7/26/2021

Assessing the Role of Spatial Management Areas and Coral Reef Associated Species Diversity between Selected Sites Across the Gulf of Mexico

White Paper

July 2021

Gulf of Mexico Fishery Management Council

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1.1 Background

The Gulf of Mexico (Gulf) is one of the world's 64 Large Marine Ecosystems (Sherman and Hempel 2009). This ecosystem spans tropical and subtropical climates and is enveloped by the economic exclusive zones (EEZ) of the United States, Mexico, and Cuba. The EEZ of the United States alone supports 63.3 million saltwater recreational fishing trips (NMFS 2018) and a commercial fisheries landing volume totaled 9.6 billion pounds in 2016 (NMFS 2018) .

Spatial management areas are used in the form of Marine Protected Areas (MPA) or habitat areas of particular concern (HAPC) as a strategy to conserve biodiversity in areas vulnerable to climate and anthropogenic stress. In the U.S., MPAs are defined in Executive Order 13158(Order 2000) as “any area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein.” The Gulf is managed by a collection of federal, state, and private organizations that work to understand and protect this large natural area. Each of the individual MPAs throughout the Gulf is classified based on the way they are managed and protected by the organization that manages them. Some examples of protected areas in the Gulf include National Marine Sanctuaries, National Estuarine Research Reserves, National Parks, and National Wildlife Refuges, as well as aquatic preserves and state preserves.

The Gulf accounts for 6% of the total area of MPAs in U.S. waters, including at least 290 MPAs. However, the vast majority of MPAs are multiple use and allow at least some extractive use (i.e., fishing) activities. In the Gulf, only 0.5% of the MPAs are ‘No Take’ (see National MPA Center MPA Inventory website at https://marineprotectedareas.noaa.gov for details). Stand-alone MPAs can be useful for conservation, but often fail to achieve intended objectives when they are not designed as a network of areas. This network of managed protected areas can increase resilience of the ecosystem by accounting for biological and socio-economic implications (McLeod et al. 2009). MPA networks have been used for marine species conservation and are established in many countries to reduce the adverse effect of the expanding human footprint on biodiversity (Gladstone 2007). While no MPA networks exists in the Gulf, it was suggested as a pro-active approach to benefits to conservation and efficient management of the species in the Gulf by reducing their exposure to changing environment (Pinsky et al. 2020). An approach that narrows the focus and scale of conservation and protects those species at the greatest risk of extinction is the classic hotspot analysis (Possingham and Wilson 2005). Hotspots are defined as areas with the greatest numbers of species.

This study summarizes a Gulf-wide review of existing literature, in collaboration with our federal and academic partners, to evaluate the effectiveness of MPAs in the Gulf. We developed species hotspot maps of selected sites and compared them to appropriate control sites to identify locations between and among the selected sites which has the highest species density, richness, and diversity. The objective of this work is also to evaluate existing management practices and prioritize potential locations that might need additional spatial management. An extensive literature review, followed by the compilation of species occurrence information (corals, fish, and invertebrates) from existing surveys was used for this analysis. Differences between species diversity patterns at each site were compared and spatial hotspot analysis was used to evaluate the effectiveness of existing MPAs in the Gulf for protecting coral and coral reef-associated species.

2.1 Methods

2.1.1 Study Area

Sampling sites for the study were selected based on the availability of data from collaborative partner agencies, literature, and long-term monitoring programs. Although many of the selected sites for this study have been known to have existing management and fishery regulation plans (See details on MPA Viewer at NOAA MPA Inventory Database website http://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/mpaviewer/), they also have different topographic features and biological communities.

Data were gathered from both spatially managed areas and areas without specific place-based management measures located in the eastern and western Gulf. Eastern Gulf sites include Madison-Swanson, The Edges, and Steamboat Lumps (Figure 1). Sites and locations without any spatially defined fishing regulations are considered as control sites in this study. The control sites had control locations which were designated areas studied immediately outside of these managed areas (e.g., Twin Ridges). Northwestern Gulf sites include East and West Flower Garden Banks and Stetson Bank (Figure 1). Several sites in South Texas Banks (Figure 1) were also used as control sites (See table 1 for details). Understanding the species (i.e., coral, fishes, and invertebrates) diversity and establishing baseline information about these sites is invaluable for comparison of before and after manmade or natural disasters. It is also a key element to design any effective management plans for these (control) sites or to modify current plans to ensure the protection of habitats and maintaining sustainable fishery stocks for the future.

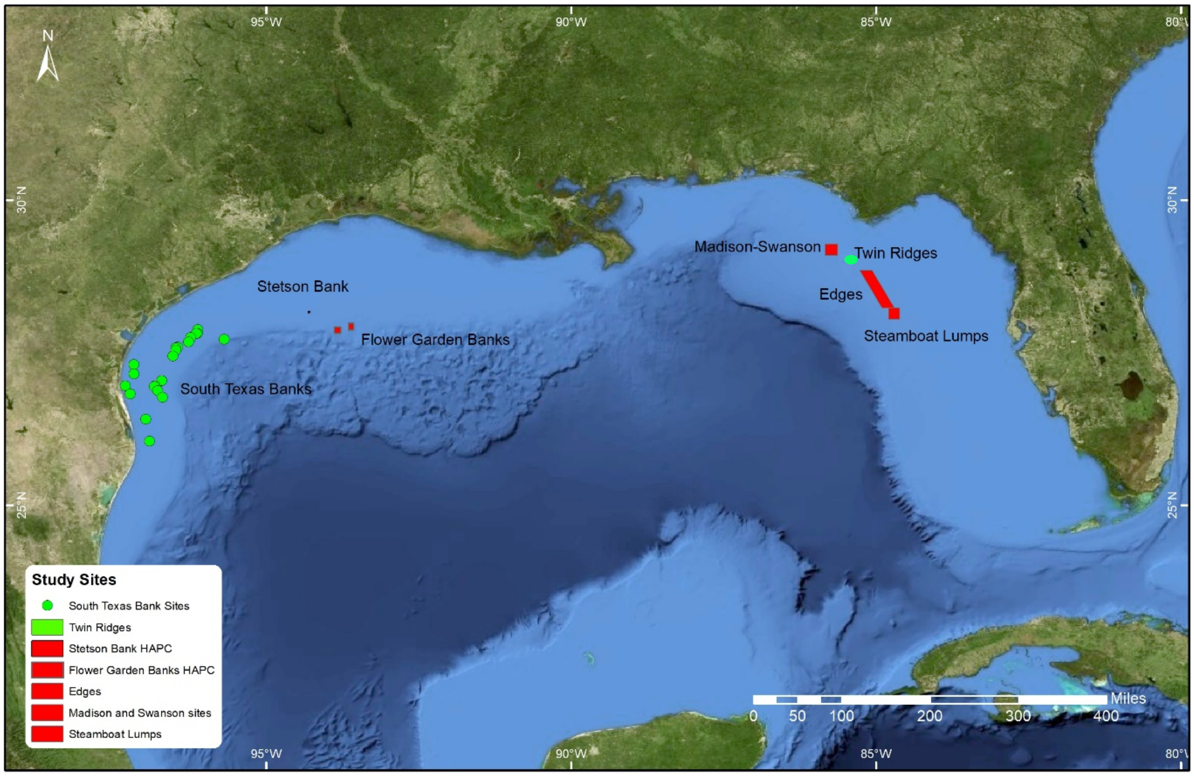


Figure 1. Selected study sites and their locations in the Gulf of Mexico. Green color represent control sites.

2.1.2 Species Observation Data

An extensive literature review was conducted to compile species (i.e., coral, fishes, and invertebrates) occurrence information from partner agencies. Datasets included long term monitoring surveys from 1969 through 2018 for managed (i.e., MPA, HAPC sites which have gear restrictions) and observational data from control areas (i.e., areas without any additional place-based fishing regulations) for the intended analysis (Table 1).

Table 1. Details of selected sites and collated data for the hotspot analysis.

Site Name	Protection Type / Fishing Regulations	Data Range	Species Groups	Data Sources
Stetson Bank	Managed [a]	2012-2018	Corals, Reef Fish	1
Flower Garden Banks	Managed [a]	1985-2018	Corals, Reef Fish, Invertebrates	1,2,3
Steamboat Lumps	Managed [b]	2001-2014	Corals, Reef Fish, Invertebrates	1
The Edges	Managed [c]	2012-2014	Corals, Reef Fish, Invertebrates	1
Madison-Swanson	Managed [b]	2001-2014	Corals, Reef Fish, Invertebrates	1
Twin Ridges*	Not-Managed [d]	2001-2014	Corals, Reef Fish, Invertebrates	1
South Texas Banks*	Not-Managed [d]	1969-2012	Corals, Reef Fish, Invertebrates	4,5,6

* Control Sites; **References:** 1. NOAA, 2. (Bright and Pequegnat 1974), 3. (Rezak et al. 1985), 4. (Tunnell Jr et al. 1978), 5.(Nash et al. 2013), 6. (Streich et al. 2017); **Fishing Regulations:** a. Fishing with bottom longline, bottom trawl, buoy gear, pot, or trap and bottom anchoring by fishing vessels is prohibited year-round and prohibit the possession of Gulf of Mexico reef fish, with no exception for vessels in transit unless the vessel has an operating vessel monitoring system, a valid federal commercial Gulf of Mexico reef fish permit, and fishing gear appropriately stowed.; b. All Fishing throughout the year; c . All Fishing prohibited January – April; d. No prohibition of fishing, only protection of corals (if present)

All collated data were consolidated and synthesized in a uniform database format that is understandable to the public and usable by the Gulf of Mexico Fishery Management Council (Council). With the deliverables from this task, we intend to provide coral and reef associated species richness, diversity, and hotspot maps across selected Gulf sites to evaluate the role current spatial management areas with fishing gear regulation plays in conserving corals and reef fishes.

2.1.3 Hotspot Identification Method

Several metrics were used to identify hotspots in the Gulf. Marine Geospatial Ecology Toolbox 0.8a73 (Roberts et al. 2010) in ESRI ArcGIS 10.8.1 software was used to calculate species richness and diversity metrics for this analysis. First, density maps were visualized using kernel density estimates on the raw data. Second, species richness was calculated for a 5 km by 5 km gulf wide grid by counting the total number of species present in each of the grids. This grid size was selected based on the availability of existing data in the same grid scale. Lastly, Shannon's index was calculated in the same grid cells to identify the variation of community composition in selected sites, and finally, where detailed species count data was available, cluster (hotspots) sites were calculated that host the greatest number of species. Differences between species richness and diversity patterns at each site were compared and overlaid with the hotspot data (when available) to evaluate the effectiveness of existing MPAs in the Gulf for protecting coral and other reef-associated species.

2.1.3.1 Species Density

Species density heatmaps visualize the observed density of various species from the raw sampling locations. Each visualized cell has a value that represents the relative density (i.e., count of individual points representing a species for each site), that was calculated using the Kernel density estimate (KDE) method. KDE takes known quantities of some phenomena (e.g. species occurrences) and creates a continuous surface showing the predicted distribution of the population throughout the landscape is an established method of hotspot mapping. First, a circular search area is applied to each cell in the output raster. The search area determines the distance to search for points to calculate a density value. The density around each raster cell is calculated based on a quadratic kernel function (Silverman 1986). Conceptually, a smooth curved surface is fitted over each point extending out to the defined search radius. The resulting surface is based on the quantity of points measured at each location and the spatial relationship of the locations. Example application of KDE includes hotspot identification for observational data such as insect infestation (Nelson and Boots 2005), wildlife-vehicle collisions (Ramp et al. 2006), mapping biodiversity hotspots (Schofield et al. 2010; Lyon et al. 2011), and crime reports (Chainey et al. 2008).

2.1.3.2 Species Richness

Species richness represents a measure of the variety of species based simply on a count of the number of species in a particular sample (Colwell 2009), although it can be expressed more usefully as species richness pre-unit area, ranging from alpha (referring to a certain site) to gamma (for an entire study area) level. Species richness is generally abbreviated as S in the literature and is the simplest measure of diversity. Species richness is simply a count of species, and it does not consider the abundances of the species or their relative abundance distributions. Species richness for each sampling sites were calculated in 5 km x 5 km grid cells.

2.1.3.3 Species Diversity

A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than species richness. Diversity indices also consider the relative abundances of different species into account along with species richness. Diversity indices provide important information about the rarity and commonness of species in a community. The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure. Shannon-Weaver's diversity index was used to measure the diversity of sites across the Gulf. Shannon (H′)—the Shannon (or Shannon–Weaver) index considers both the number of unique species and their relative abundances within a sample (Shannon et al. 1949). Larger values reflect communities with greater species richness and evenness, while lower numbers reflect communities with fewer species and/or a very uneven distribution among them (e.g., one species may account for a very large percentage of the community). Shannon's index for each sampling site were calculated in 5 km x 5 km grid cells.

2.1.3.4 Species Hotspots

When total count data are available, species hotspot analysis can be used to identify statistically significant spatial clusters of locations with high values (hotspots) and low values (cold spots) using Getis-Ord GI* statistic (Getis and Ord 1992). It produces Z scores and P-values. The resultant Z-scores and P-values tell you where features with either high or low values cluster spatially. A high Z-score and small P-value for a particular site indicate a significant hotspot. A low negative Z-score and small P-value indicate a significant cold spot. The higher (or lower) the Z score, the more intense the clustering would be. A Z-score near zero indicates no evidence of spatial clustering.

Most of the compiled observation data for this study are presence/absence. Species hotspot analysis tools used for this analysis needs data with total number of individuals recorded in each location. Due to such limitation of species count data, the analysis was performed in areas where we have detailed species count data available (Stetson Bank and North East Gulf sites).

3.1 Results

3.1.1 Gulf Coral and Associated Species Database

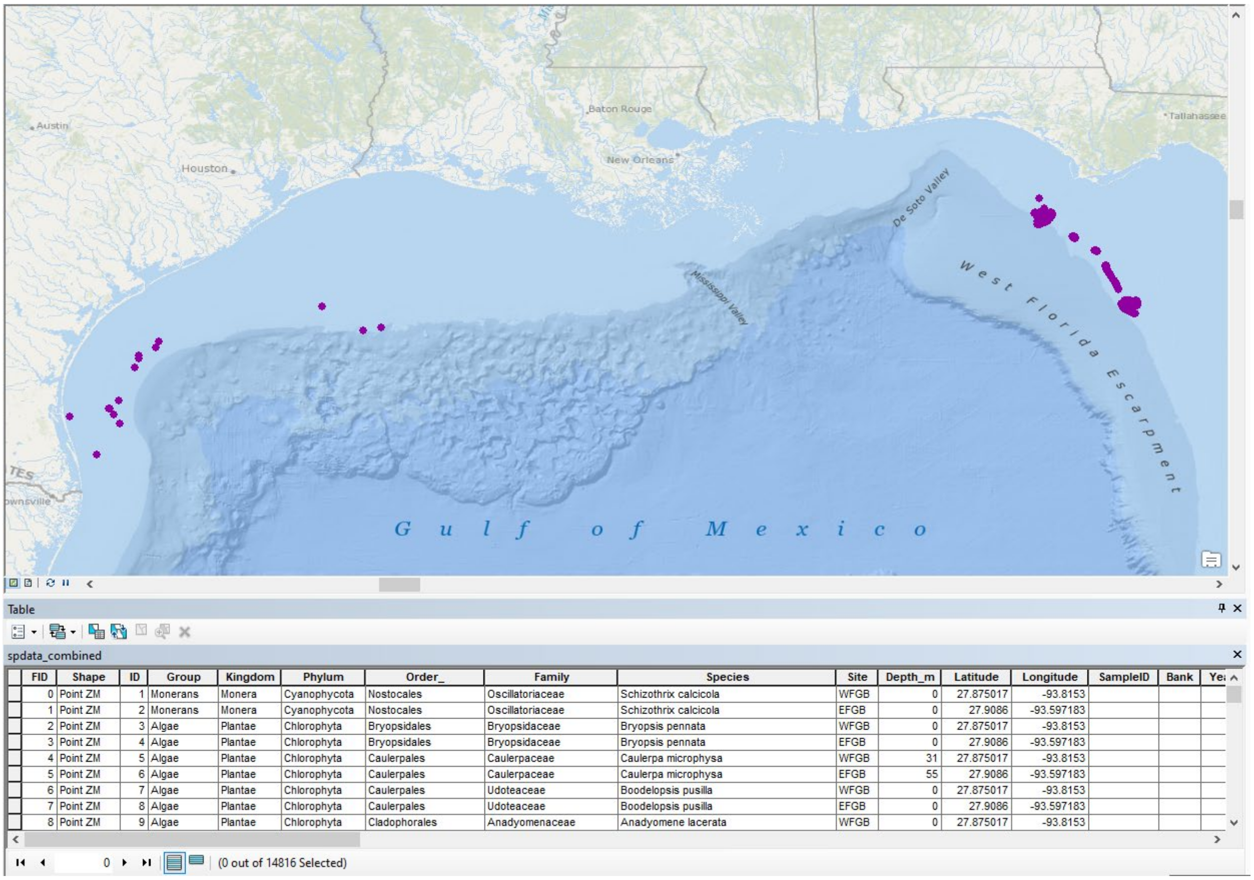
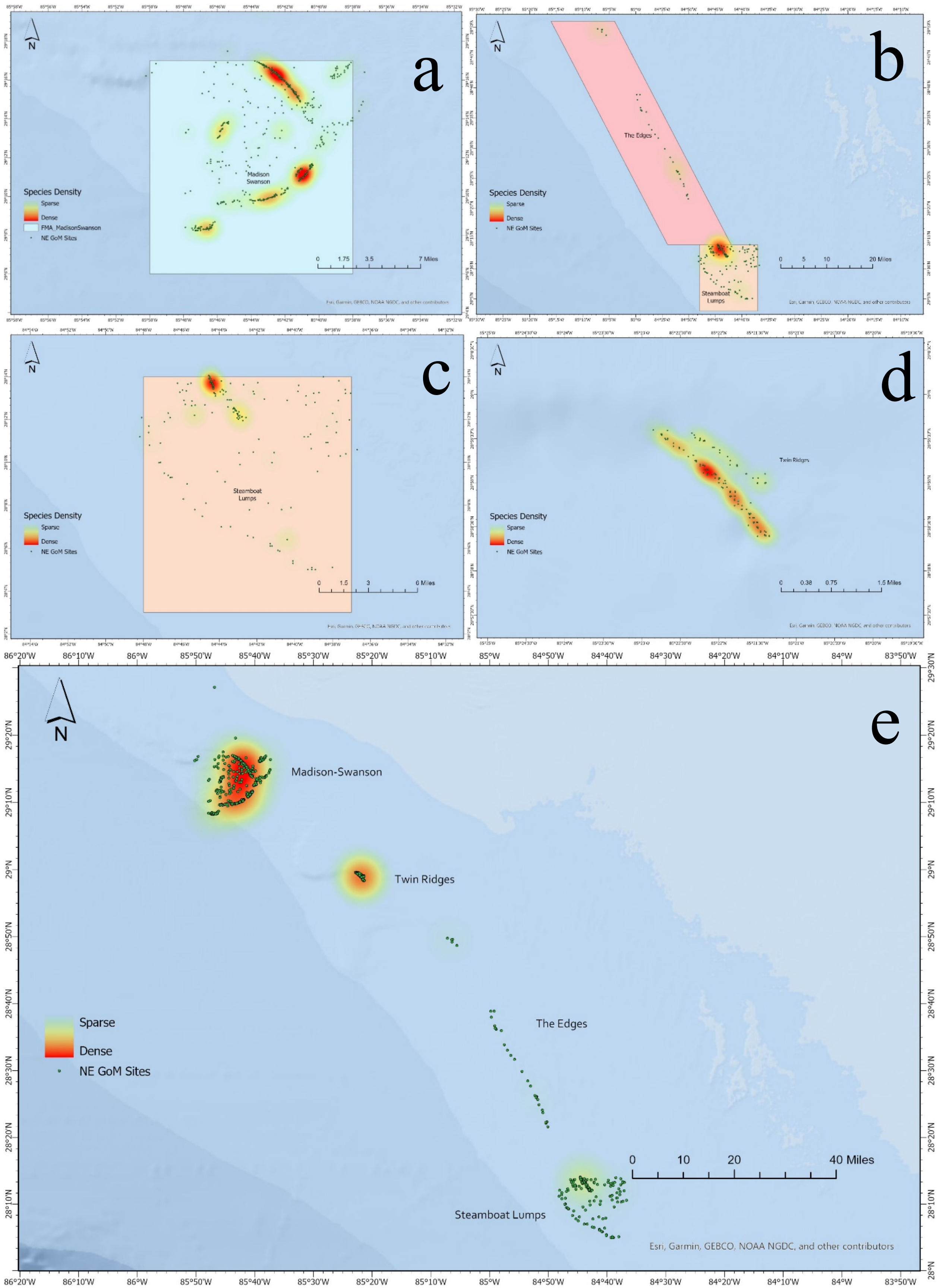


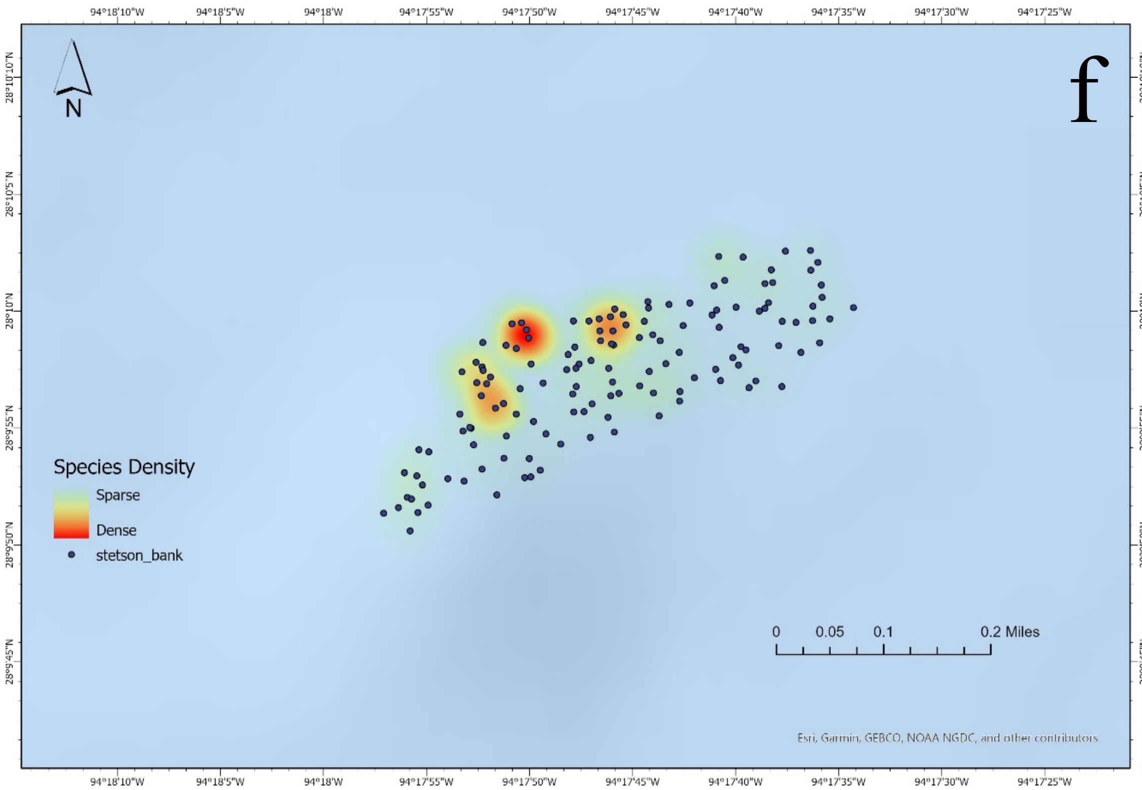
Figure 2. Combined species observation data with the database fields. Dots in the map represent sampling locations where one or more species data were compiled from various sources.

The compiled dataset combined spatially-limited species observation data (n=14,816) where at least one or more species were observed (Figure 1). The dataset is published in the Portal as a visual layer with the interactive web app that summarized the results from this paper and is accessible at https://portal.gulfcouncil.ogrg/spdiv20/. A full database will be available upon request.

3.1.2 Species Density

Among the MPAs, Madison-Swanson and Flower Garden Banks had the highest number of species observed among the samples. Among the control sites, South Texas banks and Twin Ridges had the highest numbers of species (Figure 3).


a
Madison Swanson
Species Density
Sparse
Dense
FMA_MadisonSwanson
NE GoM Sites
b
The Edges
Steamboat Lumps
c
d
Twin Ridges
e
Madison-Swanson
Twin Ridges
The Edges
Steamboat Lumps
0 10 20 40 Miles
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors



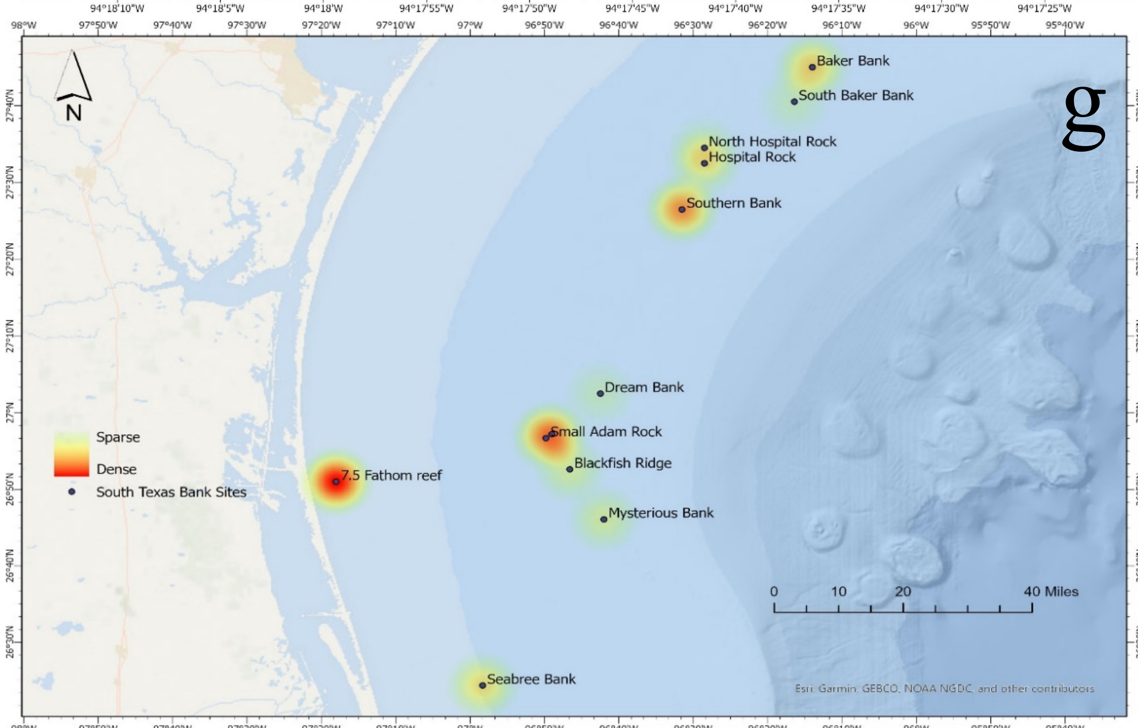


Figure 3. Heatmaps of selected sampled locations in different sites where total number of species observed is highest to lowest (sparse=low cluster, dense=high cluster of total number of species) at sites of a) Madison-Swanson, b) the Edges, c) Steamboat Lumps, d) Twin Ridges, e) all north eastern sites together, f) Stetson Bank, and g) South Texas Bank. Dots on the map represent sampled locations.

3.1.3 Species Richness

Among the MPA sites species richness was high at individual sites located at Madison-Swanson and Steamboat Lumps and highest at Stetson Bank, Flower Garden Banks sites. Madison-Swanson has more locations with high species richness than Edges, and Steamboat Lumps. Among the control sites, Twin Ridges had high and several South Texas Bank sites (i.e., Southern Bank, Hospital rock, 7.5 Fathom reef) had highest richness among all the sites in Gulf (Figure 4).

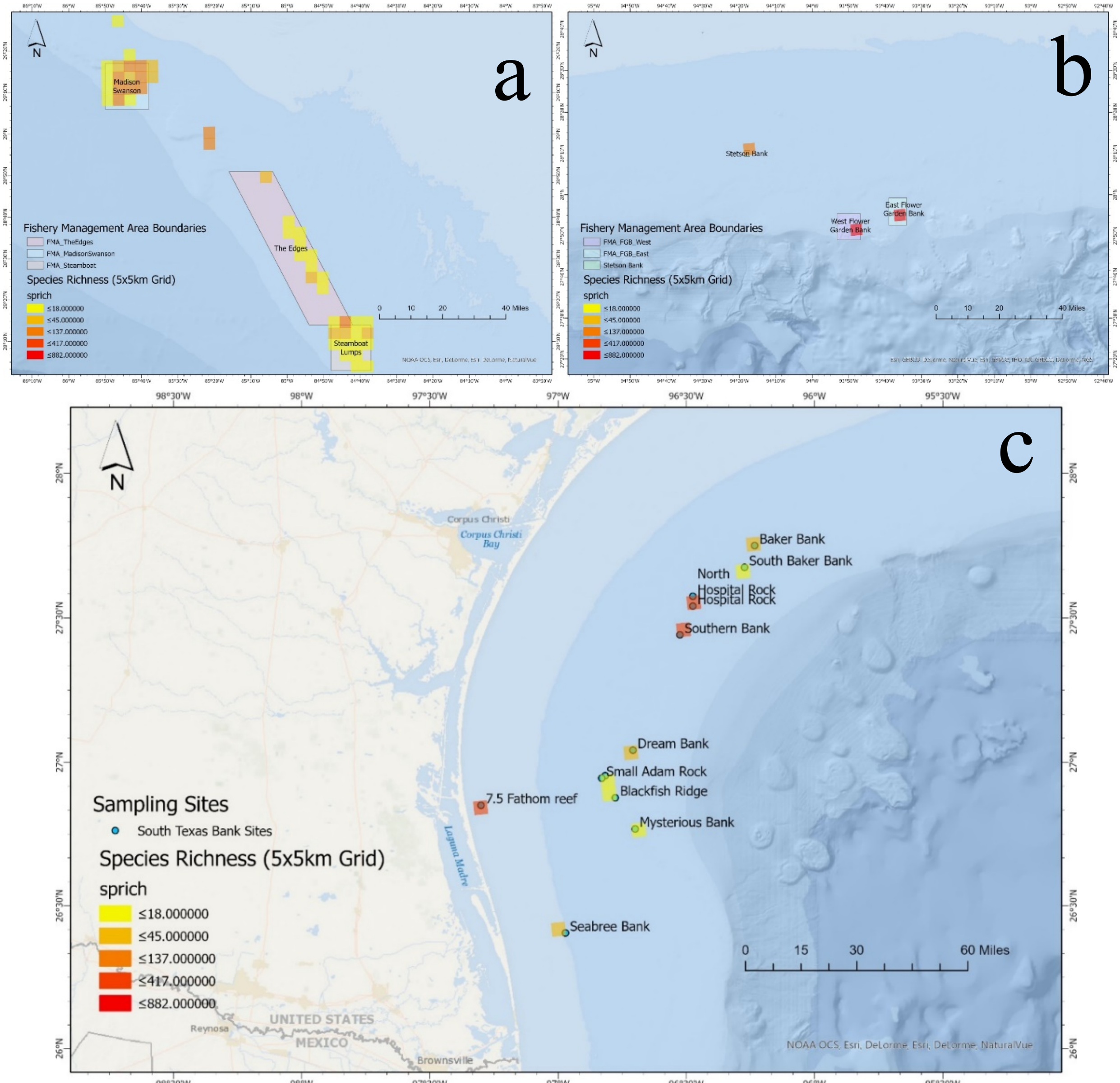


Figure 4. Species Richness maps showing the density of unique species present in 5 km x 5km grid cell for each of the sampling locations (red = more unique species present, yellow= few unique species present) at sites of a) Madison-Swanson, Twin Ridges, the Edges, Steamboat Lumps, b) Stetson Bank and Flower Garden Banks, c) all South Texas Bank sites. Dots on the map represent sampled locations.

3.1.4 Species Diversity

Similar to species richness, species diversity was also higher (Shannon's index H′ 3-4) at MPA locations inside Madison-Swanson, Steamboat Lumps, Stetson Bank, and some sites located at the Edges. Madison-Swanson has more locations with high species diversity than Edges, and Steamboat Lumps. However, Flower Garden Banks has the highest diversity (H′ > 6). Among the control sites, Twin Ridges had the higher (H′ >3), and many of the South Texas Banks sites had sites that host a diverse group of species (has the highest species diversity; H′ > 4+) among the Gulf sites (Figure 5).

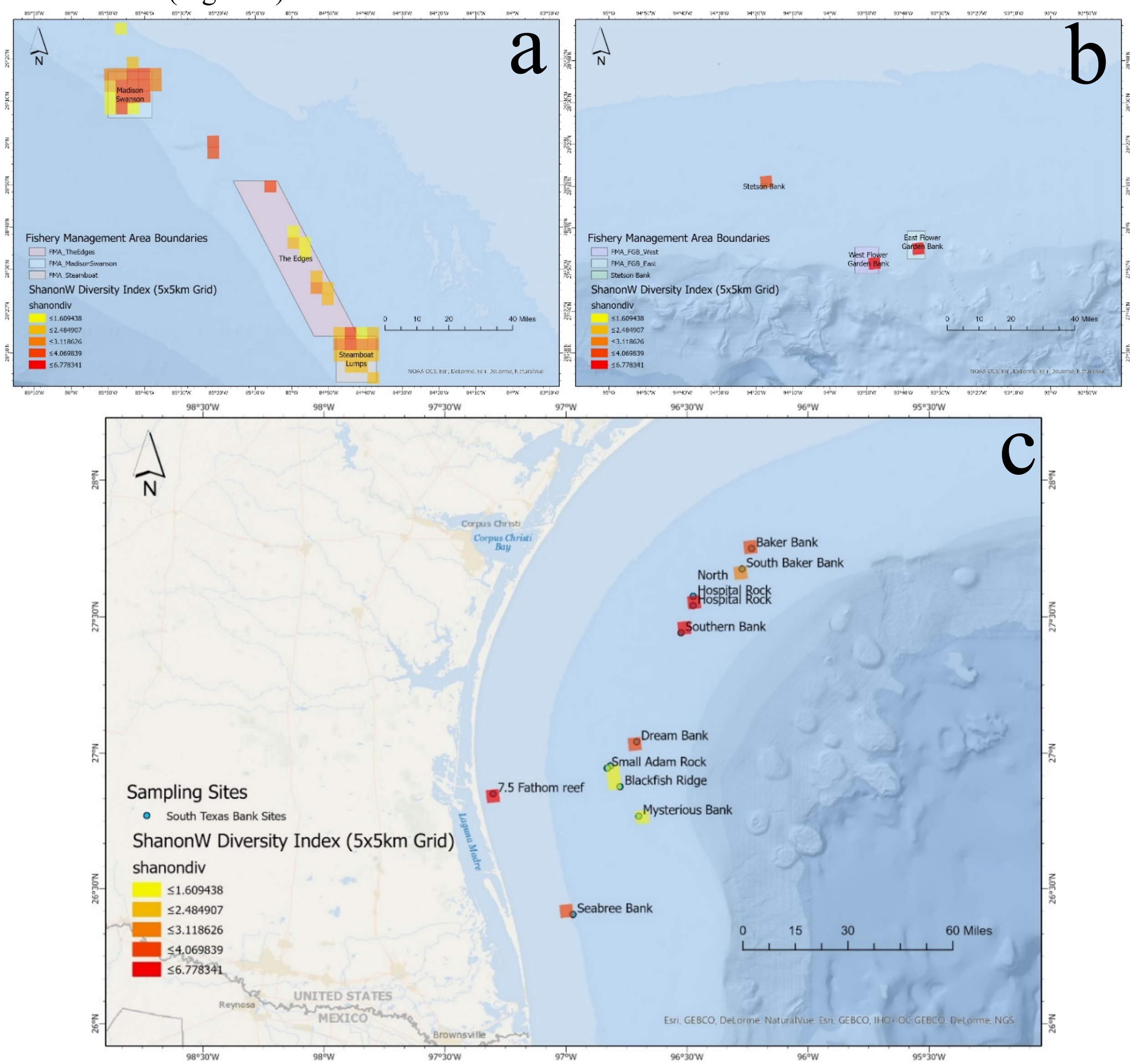


Figure 5. Shannon-Weaver Diversity Index maps showing the community composition in 5 km x 5 km grid cell for each of the sampling locations (red = community is composed of more diverse group of species, yellow = community is composed of few unique species) at sites of a) Madison-Swanson, Twin Ridges, the Edges, Steamboat Lumps, b) Stetson Bank and Flower Garden Banks, c) all South Texas Bank sites. Dots on the map represent sampled locations.

3.1.5 Species Hotspots

The tool was able to identify individual hotspot locations inside Madison-Swanson, Steamboat Lumps, The Edges, and Stetson Bank sites where the majority of the species were present among collated sampling records (Red dots in Figure 6).

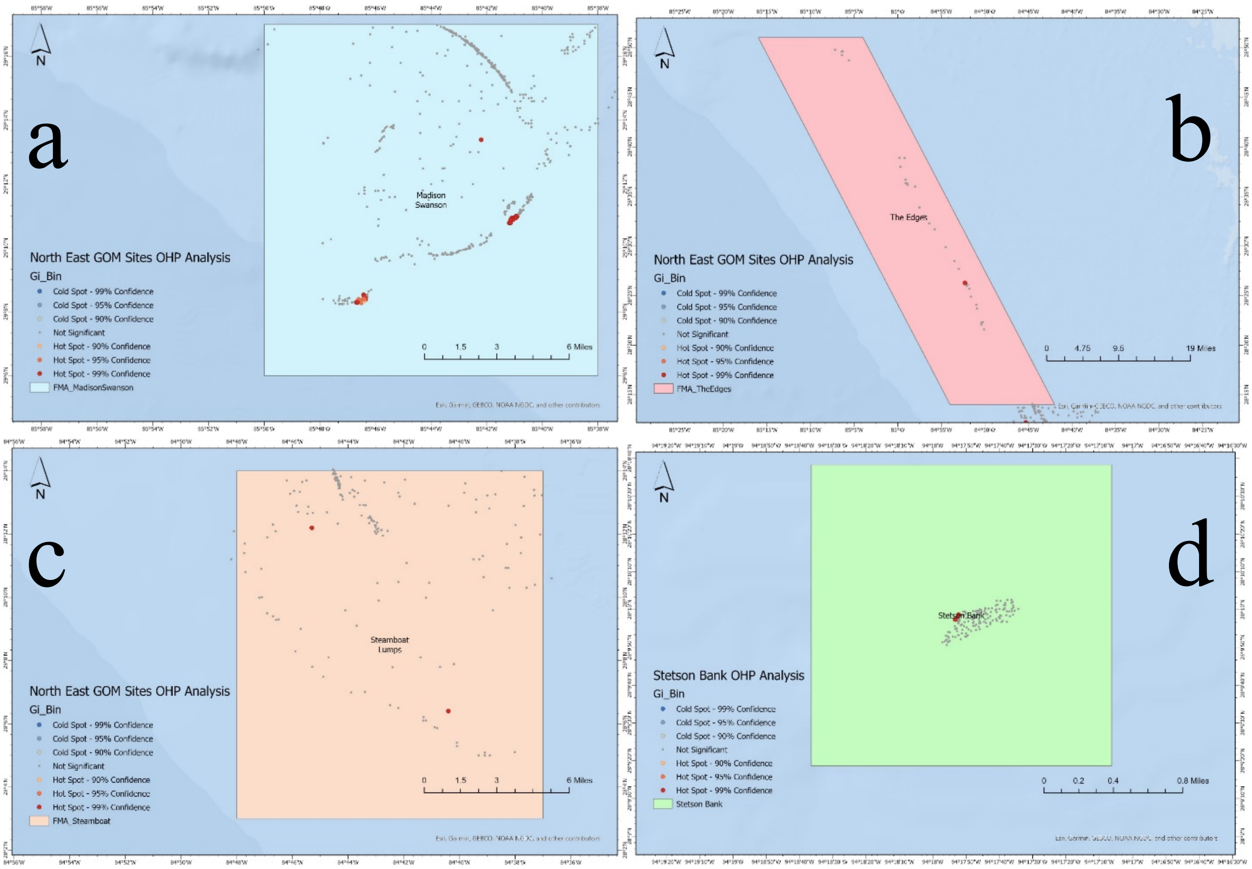


Figure 6. Maps showing hotspot locations with statistically significant spatial clusters of high/low biodiversity (red dots) among the selected sampling locations of a) Madison-Swanson, b) Edges, c) Steamboat Lumps, and d) Stetson Bank based on hotspot analysis. Dots on the map represent sampled locations.

4.1 Discussion

Prior to this analysis, there were no previous studies that had compared the role of spatial management in species diversity and richness in the Gulf. Species richness, species diversity, and hotspot analyses in the Gulf in the past are either focused on individual species or broader functional species groups. Some of these studies include community composition and diversity work on copepods (Baguley et al. 2006), isopods (Wilson 2008), decapod crustaceans (Wicksten and Packard 2005; Escobar-Briones et al. 2008), sea turtle (Hart et al. 2018), bony shore fishes (Linardich et al. 2019), pelagic fishes (Rooker et al. 2013), corals (Farrell et al. 1983; Cordes et al. 2008; Green et al. 2014), and reef fishes (Brizzolara et al. 2020). While this study focused on all available observation data that included corals, fishes and invertebrates, this makes the direct comparison of the results difficult. But this study addressed a need of a comprehensive analysis to understand the broader context of how effectively present spatial management and regulations provide protection to species inside the management areas. The study also identified multi-species hotspots inside and outside the management boundaries, rather than single species hotspots that were identified across the Gulf from past studies.

Numerous agencies in the Gulf are involved in monitoring and data collection from selected sites, but they often have limited opportunity to conduct broad-scale analysis. This needs collaboration with other agencies to collate data from existing long-term monitoring surveys conducted by researchers and agencies in selected sites. Together with the federal, state, and university partners, the Council occasionally assesses commercially and ecologically important species richness and diversity as part of developing various management regulations (e.g., Coral 9 for development of new HAPC areas). There is an ongoing effort by the Council to better understand and document species diversity in areas that may warrant protection or HAPC status in the future, as this provides the rationale for management actions. This analysis is one of the first attempts to utilize available observation data to produce spatially delineable products to assess the role of spatial management and their relation to species diversity in the Gulf.

Among the MPA sites Madison-Swanson, Edges, Steamboat Lumps, Stetson Bank has multiple locations which showed higher species richness, diversity and hotspots. Madison-Swanson has the greatest number of sites with high species richness and diversity compared to other sites. However, both Flower Garden Bank sites (East and West) has limited number of sampling locations and they ranked highest in major metrices (species density and diversity). Overall, results from the species richness, diversity, and hotspot analyses indicate that among the managed sites, Madison-Swanson, Edges, Steamboat Lumps, Flower Garden Banks, and Stetson Bank sites existing management boundaries provide additional protection for a variety of species found in these locations. This result agrees with the most recent finding from Brizzolara et al. (2020), who compared species composition and diversity among two MPA sites and found Madison-Swanson has higher fish richness and diversity compared to Steamboat Lumps. Among the control sites, Twin Ridges and the South Texas Bank, results suggest several areas (marked as light to a deep red rectangle in the Figures 4, 5) contain high species richness and diversity. To ensure the long-term sustainability of the Gulf fishery, future effort should focus on identifying the individual species and environmental features responsible for causing aggregation of species in these hotspots and refine locations based on these analyses to designate areas which might benefit from additional protection. These may also be appropriate for consideration of implementing management measures that could help preserve the current level of species diversity (see Figure 7).

It is expected spatial products and documents produced from this analysis will assist agencies and the Council in future discussions of planning spatial management for Coral and other reef associated species. Areas identified as species hotspots in this analysis may be considered by the Council for new HAPCs in the Gulf and be added as MPAs on the registry of marine protected areas which ensures sustainability of existing fishery stocks through protection of recruitment and nursery sites inside the HAPCs.

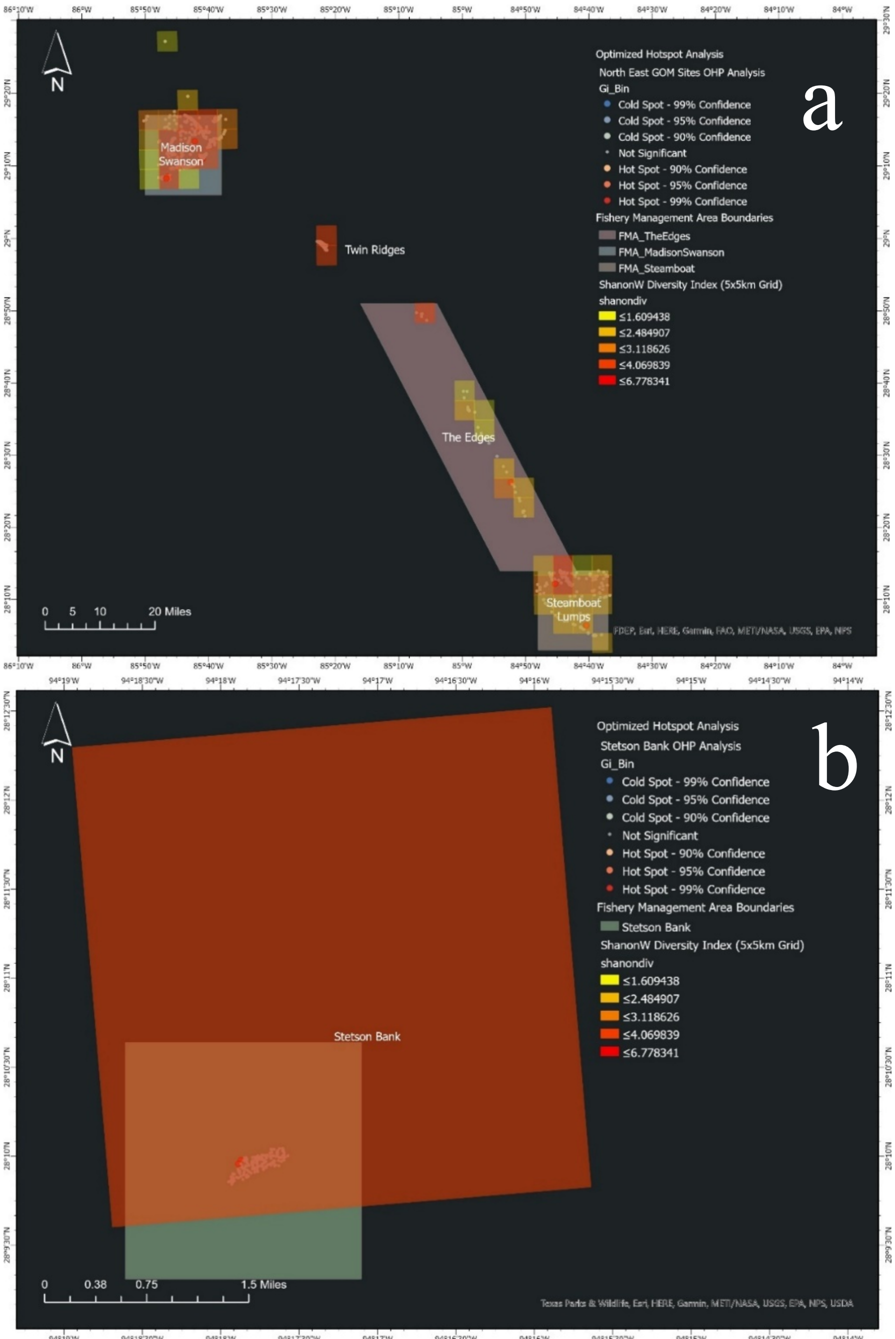


Figure 7. Combined species hotspot maps showing a) North East Gulf sites and b) Stetson Bank to highlight the effectiveness of management areas in protecting individual sites with high species diversity and richness (Red dots and orange to red rectangles).

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