Westport Aquaculture Siting Prioritization

Study Region

Aquaculture siting aimed to be within 20 miles of Westport, Massachusetts. To identify potential locations, the study region was constrained to areas within federal waters that had depths between 30 and 50 meters. A hexagonal grid with 10-acre cells covered all areas that met these three criteria.

Data components

A majority of the data used in the analysis were hosted on a publicly open domain operated by a government agency. For these data, an R script downloaded the data using to ensure the most current data were obtained before conducting any further analyses. One dataset, the export cable corridors (proposed), got accessed through a REST Server using the R package arcpullr. When possible, the analysis downloaded the data as GeoPackages.

All data were transformed to the coordinate reference system of NAD83 / UTM 18N ([EPSG:26918](https://epsg.io/26918)) to ensure they could get analyzed together. Datasets often covered areas larger than the study area. For these datasets, only data within the study region were kept. A value of 0 got allocated to any dataset that was classified as a constraint. Suitability datasets received either a discrete scores for all areas located within the study region, while other datasets with continuous values were rescaled to have scores between 0 and 1.

Constraints

*Bathymetry*

Aquaculture siting had to get limited to water depths between 30 and 50 meters. NOAA maintains a data portal to identify and download all potential bathymetry datasets for the United States. This analysis relied on the Continuously Updated Digital Elevation Model (CUDEM) for constructing the bathymetry datasets to limit the study region. These bathymetry datasets have multiple resolutions. This analysis required integrating two different resolutions for covering the entire region as no one resolution could cover all the area. Three bathymetric-topographic tiles from the [1/9-arc second](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_ninth_Topobathy_2014_8483/) (~3 m) and [1/3-arc second](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_third_Topobathy_2014_8580/) (~10m) tiles covered the study region. The tiles for the ninth-arc second were from 2018 and cover the blocks [41x50 north and 71x00 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_ninth_Topobathy_2014_8483/rima/ncei19_n41x50_w071x00_2018v1.tif), [41x50 north and 71x25 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_ninth_Topobathy_2014_8483/rima/ncei19_n41x50_w071x25_2018v1.tif), and [41x50 north and 71x50 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_ninth_Topobathy_2014_8483/rima/ncei19_n41x50_w071x50_2018v1.tif). Tiles for the third-arc second data were from 2021 and cover the blocks to the south: [41x25 north and 71x00 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_third_Topobathy_2014_8580/MA_NH_ME/ncei13_n41x25_w071x00_2021v1.tif), [41x25 north and 71x25 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_third_Topobathy_2014_8580/MA_NH_ME/ncei13_n41x25_w071x25_2021v1.tif), and [41x25 north and 71x50 west](https://chs.coast.noaa.gov/htdata/raster2/elevation/NCEI_third_Topobathy_2014_8580/MA_NH_ME/ncei13_n41x25_w071x50_2021v1.tif). Tiles for the third-arc second data got disaggregated to match the resolution of the ninth-arc second data. After mosaicking the six tiles together, any bathymetric value above 50 meters or below 30 meters was given an NA value, meaning these data were not available for that location.

*Federal waters*

Areas defined as federal waters came from the [Coastal Zone Management Act dataset](https://marinecadastre.gov/downloads/data/mc/CoastalZoneManagementAct.zip) hosted on Marine Cadastre. In the dataset, federal waters get labeled as “federal consistency.”

*Westport distance*

Massachusetts GIS provided the [administrative boundary data](https://s3.us-east-1.amazonaws.com/download.massgis.digital.mass.gov/gdbs/townssurvey_gdb.zip) for its state’s towns. The boundary for Westport got a 20-mile buffer to determine which federal waters would overlap within this constraint.

*Unexploded ordnance (locations and areas)*

During the modeling process, the [munitions and explosives of concern](https://marinecadastre.gov/downloads/data/mc/MunitionsExplosivesConcern.zip) became the authoritative dataset instead of the previous unexploded ordnance locations ([link](https://marinecadastre.gov/downloads/data/mc/UnexplodedOrdnance.zip) is no longer functional), which were comprised of areas and locations. These can included unexploded ordnances, discarded military munitions, and munition components that exist in a high enough concentration that they have been deemed as a possible harm. No setback distance was required for these data to ensure safety of the aquaculture sites.

*Danger zones and restricted areas*

Any areas designated as [danger zones or restricted zones](https://marinecadastre.gov/downloads/data/mc/DangerZoneRestrictedArea.zip) were not viable options for aquaculture and became constraints. Both danger zones and restricted areas get [defined](https://www.ecfr.gov/current/title-33/chapter-II/part-334/section-334.2) within the Code of Federal Regulations. According to the regulations, a danger zone can get closed to the public fully or when needed. These areas get used for a variety of uses, including, but not limited to: target practice, bombing, and rocket firing or other especially hazardous operations. Restricted areas, as defined within the CFR, get closed for the security of government operations or protect the public from the government’s use of that area.

*Environmental sensors and buoys*

The Northeast Ocean Data portal [hosted](https://www.northeastoceandata.org/files/metadata/Themes/PhysicalOceanography.zip) geographic locations for environmental sensors that encompass the network in the Northeast Regional Association of Coastal Ocean Observing Systems ([NERACOOS](https://neracoos.org/index.html)). This dataset gets comprised of stations from NERACOOS Buoys, Bowdoin Buoys, CDIP Buoys, NOAA CMAN stations, DeepC Wind, Gulf of Maine Array, Long Island Sound Array, NOAA buoys, RI-SAMP, and URI Buoys. Most of these buoy systems did not have stations present in the study area. To minimize the effect of aquaculture on the sensors, no aquaculture can get sited within 500 meters of a sensor.

*Wastewater locations*

[Wasterwater data](https://marinecadastre.gov/downloads/data/mc/WastewaterOutfall.zip) are comprised by three datasets: (1) facility locations, (2) outfall pipes, and (3) outfall discharge points. These data summarize geographic data for public treatment works that can affect the United States coastlines and waters. All the locations got a 500-meter setback. None of the outfall pipes nor outfall discharge points extend far enough in coastal waters for the coastal facility locations to impact the study region. Even with the setback distance applied, the publicly available wastewater discharge data as of January 2024, were not located within the study region.

*Ocean disposal sites*

Aquaculture sites will not get affected by contemporary disposal sites that deposits sediment from navigation channel projects. The publicly available data for current and past [ocean disposal sites](https://marinecadastre.gov/downloads/data/mc/OceanDisposalSite.zip) do not contain any locations that exist within the study region.

*Aids to navigation*

Navigational aids help vessels and crew avoid dangerous obstructions and chart a safe course. Types of aids include lights, signals, buoys, and beacons. A 500-meter setback got applied to the [aids to navigation](https://marinecadastre.gov/downloads/data/mc/AtoN.zip) so that vessels do not pass through the aquaculture site nor a aquaculture site gets placed where a key navigational aid is currently located making passage for a vessel less safe.

*Wrecks and obstructions*

The wrecks and obstructions datasets came together from two sources: NOAA’s [Automated Wreck and Obstruction Information System](https://www.nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html) (AWOIS) and NOAA’s [Electronic Navigational Charts](https://www.nauticalcharts.noaa.gov/charts/noaa-enc.html) (ENC). The AWOIS database stopped getting updated in 2016. While the ENC gets updated weekly, wrecks may have been last updated at a similar time as those data in the AWOIS database. Aquaculture sites were constrained to areas beyond a 152.4-meter setback of any [wreck and obstruction](https://marinecadastre.gov/downloads/data/mc/WreckObstruction.zip) site. These sites could have been either a wreck, wreck area, obstruction, or something unknown.

*Shipping fairways*

To eliminate disruption to shipping and by shipping on the aquaculture sites, all [shipping fairways](http://encdirect.noaa.gov/theme_layers/data/shipping_lanes/shippinglanes.zip) got classified as no-go areas for the siting analysis. All shipping theme classifications were considered equally off limits. For instance, precautionary areas, particularly sensitive sea areas, and traffic lanes were all classified as prohibited areas even though they have different regulations for what can and cannot occur in those waters by shipping activity. These shipping lanes are only for federal waters (3 nautical miles – 200 nautical miles for the study region).

*Wind energy areas*

Areas in federal waters have been auctioned to provide the construction and operation for offshore wind energy production. These areas can generate power for commercial and research. Lease areas also exist for right-of-way. Currently offshore wind energy and aquaculture cannot operate in the same waters. To ensure this reality, all [offshore wind leases areas](https://www.boem.gov/BOEM-Renewable-Energy-Geodatabase.zip) received a constraint designation.

*Offshore wind export cable corridors*

Future offshore wind energy areas require connection to the electrical grids at points of connection and power substations. Many of these wind energy areas have not yet determined where these cables will get located, developers have proposed routes that they aim to explore. The [proposed export cable corridors](https://services7.arcgis.com/G5Ma95RzqJRPKsWL/arcgis/rest/services/Offshore_Wind-_Proposed_Export_Cable_Corridors/FeatureServer/0) superseded priority to aquaculture sites. Proposed corridors received a favorable ranking (from 1 to 3) by the developer. Regardless of the developer’s rankings, all corridors got considered equally and designated as constraints.

National Security

*Military operating areas*

Marine Cadastre worked with the United States Navy to create the [military operating areas](https://marinecadastre.gov/downloads/data/mc/MilitaryCollection.zip) where training exercises and tests get run. Another dataset exists on Marine Cadastre, but [those data](https://marinecadastre-noaa.hub.arcgis.com/datasets/noaa::military-operating-area-boundary/about) were deprecated on 9 February 2024.

*Special use airspace*

Federal airspace can get limited to particular [special use activities](https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap3_section_4.html). The military operates particular special uses that could include special operation areas, prohibited areas, restricted areas, warning areas, and altitude reservations. These [special use airspace](https://marinecadastre.gov/downloads/data/mc/MilitarySpecialUseAirspace.zip) data got provided from the National Geospatial-Intelligence Agency’s Digital Aeronautical Flight Information File and are a subset of Navy data that aid in ocean planning. No areas designated as military special use airspace overlap with the study region.

Industry

*Automatic identification system (AIS)*

[Automatic identification system](https://services.northeastoceandata.org/downloads/AIS/AIS2022_Annual.zip) data for all of 2022 were analyzed for the study region. Count data were summarized at the annual level for all vessel types. Vessel types included are: cargo, fishing, other, passenger, pleasure craft and sailing, tanker, and tug-tow vessels at 100 by 100 meter cell resolution. These count data were rescaled using an adapted [z-shaped membership function](https://www.mathworks.com/help/fuzzy/zmf.html) to rescale between 0 and 1. Confining raster cells into hex grids caused hex grids to have multiple rescaled count values associated with them. To ensure that each hex grid had only one value, the maximum value got selected.

Fisheries

*Vessel monitoring system (all)*

The National Marine Fishery Service provided vessel monitoring system data between 2015 and 2019. Vessel monitoring system data provided geographic location data for vessels through their onboard satellite communication systems. The analysis used only data between 2015 and 2016. Data for those years had a different processing method than the more recent data since their source data came from a different dataset; one that covered between 2011 and 2016. Seven fisheries got summarized together for this product on their vessel activity: herring, monk fish, multiple species, pelagics, surfclam and quahog, scallops, and squid. These data do not differentiate between activities taken by the vessels; the data reflect approximate vessel locations at unique particular times. They do not inform if the vessels were fishing, transiting, or any other fishing-related activity. Any data not abiding by the “Rule of Three” were removed from the analysis.

With extents varying for the seven fisheries, the analysis calculated the maximum and minimum values for longitude and latitudes across the seven fisheries. Each fishery got extend to this main extent grid in order to calculate the mean value of the seven fishery counts between 2015 and 2016. An adapted z-shaped membership function (Equation 5) rescaled the mean values between 0 and 1. When more than one rescaled value existed in a hex grid, the maximum possible value was returned.

*Vessel monitoring system (< 4-5 knots)*

Vessels were deemed slow if they were transiting at below 4 to 5 knots in speed. That threshold is the [determining factor](https://neoceanplanning.org/wp-content/uploads/2021/09/Portal_FisheriesData_FinalReport_2021.pdf) between fishing and transit activity. Vessels in port did get grouped within the fishing activity as their speeds were less than the threshold despite not actively fishing. To abide by the “Rule of Three” standards, any locations with fewer than three unique vessel in a 1000-meter search distance were removed.

These data had fishing densities standardized with some densities as negative in relation to other densities. Densities were calculated using the equation:

The [authors preferred method](https://www.northeastoceandata.org/files/metadata/Themes/CommercialFishing/VMSCommercialFishingDensity.pdf) for users to understand the results were qualitatively through its five classes: very high, high, medium-high, medium-low, and low.

Fisheries extents got matched to the maximum coverage of all the fisheries together. The mean value of these fisheries between 2015 and 2016 was calculated before rescaling on an adapted z-shaped membership function (Equation 11). A z-shaped membership function assumes that all values are positive. To adjust to the negative standardized densities, the absolute value of the minimum standardized fishing densities got taken. This new value got added to every value across the dataset to have only positive values for running the normal z-shaped membership function on these shifted values (Equation 7).

For instances with more than one count value in a hex grid, the maximum count got returned for that hex cell.

*Vessel trip reporting (all gear)*

Vessel trip reporting for all gear types got processed using the adapted z-shape membership function (Equation 5). The maximum returned value was chosen when a hex grid had more than one value associated with it.

*Vessel trip reporting (charter / party)*

Charter and party vessel trip reporting data had the same processing approach as all gear types. No data existed in the study area, resulting in them getting excluded from the analysis.

*Cod spawning protection areas*

NOAA enact closures around [cod spawning areas](https://media.fisheries.noaa.gov/2020-04/gom-spawning-groundfish-closures-20180409-noaa-garfo.zip) to help manage their populations. Placing an aquaculture site located in the same location or in near proximity of these areas risks cod, thus those areas are less desirable for siting. No spawning areas intersected with the study region.

*Known cod spawning areas*

Other cod spawning areas were investigated to deconflict aquaculture sites with cod protection. None of these data overlapped in the study region.

*Large pelagic survey*

NOAA oversees a survey on large pelagic species between Maine and Virginia from June through October. Three surveys make up the data summarized within the data: intercept, telephone, and biological. These surveys aim to estimate total catch of these large pelagic species (*e.g.*, sharks and swordfish) and highly migratory species (*e.g.*, tuna).

A 16093.4 meters setback (10 miles) extended each of the survey data points. The survey catch data estimates were rescaled between 0 and 1 through the adapted z-shaped membership function and the maximum value returned per hex grid cell (Equation 5).

*Combined protected resources*NOAA produced a combined protection resources dataset with a geometric mean value giving a final value score. A total of 22 species were used to calculate the final geometric mean for this dataset. The adapted z-shaped membership function rescaled these values (Equation 5) and then returned the maximum value for each hex grid cell.

Submodel

The constraints submodel identified any hex grid that had any part of it interact with a constraint dataset. Any interaction was equally weighted for removal; thus 100% coverage was the same as only 0.01% coverage. The analysis also considered the number of interactions equally; a hex grid was removed regardless of it only having one constraint or five. A constraints hex grid returned all hexes across the constraints datasets that had a constraint. The final hex grid for analysis was comprised of all the hex grids outside of that constraint hex grid.

The national security submodel was composed of the military operating areas given that special use airspace did not exist within the study region. Any hex grids with overlapping with military operating areas were assigned a score of 1. Industry’s submodel was also comprised of a single dataset with the scores from the rescaled AIS dataset. Four datasets made up the fisheries submodel. These were VMS (all gear, 2015 – 2016), VMS (speeds under 4-5 knots, 2015 – 2016), VTR (all gear types), and large pelagic survey data. Without the cod spawning data due to the lack of those data in the study region, only the rescaled combined protected resources dataset contributed to the natural and cultural resources submodel.

For all the datasets, any hex grid that did not have a value assigned to it received a score of 1. These maximum values prioritized suitability. A geometric mean of the submodel data layers calculated the final submodel suitability score (Equation 2).

Geometric mean

A geometric mean calculated the submodel and final model’s suitability score. The product of each submodel’s data layers got multiplied by each other before taking the nth root. In this situation, all data layers are weighed equally and the results tend to assuage the influence of very large or very small values.

Final model

The final model comprised of five data layers: AIS vessel transits (all vessels) summed for 2022, VMS (all vessels transits) 2015 – 2016 under 4 knots, VMS (all vessel transits) 2015 – 2016 (4-5 knots), VTR (all gear types), and large pelagic survey trip points (2011 – 2021). The second iteration had removed the submodel structure. Two submodels were removed, leaving only industry and fisheries. The national security submodel only had values of 1, so its impacts was going to have the exact same influenced on all hex grids, so suitability scores would not change at all. The combined protected species layer was eliminated for the second iteration, meaning no natural and cultural datasets remained in the study area. These data were removed as they were originally designed for the offshore wind siting analyses. For the industry submodel, only annual 2022 AIS data existed. Instead of two submodels used to calculate the final suitability geometric mean, the analysis took the geometric mean of the five remaining data layers.

Rasters

All of the data that came as raster datasets required processing through one of the two adapted z-shaped membership functions. Each raster after rescaled was converted to a polygon feature without aggregation and then clipped to the study region. These data got indexed to the hex grid so that each cell got the required values when present for the particular dataset of interest.

Z-shaped membership function

This analysis adapted the [z-shaped membership function](https://www.mathworks.com/help/fuzzy/zmf.html) (Equation 3) as outlined by MathWorks. Where is the current value, equals the minimum possible value, and equals the maximum value.

In the original membership function, any instance that is equal to the maximum possible value would produce a 0. Constraints in this analysis received values of 0 to identify removal from the analysis. A new maximum is calculated by adding 1/1000th of the current maximum value to the maximum value (Equation 4). This avoids the continuous data getting misclassified as constraints (Equation 5).

A further adaptation was taken for the slow VMS data to account for the negative values within the dataset. The z-shaped membership function relies on the difference between the minimum and maximum values, and the relationship between that range. Negatives values affected this dynamic. Taking the absolute value of the minimum allowed that value to get added to all scores (Equation 6). These new values have the same relative distribution but shift the values higher proportional to the absolute value of the minimum possible value (Equations 7 - 9). To avoid the 0 values used for constraints, the new maximum value adjustment followed the same calculation that used an additional 1/1000th of the maximum (Equation 10). This absolute maximum value () replaced the previously adjusted maximum value () from Equation 4 (Equation 11).

Overlapping values

The shape and size of the hex grid cell led to the continuous datasets often passing multiple values to cells. The maximum value was returned and the only value used for those hex cells.

Considerations

The most recent analysis updated the depth considered optimal for aquaculture. A previous iteration constrained depths between 20 and 40 meters.

The mean for vessel traffic data and fishing data got used, though in a future analysis a summed data product could better reflect the activities. While the analysis took the maximum value when hex grids had two or more values, a minimum value approach would prioritize conservation more.

Numerous datasets were examined for analysis and in the original iterations. A few of the datasets did not exist within the study region and thus were not included in the final analysis. These data included: wastewater treatment facility outfall structures, ocean disposal sites, special use airspace, traffic reporting for charter and party vessels, cod spawning protection areas, and known cod spawning areas. Military operating areas were additionally removed from the second iteration of the modeling analysis. This left no national security submodel data layers.

Software and code

Data cleaning and analyses were performed using the R programming software (version 4.4.0, R Core Team 2024). Especially important R packages used include: arcpullr (0.2.9), dplyr (1.1.4), rmapshaper (0.5.0), sf (1.0-19), terra (1.8.5), tidyverse (1.3.1). All the relevant source code supporting this analysis are available at: <https://github.com/bpfree/westport_mussels_aoa>.