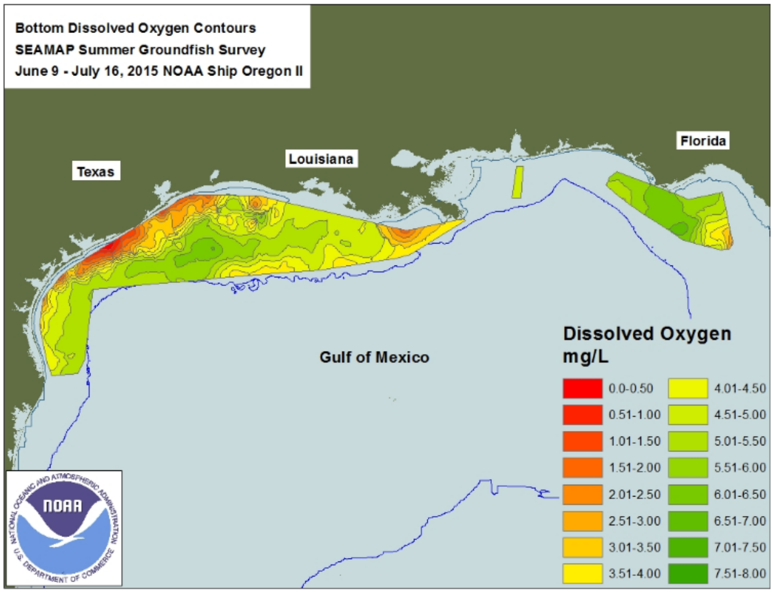

Figure 10. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 9 – July 16, 2015 NOAA Ship Oregon II

Year: 2014

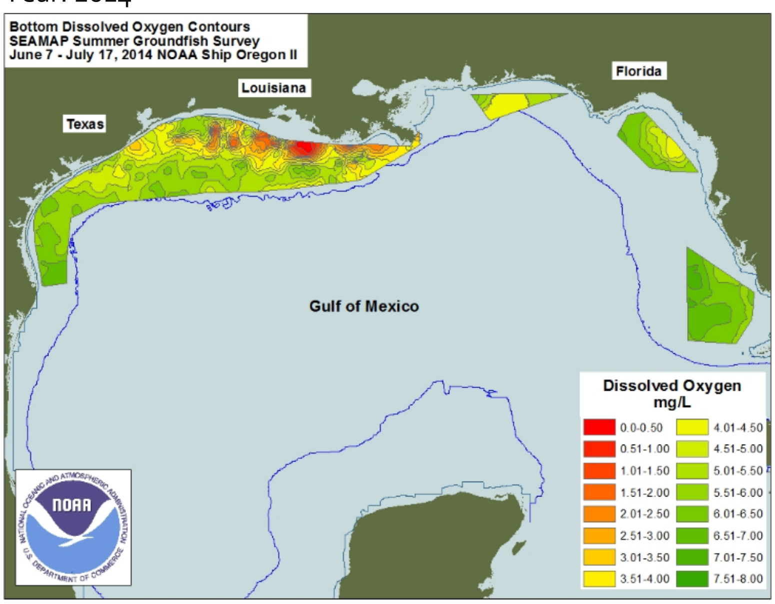

Figure 11. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – July 17, 2014 NOAA Ship Oregon II

Year: 2013

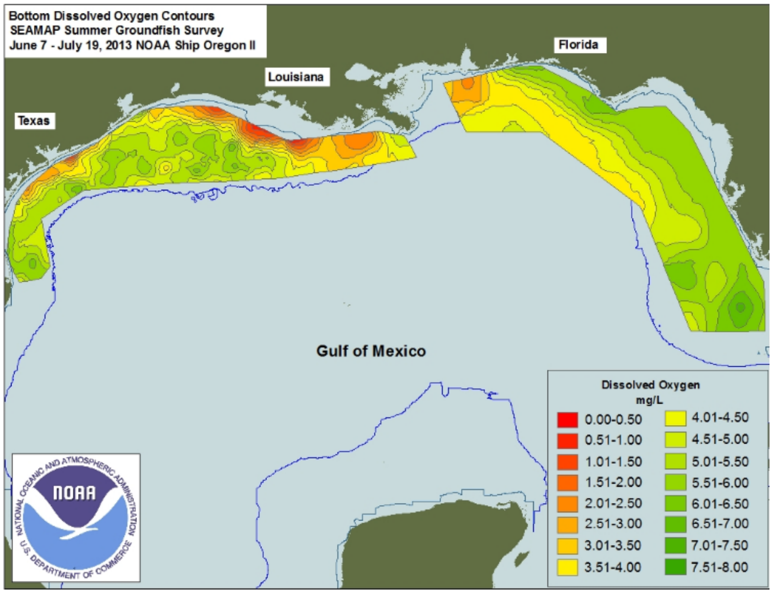

Figure 12. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – July 19, 2013 NOAA Ship Oregon II

Year: 2012

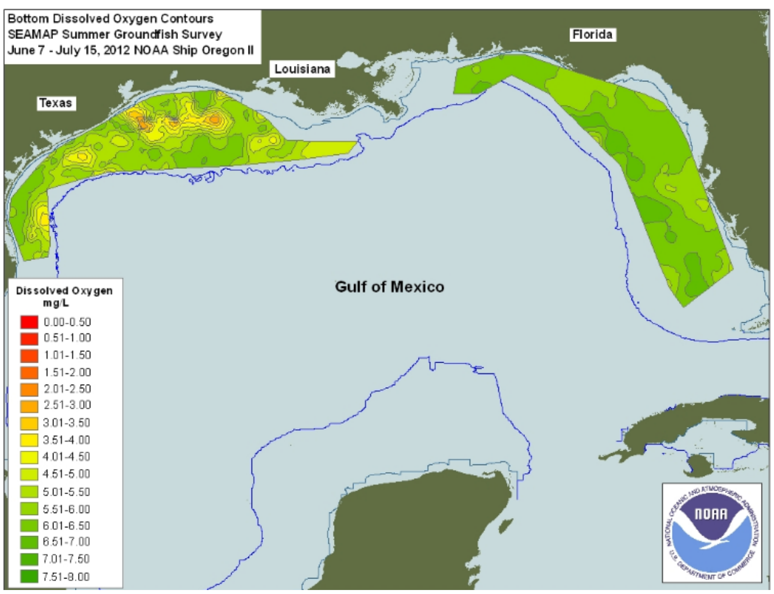

Figure 13. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – July 15, 2012 NOAA Ship Oregon II

Year: 2011

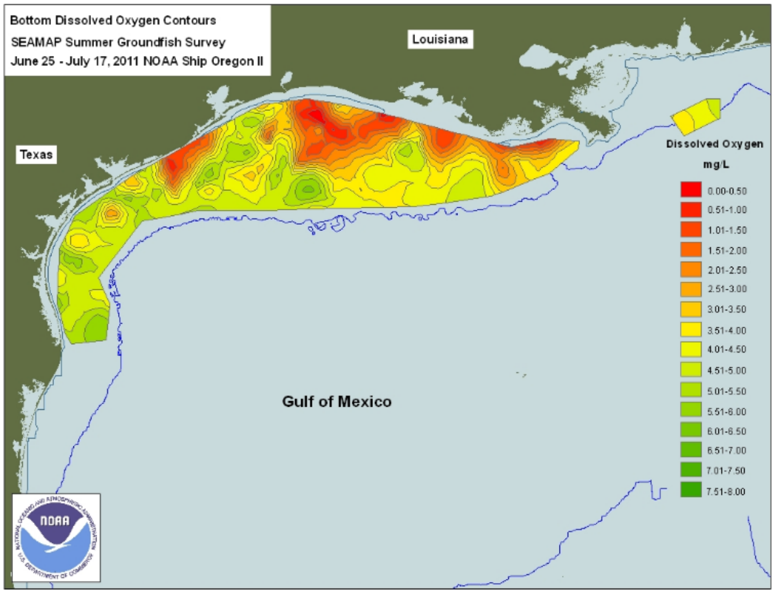

Figure 14. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 25 – July 17, 2011 NOAA Ship Oregon II

Year: 2010

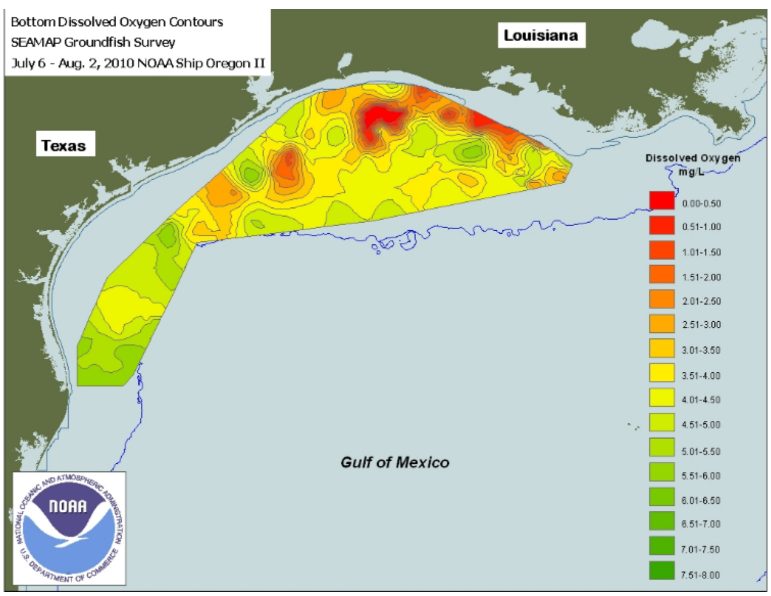

Figure 15. Bottom Dissolved Oxygen Contours SEAMAP Groundfish Survey July 6 – Aug 2, 2010 NOAA Ship Oregon II

Year: 2009

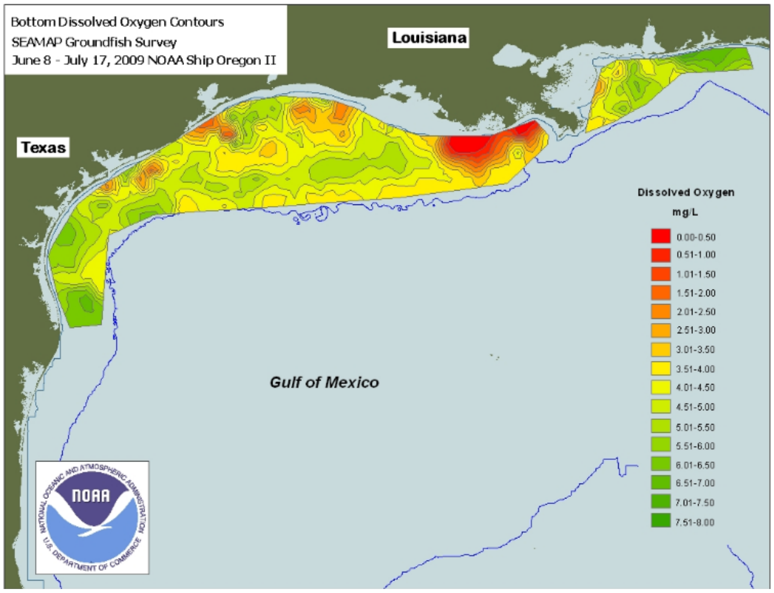

Figure 16. Bottom Dissolved Oxygen Contours SEAMAP Groundfish Survey June 8 – July 17, 2009 NOAA Ship Oregon II

Year: 2008

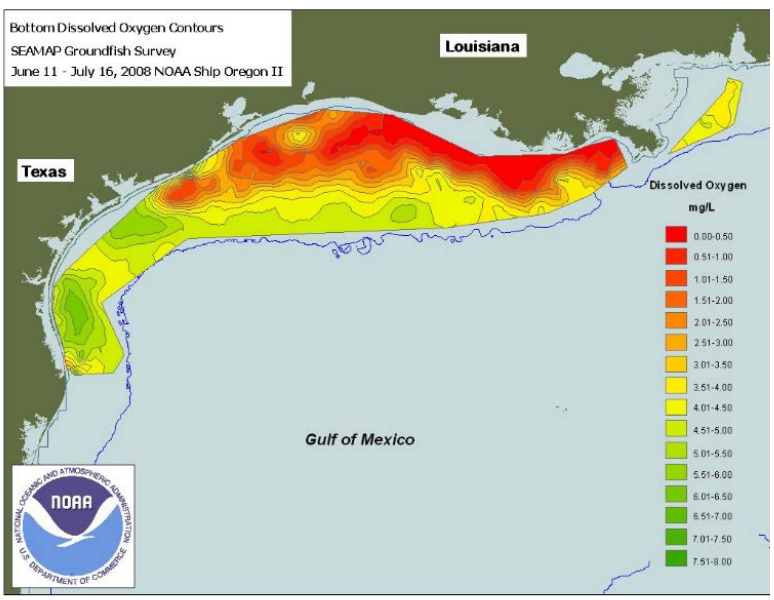

Figure 17. Bottom Dissolved Oxygen Contours SEAMAP Groundfish Survey June 11, July 16, 2008 NOAA Ship Oregon II

Year: 2007

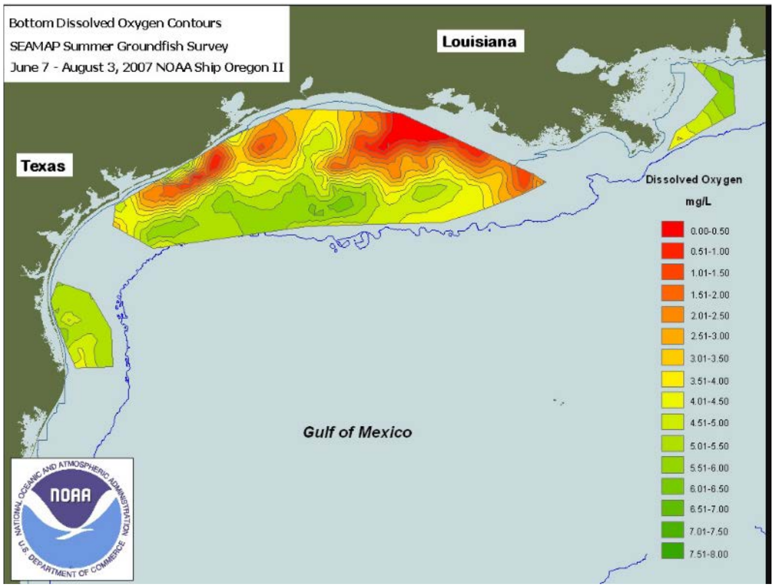

Figure 18. Bottom Dissolved Oxygen Contours SEAMAP Summer Groundfish Survey June 7 – August 3, 2007 NOAA Ship Oregon II

Example of sampling locations - 2016

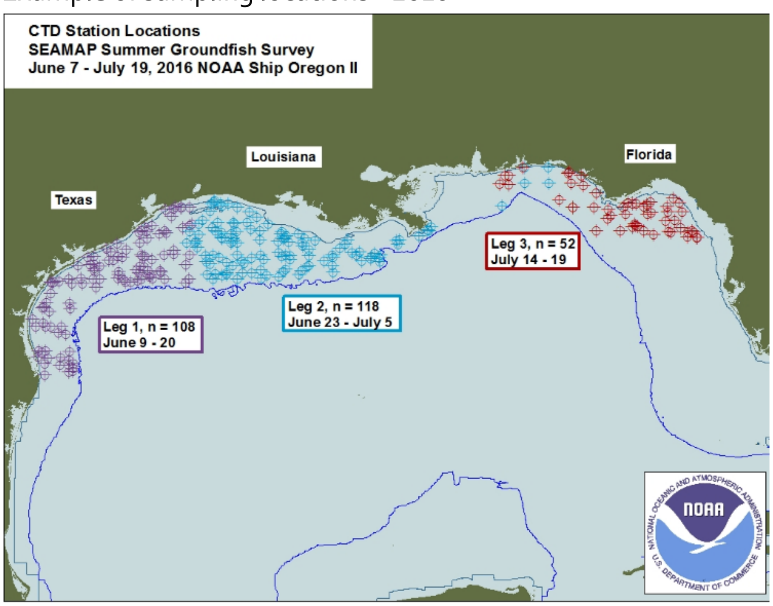

Figure 19. CTD Station Locations SEAMAP Summer Groundfish Survey June 7 – July 19, 2016 NOAA Ship Oregon II

A. Example of data layers evaluated in the study – artificial reefs, submerged points of interest, sea turtle habitat and migration pathways, and TPWD Coastal Fisheries Resource Monitoring Program footprint. An AGO online map viewer was developed to support this study and is available for use by staff participating in the development and review of the information. Please send requests for access to Lynne.Hamlin@tpwd.texas.gov and include "request for access to AGO desal viewer" in the subject line.

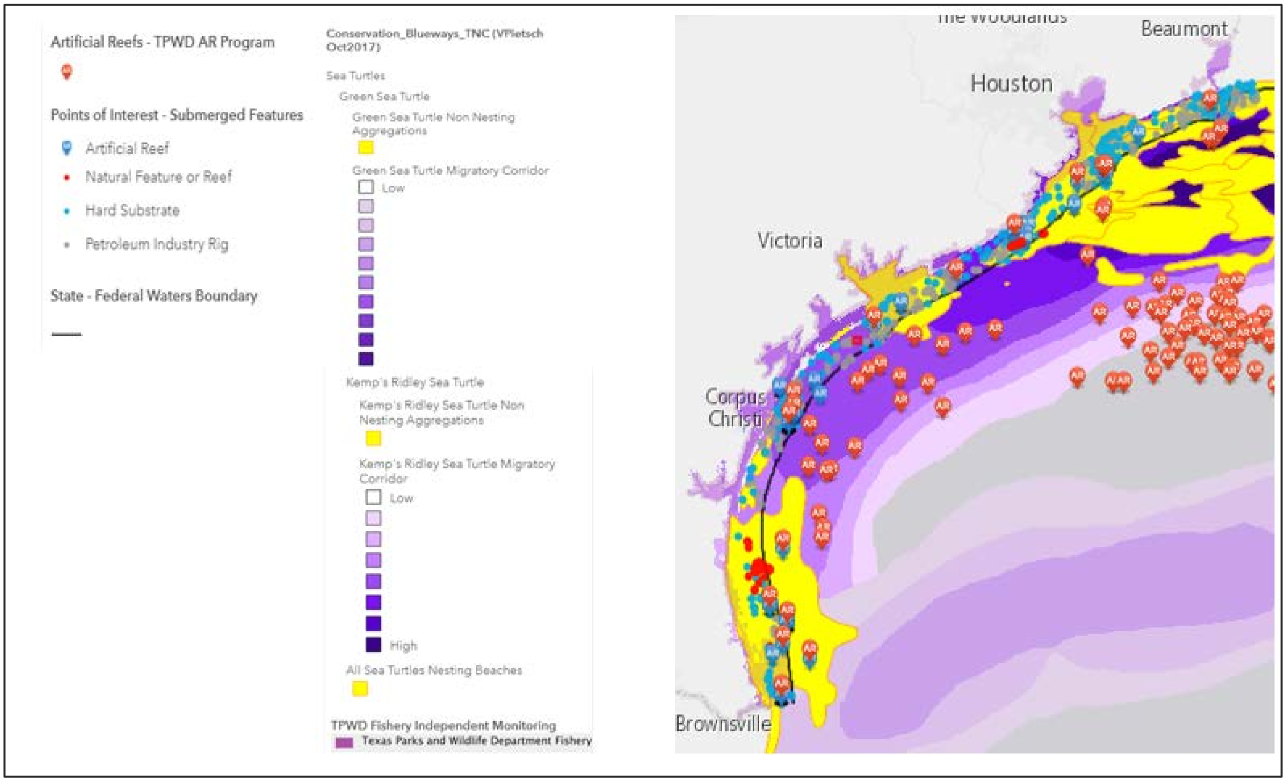

Figure 20. Example of data layers evaluated in the study – artificial reefs, submerged points of interest, sea turtle habitat and migration pathways, and TPWD Coastal Fisheries Resource Monitoring Program footprint. An AGO online map viewer was developed to support this study and is available for use by staff participating in the development and review of the information. Please send requests for access to Lynne.Hamlin@tpwd.texas.gov and include "request for access to AGO desal viewer" in the subject line.

B. Map of zones for the upper coast

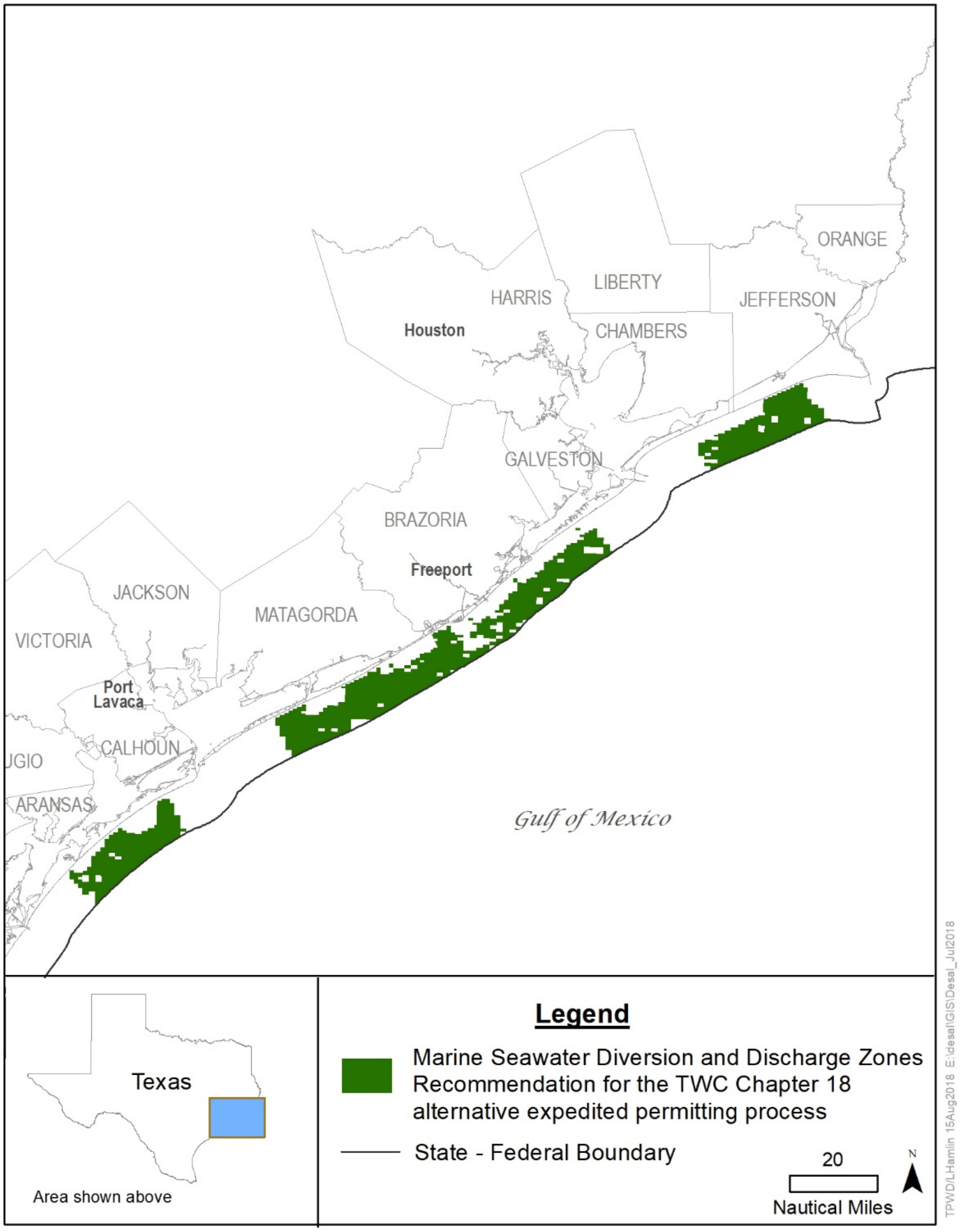

Figure 21. Map of zones for the upper coast. The green polygons represent marine seawater diversion and discharge zones recommendation for the TWC Chapter 18 alternative expedited process.

C. Map of zones for the middle and lower coast

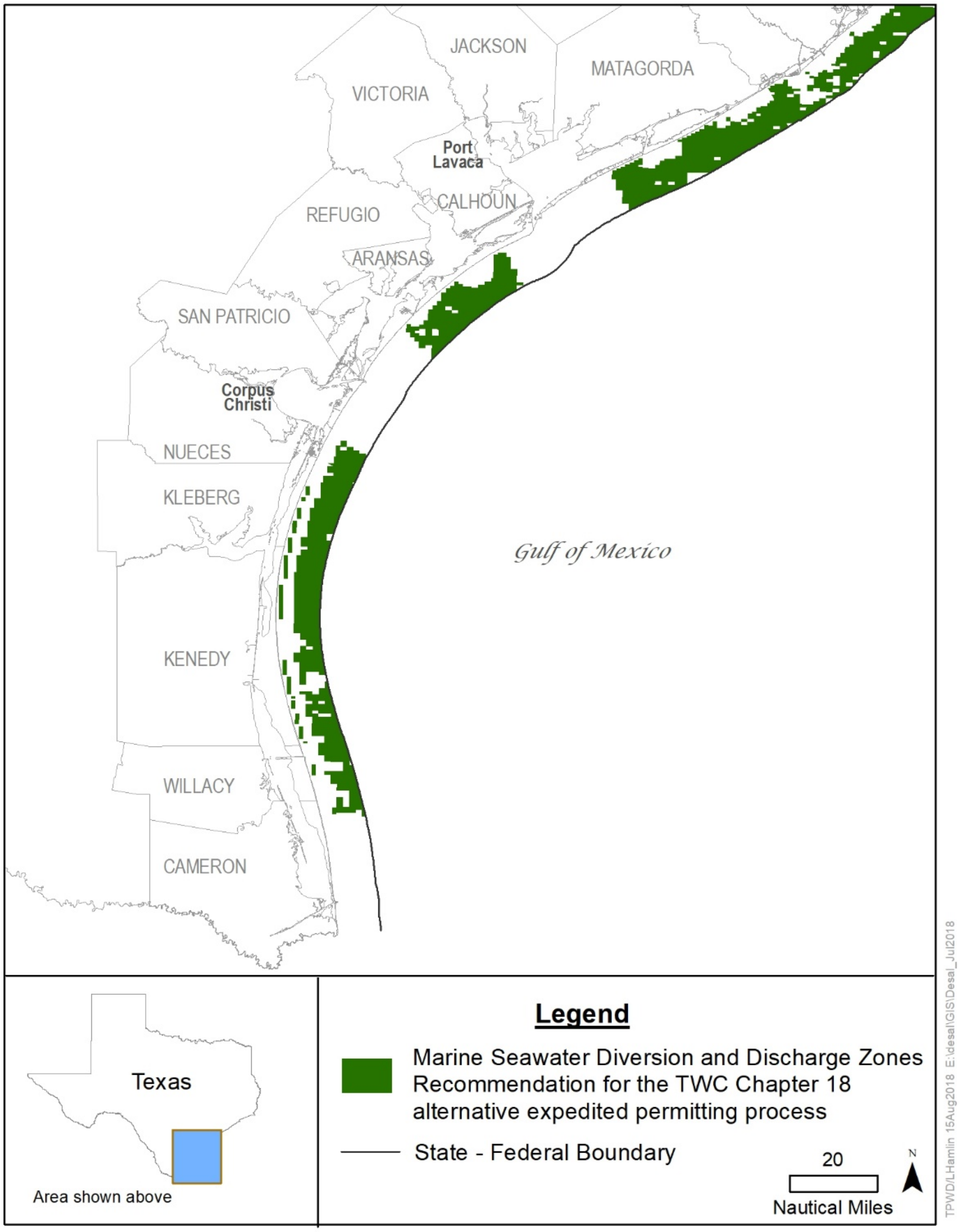

Figure 22. Map of Zones for the middle and lower coast. The green polygons represent marine seawater diversion and discharge zones recommendation for the TWC chapter 18 alternative expedited permitting process.

Cover photo: Tpwd Artificial Reef Program

PWD RP V3400-2723 (9/18)