

Geospatial Resources for the Deployment of New Artificial Reef
Materials in North Carolina

By

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EXECUTIVE SUMMARY

This project was conducted in partnership with the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) to help meet the geospatial needs of the North Carolina Division of Marine Fisheries (NCDMF). Specifically, the NCDMF seeks to explore data gaps surrounding ecological connectivity and fish use of existing and future artificial reef material placement in North Carolina. In doing so, the NCDMF hopes to maximize benefits to stakeholders through ecosystem-based management decisions. To support the overall goal of my client, my project aimed to achieve the following objectives: (1) To provide the ecological, biophysical, and regulatory geospatial data resources necessary to inform decisions surrounding the deployment of new artificial reef materials; (2) To recommend how best to use the selected geospatial data resources in future management decisions; and (3) To visually present geospatial scientific data in a way that is accessible and easy to understand.

The North Carolina Division of Marine Fisheries is responsible for the management of sixty-eight artificial reefs throughout the state's coastal waters. For the purpose of this study, I focused on the forty-three offshore artificial reefs spanning the entirety of the North Carolina coast. Presently, the NCDMF maintains and utilizes an artificial reef geodatabase containing details on permitted reef location, deployment information, and material specifications to inform management decisions. Here, I provide geospatial data resources—extending beyond the permitted artificial reef boundaries to, in some cases, include all coastal waters of North Carolina—to supplement the existing artificial reef geodatabase used by the NCDMF. The selected ecological, biophysical, and regulatory datasets are contained within six geodatabases: Artificial Reef Locations, US Maritime Limits & Boundaries, Reef Habitat, Habitat Distribution & Connectivity, Physical Oceanography, and Fish Communities. All geospatial resources are provided in NAD 1983 StatePlane North Carolina FIPS 3200 Feet, as requested by the client.

In addition to the geodatabases, this report provides the NCDMF with suggested uses for each of the twenty-one data layers provided. This includes recommendations for: (1) use at a regional scale to inform site selection decisions for the permitting of new artificial reefs and (2) use at the level of individual artificial reefs to inform the deployment of new artificial reef materials. Further, I have provided additional recommendations to the NCDMF to improve upon the North Carolina Artificial Reef Program, which are as follows: (1) To more formally engage stakeholders in artificial reef management decisions; (2) To increase data collection and monitoring efforts; and (3) To create a criteria ranking system and decision support tool for future management decisions.

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INTRODUCTION

Artificial Reefs

Artificial reefs are increasingly installed across the seascape to both restore and enhance natural reef habitats. Broadly defined, artificial reefs are human-made structures intentionally deployed on the seafloor as part of a state-managed artificial reef program (USACE, 2022; Steward et al., 2022; Paxton et al., 2020). These reefs often attempt to replicate the functionality of natural reefs (Layman et al., 2016), including enhancing and protecting marine resources (Paxton et al., 2020). As such, unintentionally sunk materials, such as shipwrecks, and unmanaged reefs, such as offshore energy infrastructure, are not formally classified as artificial reefs (Steward et al., 2022; Lemoine et al., 2019).

Historically, disposable items, such as tires, were deployed by fishers to create benthic habitat and encourage the aggregation of fish assemblages (Paxton et al., 2020; Lemoine et al., 2019). The absence of durability in these items led to the development of stricter criteria on types of materials allowed for present day artificial reefs. These include criteria on functionality, durability, stability, and compatibility of materials (NCDMF, n.d.), with additional consideration for the financial cost of deployment (Lemoine et al., 2019). In North Carolina, about 50% of the materials used in artificial reef construction are materials of opportunity, or items that are donated to the North Carolina Division of Marine Fisheries (NCDMF) with the intention of repurposing them for permitted projects. These materials of opportunity include secondary-use concrete that might have previously been used in construction but is now being replaced or was found to be faulty by the manufacturer. Obtained materials are inventoried, classified by size and weight, and staged at yards throughout coastal North Carolina until they are needed for a project. The remaining 50% of materials used in North Carolina are distributed between decommissioned vessels, designed modules (e.g., Reef Balls), and other miscellaneous items.

With intentionality being the main requirement of what constitutes an artificial reef, there are a variety of reasons state managers decide to deploy these materials. For example, artificial reefs might be deployed to mitigate habitat loss, prevent destructive extraction practices (e.g., trawling), or restore degraded seafloor habitat (Becker et al., 2017; Paxton et al., 2020; Steward et al., 2022). In North Carolina, the primary purpose for artificial reef deployment is to provide recreational opportunities for fishing and diving (NCDMF, n.d.; Paxton et al., 2022). In addition to socioeconomic considerations, the secondary purpose of artificial reef deployment in North Carolina is to enhance benthic habitat (NCDMF, n.d.; Paxton et al., 2022), through increased structural complexity and habitat connectivity (Paxton et al., 2022; Steward et al., 2022).

Often, these secondary ecological considerations further augment the primary socioeconomic benefits of artificial reef deployment. The introduction of materials to the seafloor initiates bottom-up processes in which the recruitment of marine organisms at the base of the food web supports the expansion of higher trophic levels (Comer & Love-Adrick, 2016; Layman et al., 2016).

Specifically, the structural complexity of artificial reef materials provides a surface for encrusting marine invertebrates to recruit to, thus increasing resource availability for small fishes and secondary consumers (Comer & Love-Adrick, 2016; Layman et al., 2016). Further, a study by Paxton et al. found fish metrics—density, biomass, richness, and diversity—to be similar between natural and artificial reefs (2020). Thus, secondary ecological purposes for deploying artificial reefs help maximize the benefits received by those that utilize these spaces for recreational purposes.

Relevant Stakeholders

The two user groups that utilize artificial reefs for recreational purposes include recreational divers and recreational anglers. As recreation is the primary purpose for the deployment of artificial reefs in North Carolina, the NCDMF engages these stakeholders throughout the decision-making process by means of informal consultation for the selection of new artificial reef sites and the deployment of new materials in existing artificial reefs. Through this collaboration, state managers are able to identify the characteristics of artificial reefs that are important to stakeholders. In North Carolina, stakeholder priorities center around artificial reef accessibility, depth, and material.

For recreational anglers and divers, it is critical that accessibility is considered during the site selection for the permitting of new artificial reefs. In this context, accessibility encompasses distance from shore, inlets, and/or boat ramps. Presently, the only guidance on artificial reef accessibility is the stipulation that locations must fall within twenty nautical miles of shore in order to receive funding through the North Carolina Artificial Reef Program. Funding for this program is obtained through the sale of fishing licenses, and thus must be used where fishers have access to the resources provided by these funds.

Project Overview & Objectives

This project was conducted in partnership with the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) to help meet the geospatial needs of the North Carolina Division of Marine Fisheries (NCDMF). Specifically, the NCDMF seeks to explore data gaps surrounding ecological connectivity and fish use of existing and future artificial reef material placement in North Carolina. In doing so, the NCDMF hopes to maximize benefits to stakeholders through ecosystem-based management decisions.

To support the overall goal of my client, my project aimed to achieve the following objectives: (1) To provide the ecological, biophysical, and regulatory geospatial data resources necessary to inform decisions surrounding the deployment of new artificial reef materials; (2) To recommend how best to use the selected geospatial data resources in future management decisions; and (3) To visually present geospatial scientific data in a way that is accessible and easy to understand.

METHODS

Overview

The North Carolina Division of Marine Fisheries is responsible for the management of sixty-eight artificial reefs throughout the state's coastal waters. For the purpose of this study, I focused on the forty-three offshore artificial reefs spanning the entirety of the North Carolina coast (Fig. 1).

Presently, the NCDMF maintains and utilizes an artificial reef geodatabase containing details on permitted reef location, deployment information, and material specifications. Here, I provide supplementary geospatial data resources, extending beyond the permitted artificial reef boundaries to, in some cases, include all coastal waters of North Carolina. The following subsections describe the process of compiling, reviewing, and wrangling the provided geospatial data resources.

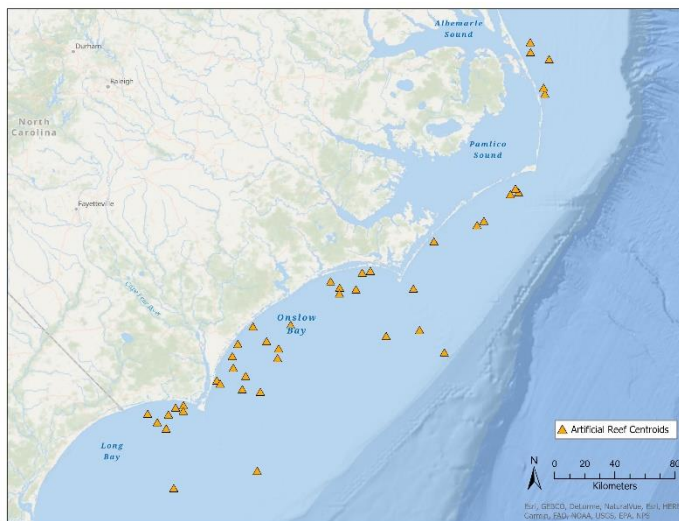


Figure 1. Artificial Reef Locations Along the NC Coast. Centroids represent central point of permitted area for artificial reef.

Data Acquisition

Data acquisition began by identifying data gaps surrounding ecological connectivity and fish use of artificial reefs. The initial brainstorming of these data gaps was done by the NCCOS and NCDMF, with an emphasis on cataloging all the potential data layers that might be desired and where these resources might be obtained. From this list, my partners at NCCOS and I narrowed down the overarching content that would be included in the final geodatabases. The initial list of potential data layers was then refined to fit within the project timeframe and reflect the geospatial priorities of the NCDMF.

Data were acquired through online, open-source repositories using the refined data layers list as guiding criteria for dataset selection. A total of twenty-one data layers were compiled for use in this project (Table 1). The selected ecological, biophysical, and regulatory datasets are contained within six geodatabases: Artificial Reef Locations, US Maritime Limits & Boundaries, Reef Habitat, Habitat Distribution & Connectivity, Physical Oceanography, and Fish Communities. Figure 2 provides an example of the geodatabases delivered to the NCDMF. All geospatial resources are provided in NAD 1983 StatePlane North Carolina FIPS 3200 Feet, as requested by the client.

Table 1. List of Geospatial Resources Provided to the North Carolina Division of Marine Fisheries. Some resources were directly obtained from partners at the NCCOS and NCDMF, and thus don't contain a hyperlink to an online repository.

GEODATABASE	DATA LAYER	SOURCE
Artificial Reef Locations	Permitted Boundaries	NCDMF
	Permitted Area Buffer Zone	Derived
	Reef Centroids	Derived
	Reef Materials	NCDMF
	PCA-Based Structure Delineation	NOAA
	Reef Materials Buffer Zone	Derived
US Maritime Limits & Boundaries	Exclusive Economic Zone	Marine Cadastre
	Contiguous Zone	Marine Cadastre
	Territorial Sea	Marine Cadastre
	State Waters	Marine Cadastre
	Vessel Traffic	Northeast Ocean Data
Reef Habitat	Side-Scan	NCDMF
	Bathymetry	NCDMF/NOAA
	Backscatter	NCDMF/NOAA
Habitat Distribution & Connectivity	Seafloor Habitats	TNC
	Regional Depth Contours	Marine Cadastre
	Regional Sand Shoals	NOAA
Physical Oceanography	Bottom Currents	NOAA
	Mean Tidal Currents	Marine Cadastre
Fish Communities	Fish Abundance	NOAA
	Fish Density	NOAA



Figure 2. Artificial Reef Locations Geodatabase and US Maritime Limits & Boundaries Geodatabase. SP = StatePlane. AR = Artificial Reef. NC = North Carolina. CZ = Contiguous Zone. EEZ = Exclusive Economic Zone. TS = Territorial Seas.

Data Manipulation

Once acquired, all datasets were processed and packaged within ArcGIS Pro 3.1. Each data layer required varying degrees of manipulation—described as minor, moderate, and substantial manipulation—in order to be added to the appropriate geodatabase. Once complete, the symbology for each data layer was saved as a layer file to its respective geodatabase folders to be delivered to the NCDMF. In addition to the data layers and their symbology, accompanying metadata were supplied to the client. Metadata includes a description of the datasets, source of datasets, details of how data were collected, and additional analysis conducted for the purpose of this project.

The following data layers required minor data manipulation: Permitted Boundaries, Reef Materials, Side-Scan, Bathymetry, Backscatter, PCA-Based Structure Delineation, Fish Abundance, and Fish Density. These layers were imported into the project file, symbolized in a fitting and intuitive manner, and exported to their respective geodatabases using the Raster or Feature Class to Geodatabase tools. As these layers were provided to me in the correct coordinate reference system, no additional processing was needed prior to being added to the assigned geodatabase.

The following data layers required moderate data manipulation: Exclusive Economic Zone, Contiguous Zone, Territorial Seas, State Waters, Seafloor Habitats, Regional Depth Contours, Regional Sand Shoals, Bottom Currents, and Mean Tidal Currents. After being imported into the project file, these layers required re-projection into NAD 1983 StatePlane North Carolina FIPS 3200 Feet. This was done using either the Project or Project Raster tools. As these datasets span the entire South Atlantic Region, additional processing was required to clip the extent of each data layer to the North Carolina coast. A mask of this area was created for analysis using the state borders and the Exclusive Economic Zone as the outer boundaries of the study area (Appendix A). After processing, the data layers were symbolized in a fitting and intuitive manner prior to their addition to the assigned geodatabase.

The following data layers required substantial data manipulation: Permitted Area Buffer Zone, Reef Centroids, Reef Materials Buffer Zone, and Vessel Traffic. The Permitted Area Buffer Zone, Reef Centroids, and Reef Materials Buffer Zone layers were all derived from datasets provided by the NCDMF. For the Permitted Area Buffer Zone and Reef Materials Buffer Zone layers a 150-foot buffer was added to each of the provided datasets, respectively. The Reef Centroids layer was derived using the Feature to Point tool to convert the Permitted Boundaries layer to individual points at the center of the permitted area. As these layers were provided to me in the correct coordinate reference system, no additional processing was needed prior to being added to the assigned geodatabase. For the Vessel Traffic layer, Automatic Identification System (AIS) data for all vessels were averaged over a five-year period from 2017 to 2021. Yearly AIS data were first clipped to the North Carolina coast using the Clip tool and re-projected to StatePlane with the Project Raster tool, before the Raster Calculator tool was used to average the vessel counts over time (Appendix B). The final derived layer was then added to the assigned geodatabase.

GEOSPATIAL RESOURCES

Artificial Reef Locations

The *Artificial Reef Locations* geodatabase contains geospatial data resources with the exact geographic location of existing permitted artificial reefs and where materials within the permitted area have been deployed (Fig. 3). A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. These resources aim to satisfy regulatory data gaps. On a state-level, these geospatial resources might be used to inform the locations of future artificial reef sites where spatial gaps currently exist. At the individual permitted artificial reef level, these resources might be used to inform decisions surrounding the deployment location of new materials within an existing, permitted area.

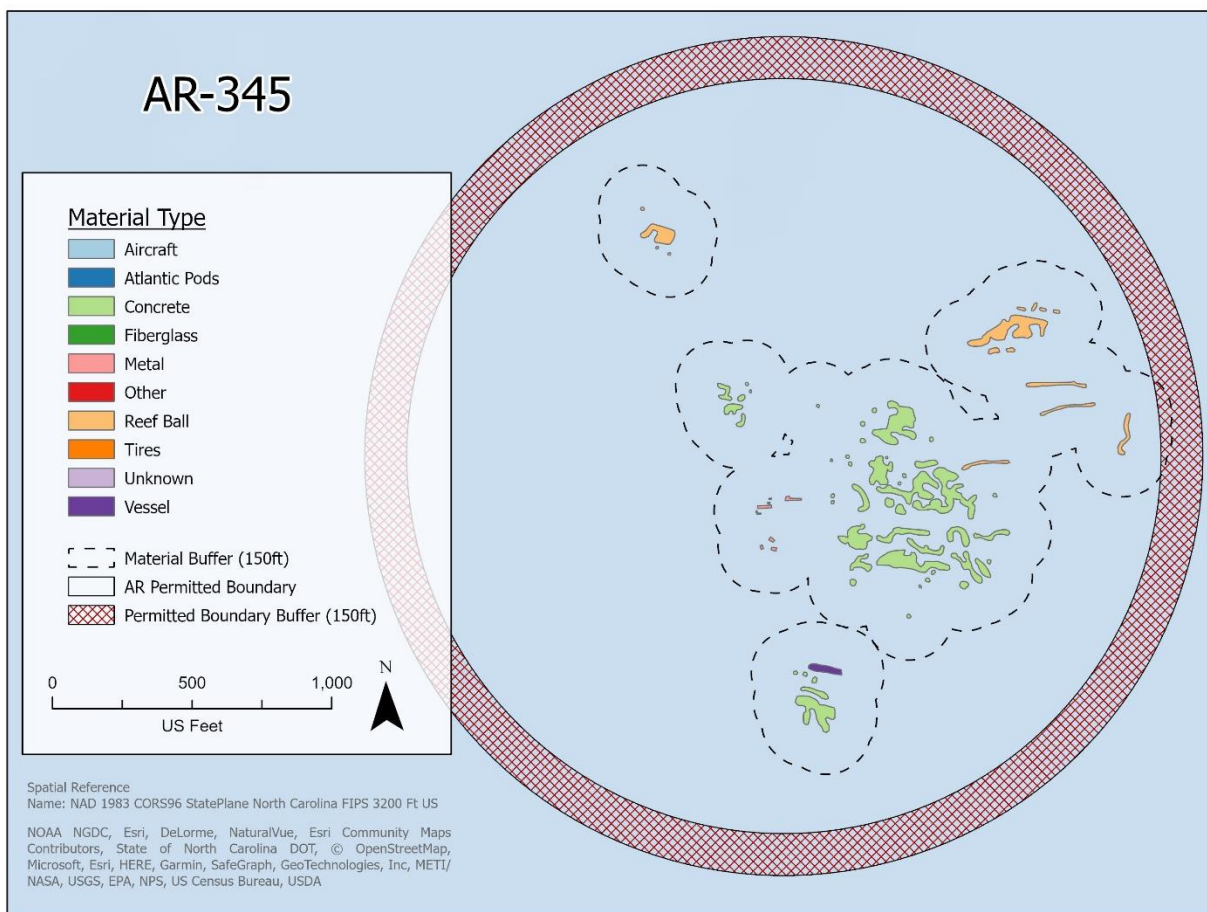


Figure 3. Artificial Reef 345 Permitted Area and Reef Materials. All data depicted here were provided directly from the NCDMF or derived from dataset provided by the NCDMF.

Permitted Boundaries & Buffer Zone: Permitted artificial reef boundary and 150-foot buffer. Buffer extends inward from permitted boundary towards centroid.

Centroids: Center point of permitted artificial reef area.

Reef Materials & Buffer Zone: NCDMF-derived polygons of deployed artificial reef materials and 150-foot buffer surrounding said materials. Polygons were hand-drawn over side-scan sonar imagery, with some aggregation of smaller materials into a singular polygon (e.g., Reef Balls).

PCA-Based Structure Delineation: Supervised delineation and classification of artificial reef materials based on the NOAA NCCOS multibeam bathymetry and derived measures of seafloor complexity (Fig. 4). When deciding where to deploy new artificial reef materials, it is my recommendation that the NCDMF utilizes the PCA-Based Structure Delineation of materials over their own material polygons. The higher resolution of the NOAA NCCOS multibeam data makes for increased accuracy in the location of individual reef materials. Therefore, there is a reduced chance of deploying new materials over top those that are already placed.

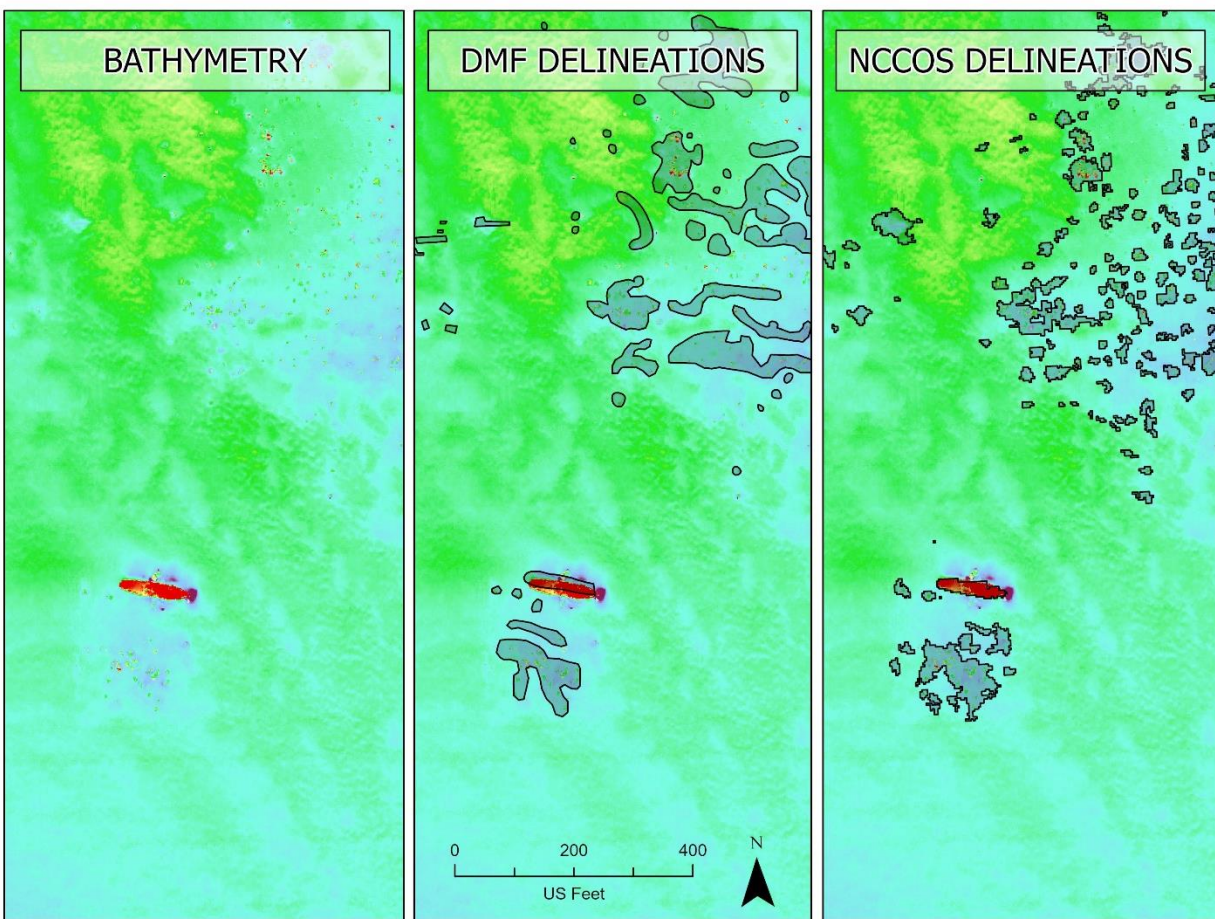


Figure 4. Artificial Reef Material Structure Delineation of AR-345. All three panels portray the same bathymetry data from the NOAA NCCOS. Black outlined objects represent artificial reef structures delineated by either the NCDMF methodology or the NOAA NCCOS methodology. Bathymetry color ramp is stretched between a percent clip of 0.5%.

US Maritime Limits & Boundaries

The *US Maritime Limits & Boundaries* geodatabase contains geospatial data resources pertaining to state and federal jurisdictional boundaries, in addition to maritime traffic patterns. A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. The jurisdictional boundaries (Fig. 5) provided should remain static and, therefore, provide a reference for the permitting of new artificial reefs. Supplementary to these boundaries, it is my recommendation that the Vessel Traffic data layer (Fig. 6) be used to inform future artificial reef site selection, as this geospatial data resource is a strong indicator of maritime “highways” that should be avoided.

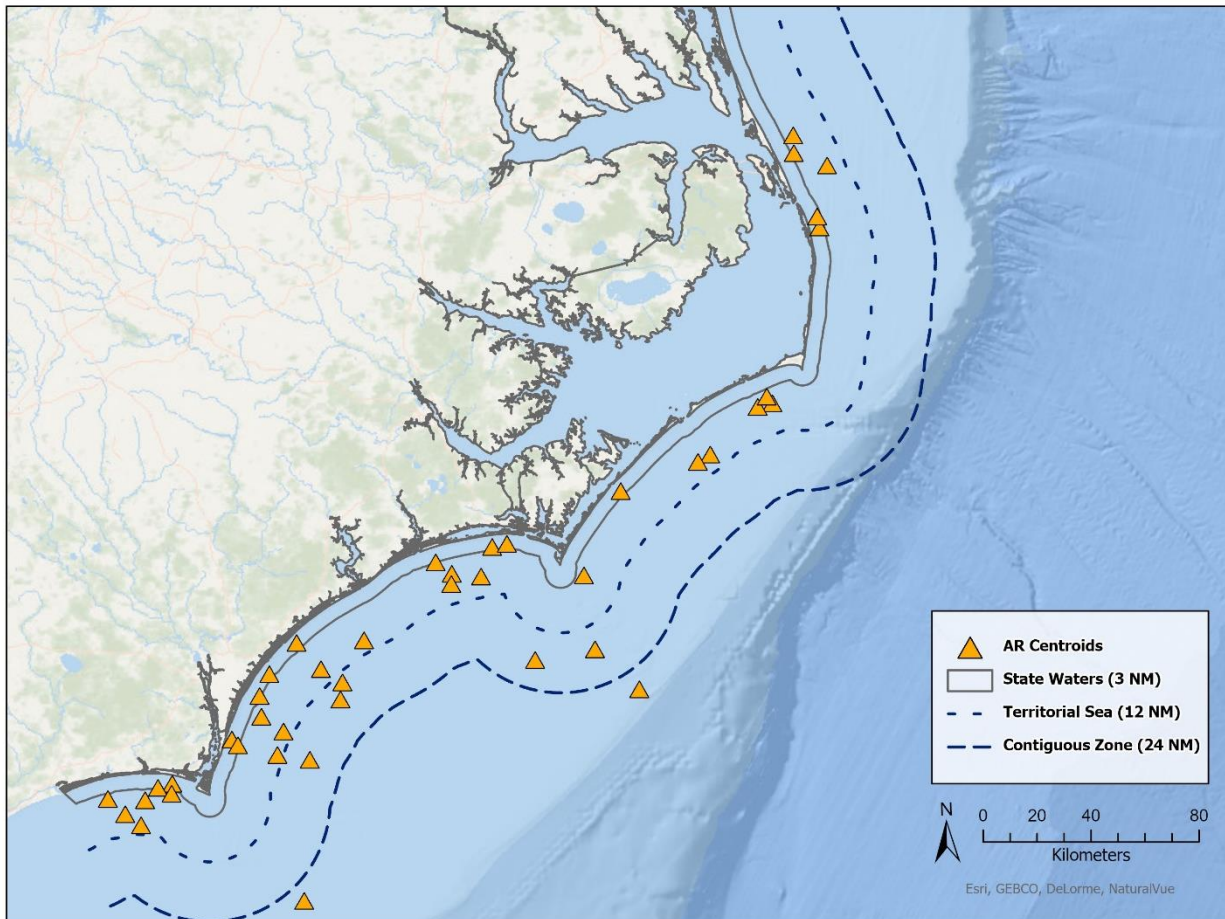


Figure 5. United States Maritime Boundaries for North Carolina. Boundaries extend the entirety of the coastal US but have been clipped to North Carolina for the purpose of this report. The Exclusive Economic Zone (EEZ) is not pictured here as most artificial reefs fall within the Contiguous Zone (CZ), with only two reefs present just outside the boundary.

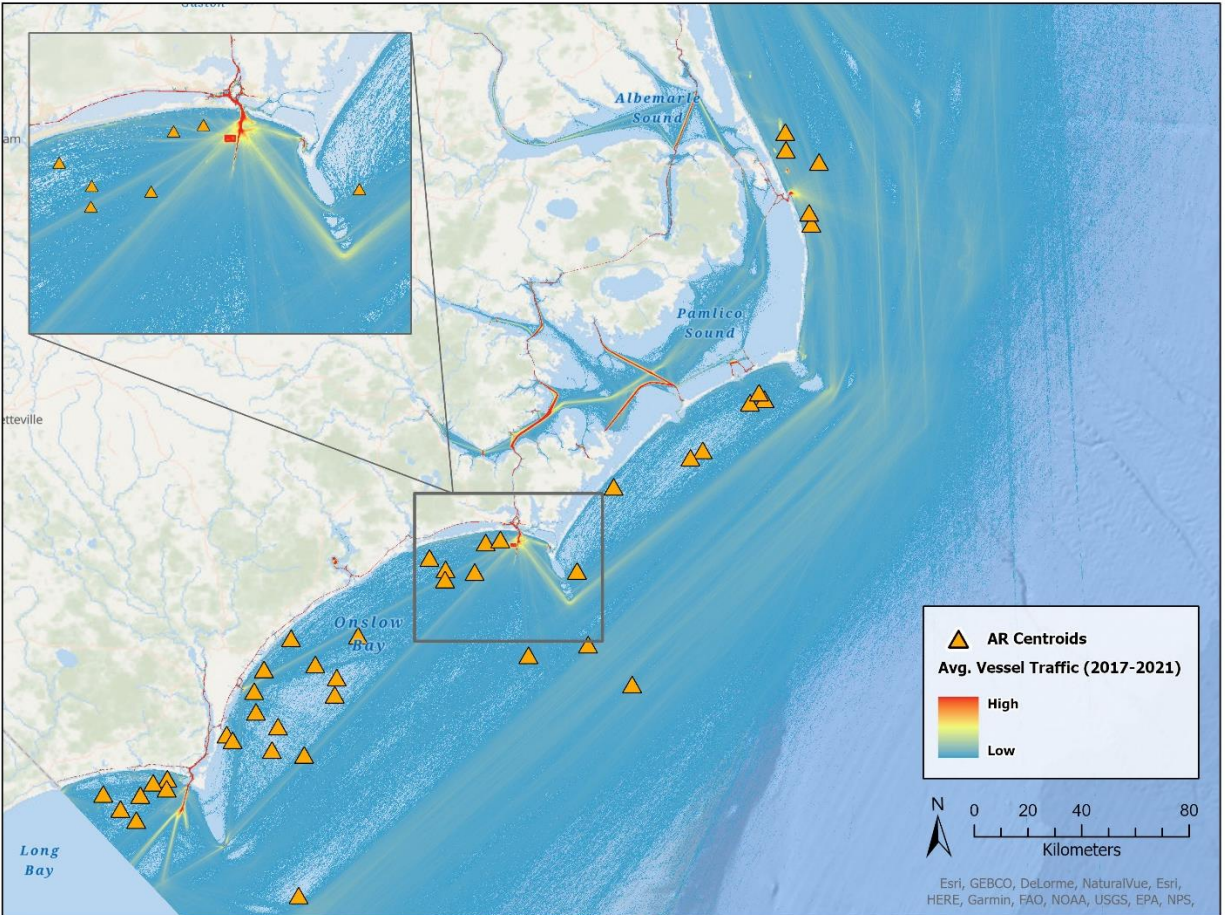


Figure 6. Average Vessel Traffic in North Carolina from 2017 to 2021. Maritime “highways” can be seen in red / yellow. Areas with the highest vessel traffic are located at inlets, ports, or indicate ferry paths between landmasses. Color ramp is stretched between 2.0 standard deviations (Low = 1.0, High = 17,606.8).

Exclusive Economic Zone (EEZ): Federal jurisdiction extending 200 nautical miles from the coastline.

Contiguous Zone (CZ): Limited State jurisdiction extending 24 nautical miles from the coastline.

Territorial Sea (TS): State jurisdiction extending 12 nautical miles from the coastline.

State Waters: State jurisdiction extending 3 nautical miles from the coastline.

Vessel Traffic: Automatic Identification System (AIS) vessel counts averaged over 2017 – 2021. In its current state, this data layer provides a strong starting point for the site selection process of permitting new artificial reefs. However, it is my recommendation that additional processing be done to remove lower vessel counts from the symbology in order to accentuate maritime “highways”. In doing so, future artificial reef sites can avoid placement within these heavily trafficked areas.

Reef Habitat

The *Reef Habitat* geodatabase contains geospatial data resources pertaining to individual artificial and natural reef seafloor habitats (Fig. 7). A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. These resources aim to satisfy ecological data gaps. As these data layers are specific to individual reef sites, they should not be used to make regional decisions on future artificial reef site selection and permitting. Instead, these resources should inform the deployment of new reef material within permitted boundaries of existing artificial reefs.

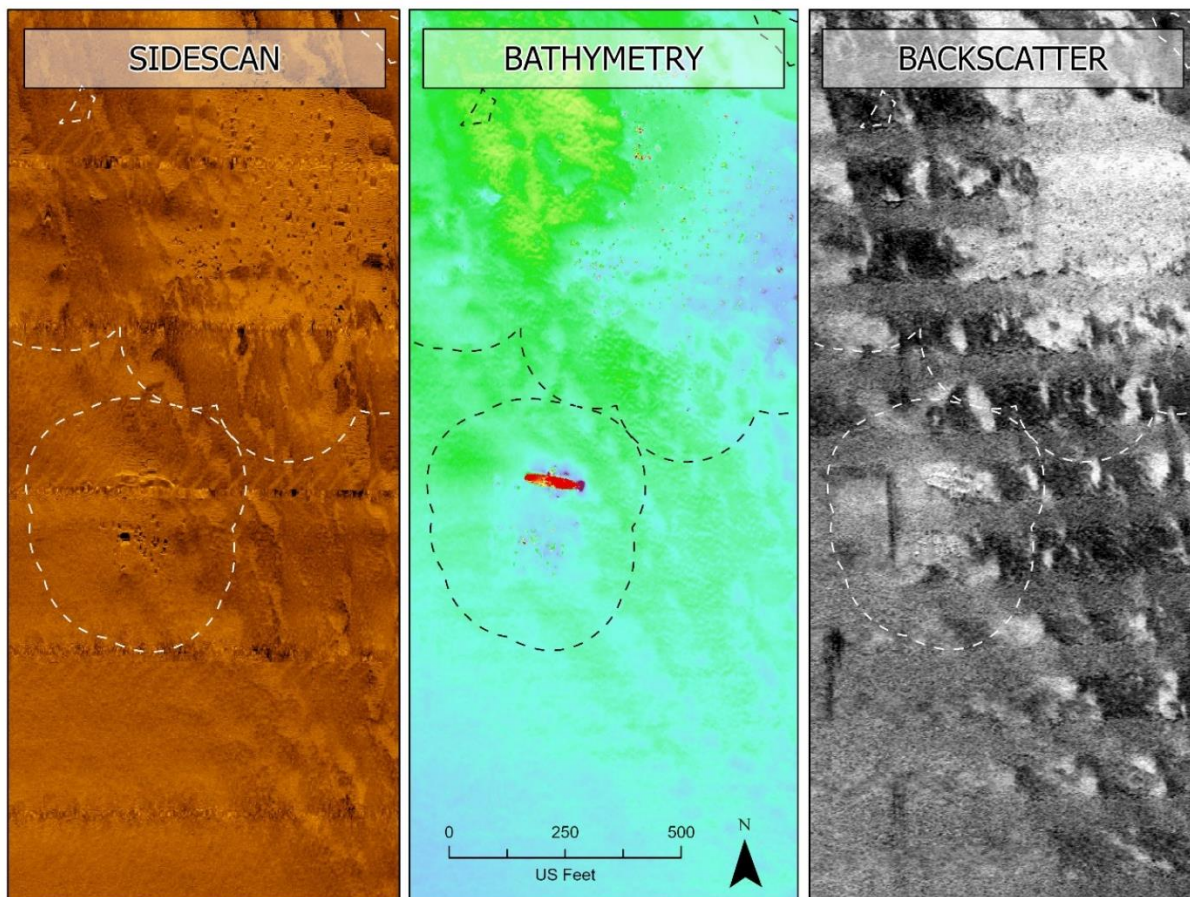


Figure 7. Habitat Mapping Imagery of Artificial Reef 345. Side-Scan imagery was obtained from the NCDMF. Bathymetry and Backscatter data layers shown here were obtained from the NOAA NCCOS. The dashed lines indicate the 150-foot buffer around deployed artificial reef materials. Bathymetry and backscatter color ramps are stretched between a percent clip of 0.5%.

Side-Scan: Sonar imagery of seafloor used to detect protruding objects.

Bathymetry: Underwater depth of ocean floor features. Bathymetric data were obtained from both the NCDMF and NOAA NCCOS. While both sets of data are included in the final geodatabase, it is my recommendation that the NOAA bathymetry be used where duplicate data layers exist due to finer resolution of the NOAA bathymetry than the NCDMF bathymetry.

Backscatter: Relative hardness and roughness of seafloor produced from the reflection of sound off the ocean bottom. Harder bottom types reflect more sound and are indicated by lighter shading. Softer bottom types reflect less sound and are indicated by darker shading. Backscatter data were obtained from both the NCDMF and NOAA NCCOS. While both sets of data are included in the final geodatabase, it is my recommendation that the NOAA backscatter be used where duplicate data layers exist due to finer resolution of the NOAA backscatter than the NCDMF backscatter.

Habitat Distribution & Connectivity

The *Habitat Distribution & Connectivity* geodatabase contains geospatial data resources pertaining to predicted seafloor habitat characterization (Fig. 8, Fig. 9). A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. These resources aim to satisfy ecological data gaps. Due to the resolution of these datasets, it is recommended that they be used to inform regional decisions on future artificial reef site selection, rather than deployment of new reef materials at individual, existing artificial reefs.

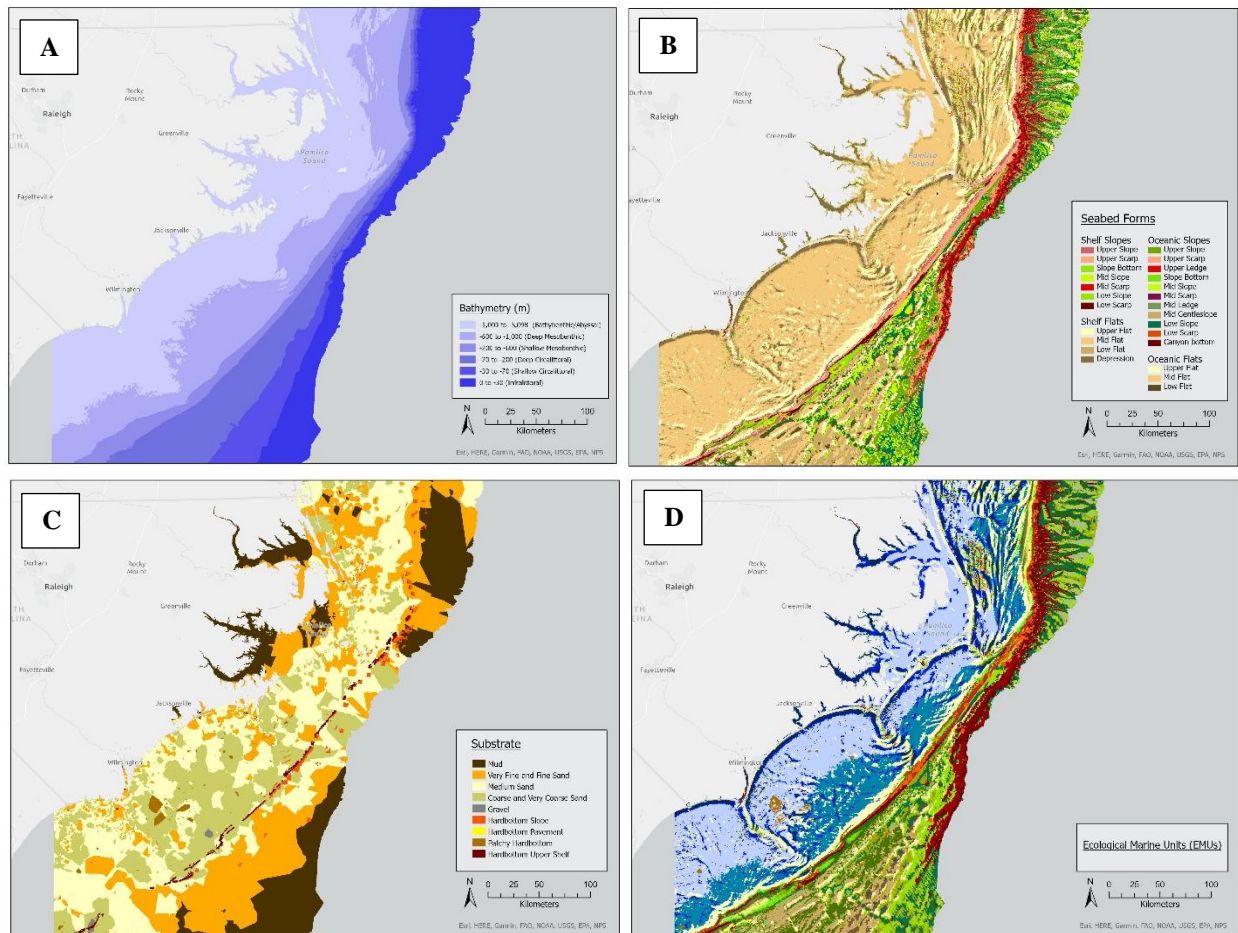


Figure 8. South Atlantic Bight Marine Assessment (SABMA) Seafloor Habitats. This dataset extends the entirety of the South Atlantic US but has been clipped to North Carolina for the purpose of this report. **A)** Bathymetry interpolated from depth sounding points throughout the region. **B)** Seabed forms interpolated from benthic topography. **C)** Substrate of seafloor interpolated from sediment softness and grain size. **D)** Ecological Marine Units (EMUs).

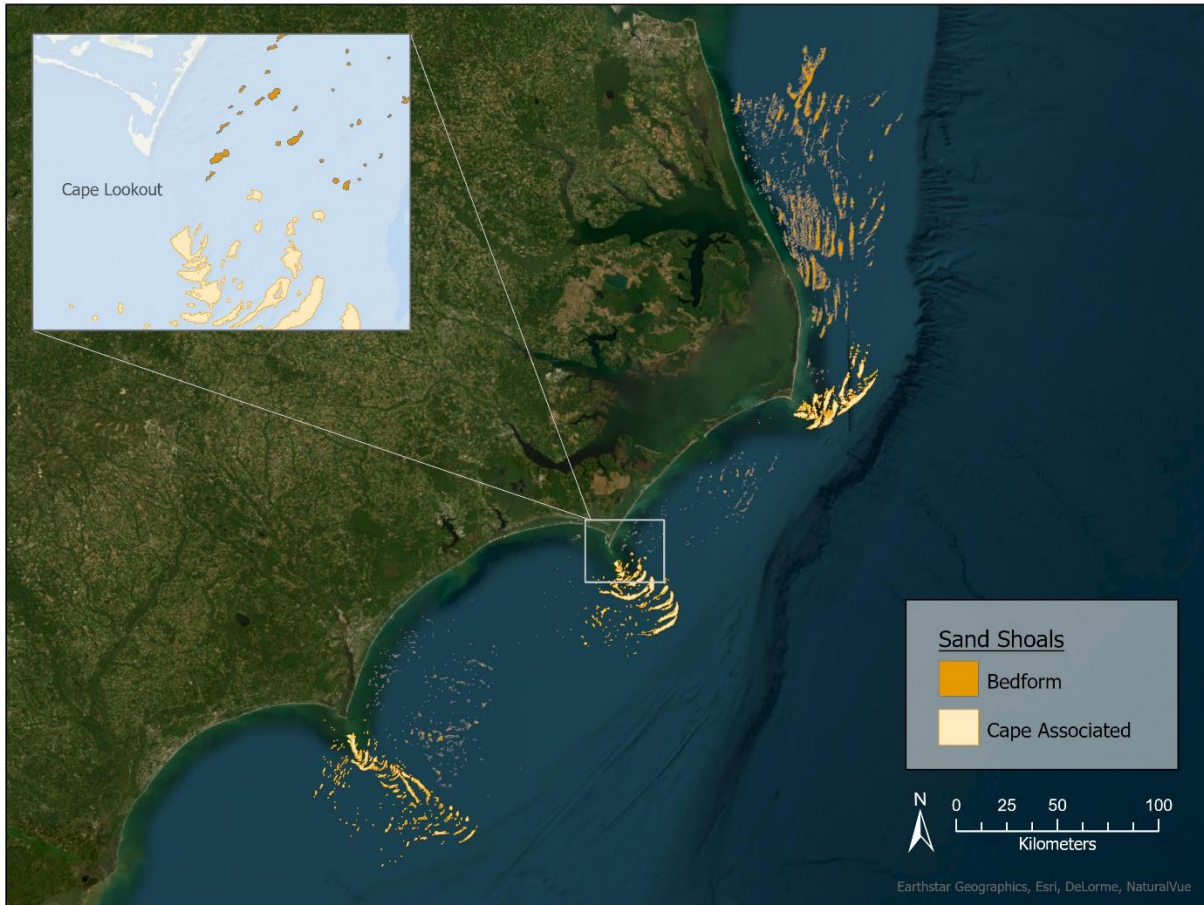


Figure 9. Predicted Sand Shoals for North Carolina. Inset panel provides an example of the location of bedform sand shoals compared to cape associated shoals off Cape Lookout, NC.

Seafloor Habitats: Distribution of seafloor habitats from the South Atlantic Bight Marine Assessment (Conley et al., 2017). This dataset includes information on bathymetry, seabed form, and substrate. Additionally, this dataset includes an Ecological Marine Units (EMUs) layer, combining the three aforementioned layers into a singular surface. EMUs can be used to predict benthic habitat at any given location.

Regional Depth Contours: Seafloor depth at 10-meter increments. This dataset provides supplemental detail to the bathymetric data provided in the SABMA seafloor habitats data layer. However, it is not showcased in this report.

Regional Sand Shoals: Model-derived predicted distribution of sand shoals sourced from a regional assessment of sand resources that could support dredging and beach management in coastal states (Pickens et al. 2021; Pickens and Taylor, 2020). Sand shoals are identified as essential fish habitat for key managed species. It is my recommendation that this data layer be used in conjunction with regional bathymetry and depth contours in order to inform site selection for new artificial reefs.

Physical Oceanography

The *Physical Oceanography* geodatabase contains geospatial data resources pertaining to oceanic currents (Fig. 10). A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. These resources aim to satisfy biophysical data gaps. Due to the resolution of these datasets, it is recommended that they be used to inform regional decisions on future artificial reef site selection, rather than deployment of new reef materials at individual, existing artificial reefs.

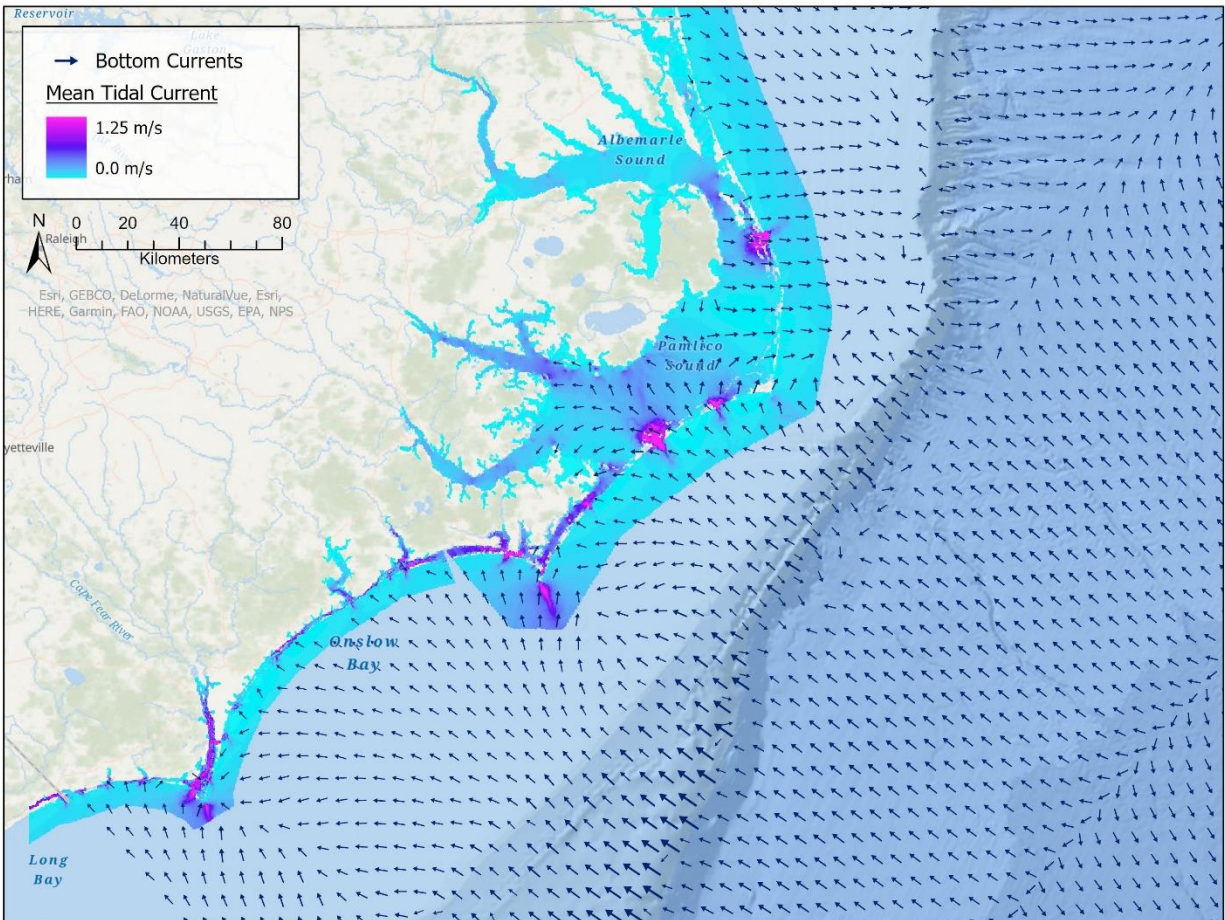


Figure 10. Average Tidal Currents and Bottom Currents for North Carolina. Bottom currents are symbolized by an arrow that indicates directionality, as well as the magnitude of the current. The larger the arrow, the bigger the magnitude. Mean tidal current color ramp is stretched between a percent clip of 0.5%.

Bottom Currents: Annual average magnitude and direction of ocean currents. Bottom currents were derived from HYCOM data obtained over a twenty-year period. While the resolution of this dataset is not necessarily fine enough for individual artificial reef management decisions, in conjunction with bathymetry data within the *Reef Habitat* geodatabase, this dataset might clarify how sediment is distributed around existing artificial reefs and the potential for erosion of sediment around large artificial structures.

Mean Tidal Currents: Average current of tidal streams in meters per second.

Fish Communities

The *Fish Communities* geodatabase contains geospatial data resources pertaining to individual fish abundance and distribution (Fig. 11), as well as the distribution of fish schools around artificial reef structures (Fig. 12). A brief description of each data layer is provided below. Additional information for state managers can be found in the provided metadata. These resources aim to satisfy ecological data gaps. It is important to note here that these data are a snapshot in time from discrete surveys and should be interpreted with caution. Further confidence in relative fish abundance and distribution might be gained from additional surveys, as well as from diver observations. As these data layers are specific to individual reef sites, they should not be used to make regional decisions on future artificial reef site selection and permitting. Instead, these resources should inform the deployment of new reef material on existing artificial reefs. However, fish preferences of artificial reef materials that are observed might be applied to the deployment of new artificial reefs in future permitted sites.

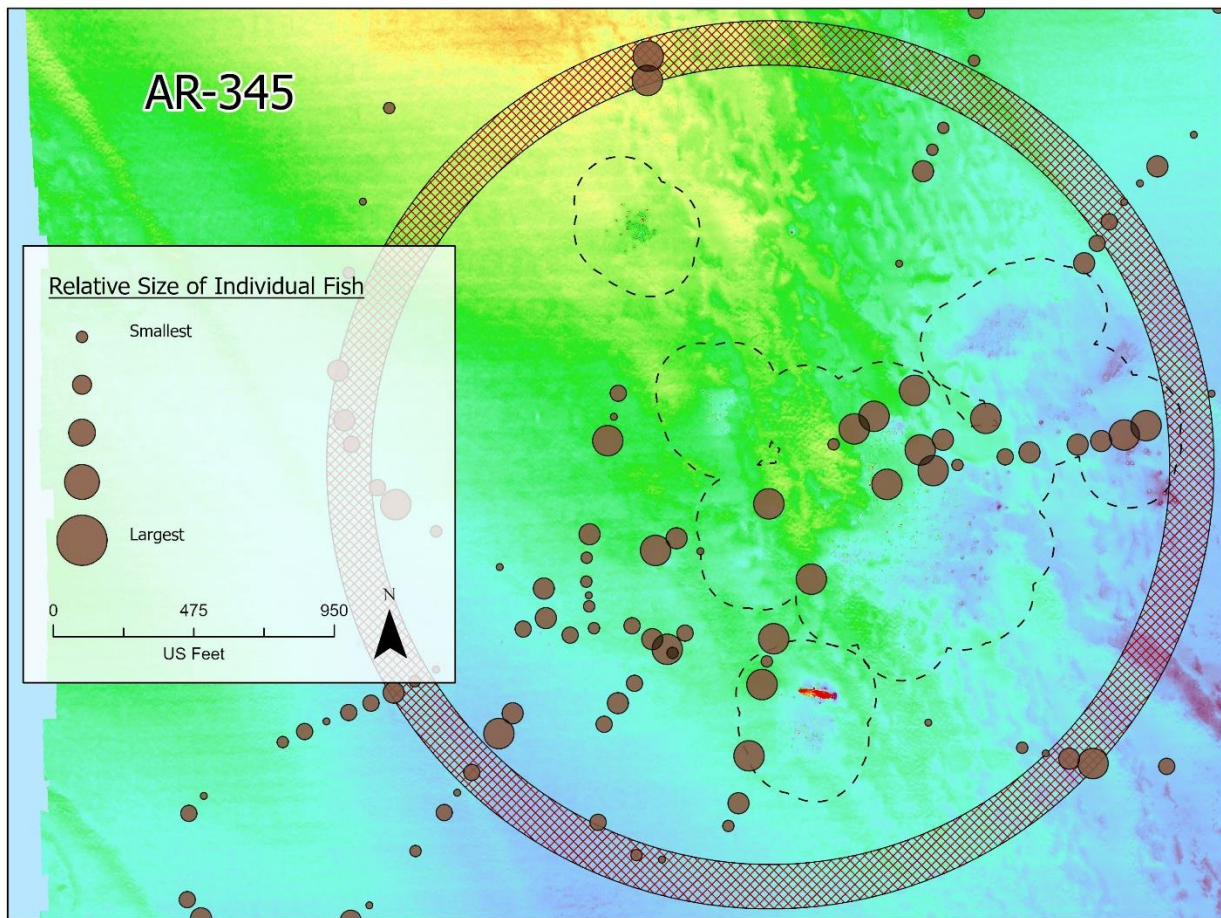


Figure 11. Relative Abundance and Distribution of Individual Fish within AR-345. Individual fish points are symbolized by relative size and overlaid on top of multibeam bathymetry data, with a color ramp stretched between a percent clip of 0.5%.

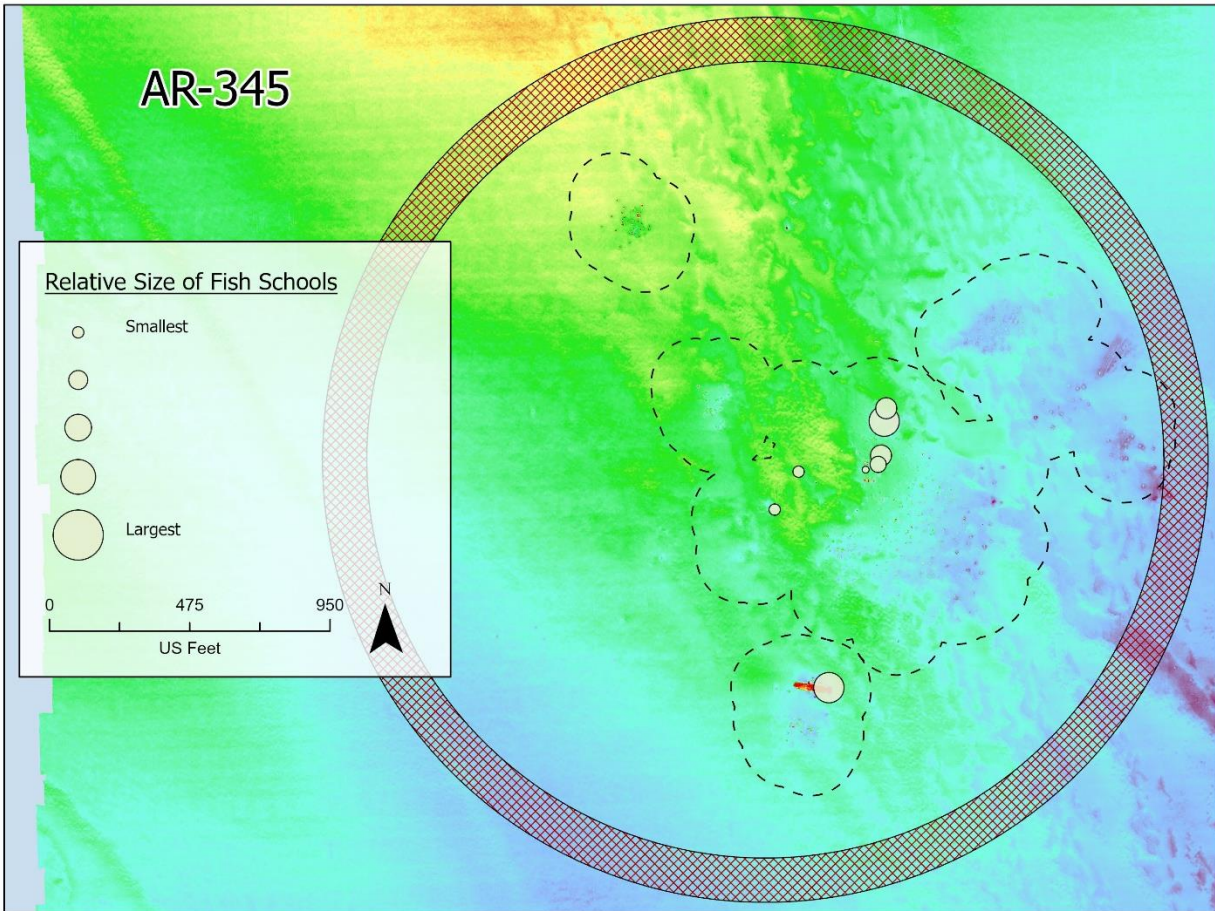


Figure 12. Relative Density and Distribution of Fish Schools within AR-345. Fish school points are symbolized by relative size and overlaid on top of multibeam bathymetry data, with a color ramp stretched between a percent clip of 0.5%.

Relative Abundance of Individual Fish: Distribution of individual fish within a reef habitat. It is my recommendation that this data layer be used in conjunction with bathymetry data from the Reef Habitat geodatabase, as pictured above, in order to understand how fish might interact with artificial reef materials throughout the permitted area. However, it is important to note that this dataset does not cover the entire permitted area, but rather is a sampling within the permitted area.

Relative Abundance of Fish Schools: Distribution of fish schools within a reef habitat. It is my recommendation that this data layer be used in conjunction with bathymetry data from the Reef Habitat geodatabase, as pictured above, in order to understand how fish might interact with artificial reef materials throughout the permitted area. However, it is important to note that this dataset does not cover the entire permitted area, but rather is a sampling within the permitted area.

POTENTIAL APPLICATIONS & FUTURE DIRECTIONS

Overview

In order to meet the overall goal of my client, this report recommends how best to use the geospatial resources provided in future management decisions. Suggestions for data use of

individual layers have been provided in the previous section of this report. The following subsections detail more broad-scaled recommendations for the site selection process of permitting a new artificial reef and the deployment of new materials at existing artificial reefs.

Stakeholder Engagement

As highlighted in the introduction of this report, stakeholders are informally engaged in the decision-making process for the site selection of new artificial reefs and the deployment of new materials in existing artificial reefs. While discussions with the NCDMF suggest ample consultation and collaboration with recreational anglers and divers, it is my recommendation that these stakeholder groups be more formally involved within the management of these artificial reefs. Specifically, the NCDMF should create a list of artificial reef siting and material criteria that can be distributed to stakeholders for them to provide their rankings of importance. Once collected, these surveys can help inform future decisions that maximize benefits to user groups.

In addition to understanding stakeholder priorities when it comes to the siting of new artificial reefs and the deployment of new material, recreational anglers and recreational divers have a unique set of local knowledge of artificial reefs that state managers might not necessarily have from occasional site visits. Therefore, it is my recommendation that the NCDMF create a space for stakeholder participation in the scientific exploration of data gaps surrounding the deployment of artificial reefs. Specifically, these user groups might be able to carry out visual surveys of the area that can provide ecological and biophysical observational data to inform future decisions. For example, recreation divers might be able to comment on how fish populations utilize the space or how sediment is distributed around reef materials.

Further, it is my opinion that the siting of new artificial reefs provides an opportunity to engage stakeholders in the restoration field. While current goals of the North Carolina Artificial Reef Program do not focus on the use of artificial reefs for restoration, they have the potential to be applied as such. However, due to the difference in fish assemblages present on deployed ships versus concrete modules, materials used in restoration focused projects may intend to best mimic fish assemblages of natural rocky reefs, which might not maximize benefits to stakeholders (Lemoine et al., 2019). The NCDMF might consider this opportunity to include groups such as the North Carolina Coastal Federation in future projects.

Increased Data Collection & Monitoring Efforts

Many state artificial reef programs, North Carolina included, lack high resolution data of individual artificial and natural reef habitats, as well as long-term monitoring programs. It is my recommendation that the NCDMF, in agreement with sentiments by Steward et al. (2022), increase the use of multibeam echosounders for artificial reef and natural reef seafloor mapping surveys. Compared to existing side-scan sonar data, multibeam echosounder data captures elevation of benthic habitats at a higher resolution. Further, utilizing this technology would allow for the

application of the NCCOS's PCA-Based Structure Delineation workflow, which more accurately characterizes spatial cover and distribution of artificial reef materials.

Additionally, it is my recommendation to increase monitoring efforts of artificial reef sites over time. Much of the regulation surrounding artificial reefs lacks a sufficient timeframe for artificial reef monitoring of observed ecological and biophysical changes to a permitted location (Becker et al., 2017). As such, the efficacy of deploying these materials is difficult to evaluate (Becker et al., 2017). Acknowledging the potential shortage of funding and/or staff for thorough monitoring, the NCDMF might consider a scheduled rotation of annual artificial reef monitoring. Doing so might eliminate data gaps surrounding ecological and biophysical considerations.

Criteria Ranking System & Decision Support Tool

Having compiled and processed the data presented within this report on behalf of the NCDMF, state managers must still examine each data layer carefully when deciding where to permit new artificial reefs or deploy new material at existing artificial reefs. In order to streamline the decision-making process, it is my recommendation that the criteria presented here be ranked by priority and integrated into a decision support tool. As the NCDMF has two primary uses for these data—1) to assist in site selection of new artificial reefs and 2) to inform decisions regarding the deployment of new material in existing permitted areas—I suggest the creation of two separate decision support tools for each use. Doing so will allow for criteria to be ranked differently based upon the goals of the NCDMF.

CONCLUSION

The ecological, biophysical, and regulatory geospatial data resources provided here satisfy data gaps surrounding ecological connectivity and fish use of existing and future artificial reef material placement identified by the North Carolina Division of Marine Fisheries (NCDMF). These resources, in conjunction with recommendations for their specific use, will support the NCDMF in focusing management decisions in order to maximize the socioeconomic and ecological benefits of artificial reefs to stakeholders. Further, I have provided additional recommendations to the NCDMF to improve upon the North Carolina Artificial Reef Program, which are as follows: (1) To more formally engage stakeholders in artificial reef management decisions; (2) To increase data collection and monitoring efforts; and (3) To create a criteria ranking system and decision support tool for future management decisions. Overall, this report provides detailed explanation of the geospatial data resources provided to the NCDMF, clear visualizations of the geospatial data resources provided to the NCDMF, and recommendations for their future use.

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APPENDIX A

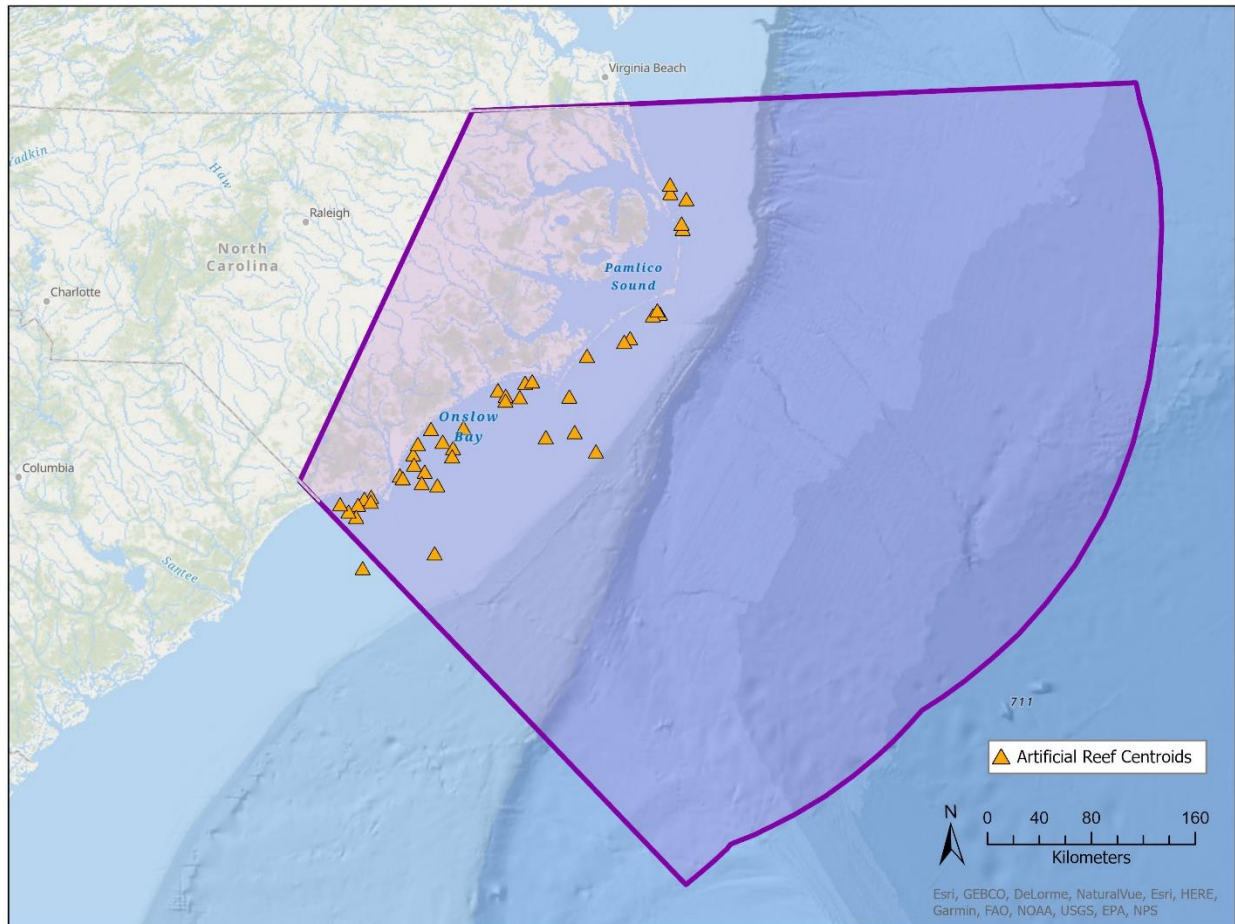


Figure 13. Mask of Study Area. This mask was used throughout the project to clip datasets to the desired extent. Mask includes the state borders and the Exclusive Economic Zone as the outer boundaries of the study area.

APPENDIX B

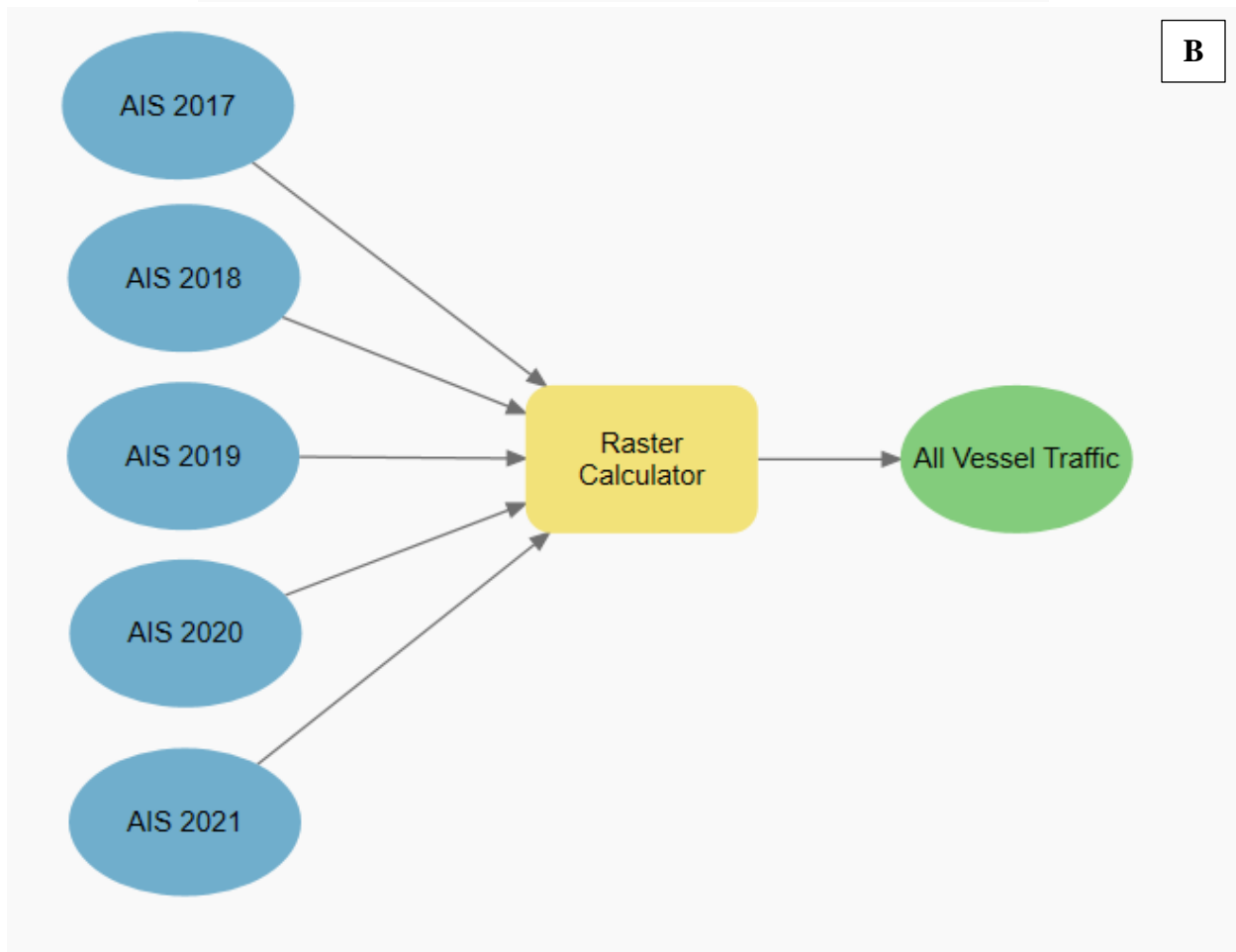
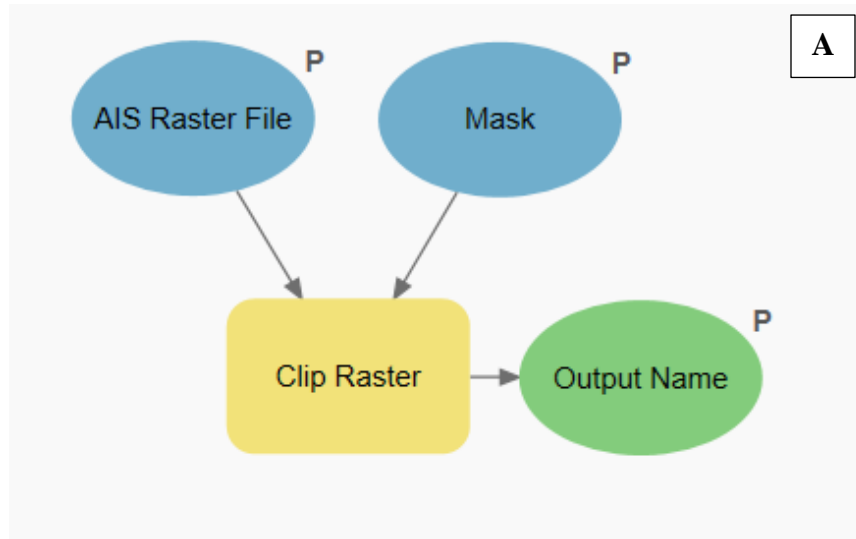


Figure 14. Vessel Traffic Models. **A)** Automatic Identification System (AIS) Clip Tool. This tool was created to clip yearly AIS raster data to the desired extent of the mask. **B)** Calculation of Average Vessel Traffic for 2017 through 2021.