AQUACULTURE OPPORTUNITIES IN SAN DIEGO BAY

NOAA

PORT of SAN DIEGO
Environment

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This map atlas is a product of NOAA for use by the Unified Port of San Diego and other coastal managers to inform aquaculture siting in San Diego Bay, California. Map atlas and spatial analyses were performed by the NOAA National Centers for Coastal Ocean Science Coastal Aquaculture Siting and Sustainability program.

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- National Ocean and Atmospheric Administration (NOAA)
- Unified Port of San Diego
- City of San Diego
- U.S. Department of Defense (DOD)
- Bureau of Ocean Energy Management (BOEM)
- National Aeronautics and Space Administration (NASA)

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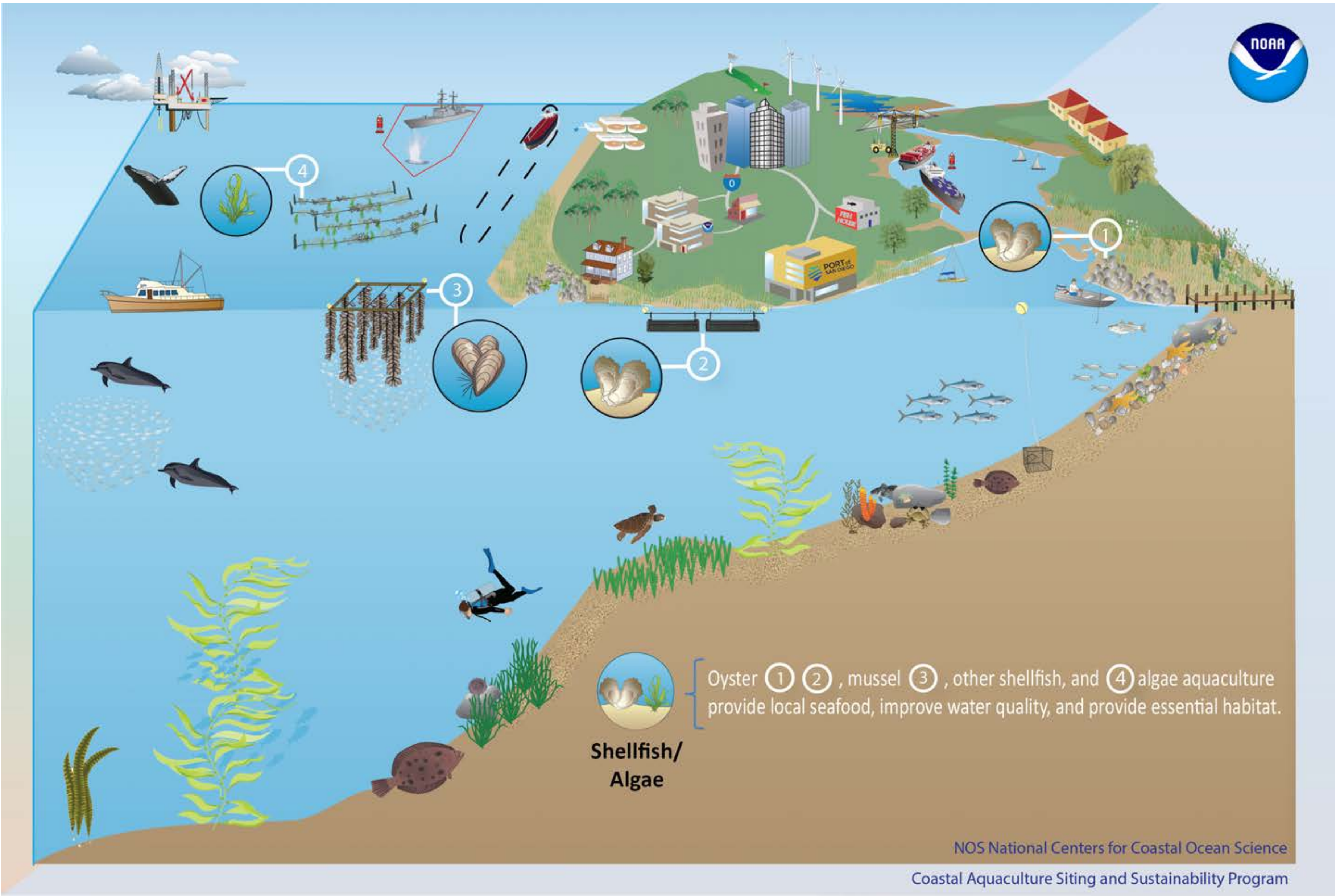
WHY AQUACULTURE IN SAN DIEGO BAY?

The United States aquaculture industry is growing at an unprecedented rate.
The U.S. currently imports over 90 percent of the seafood we consume, with over half of that seafood coming from aquaculture. The growth of the U.S. aquaculture industry could change this paradigm by providing high-quality protein, create jobs, relieve pressure on wild stocks, and decrease the current $14 billion dollar seafood trade deficit (NOAA Fisheries 2016).

The Port of San Diego can play a critical role in sustainable aquaculture.
The Port of San Diego's familiarity and expertise in the permitting and entitlement process for a variety of coastal and ocean uses makes it a candidate for aquaculture development. Since 2015, the Port of San Diego has been planning and completing pre-development work to support and inform aquaculture opportunities within San Diego Bay, California. As the state-legislated trustee of tidelands (i.e. land and water) around San Diego Bay, developing sustainable domestic aquaculture helps fulfill the Port's public trust responsibility to promote fisheries and commerce, as well as to enhance and protect the environment.

Photo | Octavio Aburto

An ecosystem approach to aquaculture requires the application of marine spatial planning techniques to ensure equitable shared use of Natural resources. Long term sustainability requires adequate and consistent environmental conditions and compatible interactions with other users over both space and time. Spatiotemporal planning for different types of aquaculture must also balance trade offs among environmental, social, economic, cultural, and management considerations.

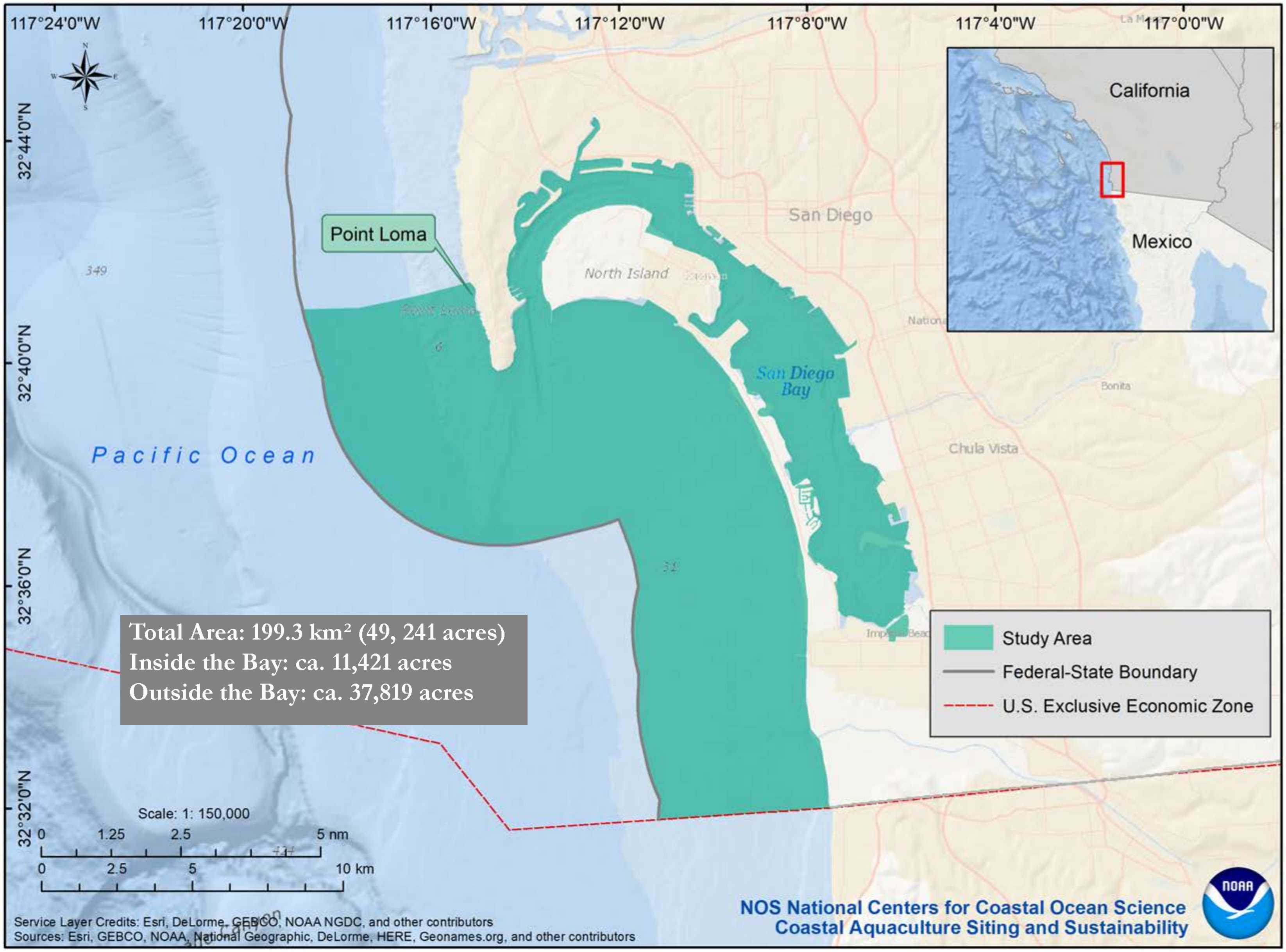


5 | An Aerial View of Northeast San Diego Bay

Photo | Dale Frost, Port of San Diego

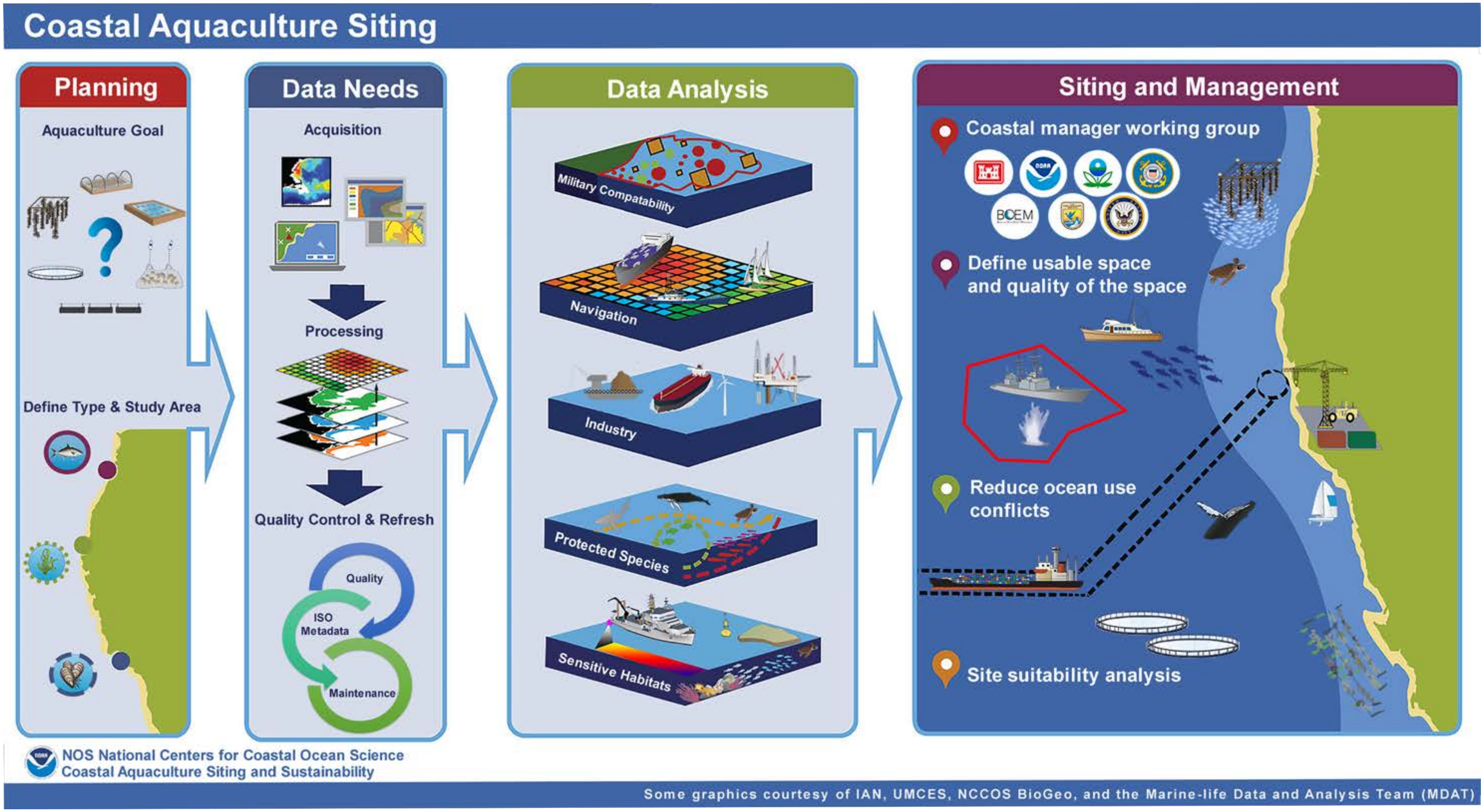
The Area of Interest

San Diego Bay is an important naval, commercial, and recreational hub on the southern Californian coast. This crescent-shaped bay is 18 miles long and bordered by two peninsulas separated at the mouth by about 600 meters (0.37 miles). The area of interest is confined to state waters and extends from Point Loma in the North to the U.S./Mexico border to the South. The total area of the area of interest is 199.3 km².



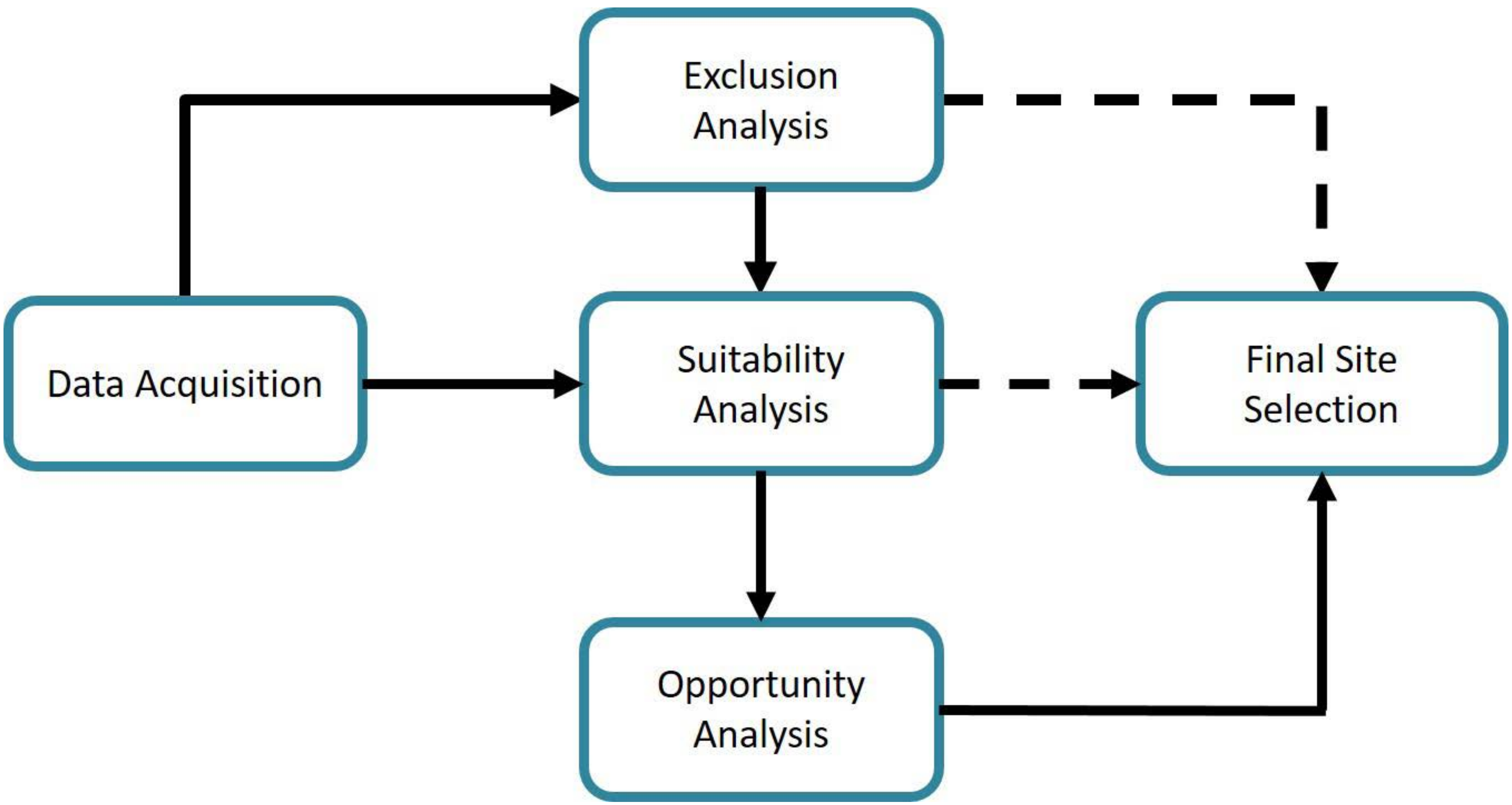
Marine Aquaculture Planning Process

Regardless of the complexity or scale of the aquaculture objective, the spatial planning process often follows a standard work flow by 1) identifying the planning objective, 2) inventory of data, 3) geospatial analysis of data, 4) interpretation of results, and 5) delivery of map products and reports to coastal managers and other end-users. This guiding framework informs site-specific aquaculture infrastructure management challenges while strengthening community resiliency and works to site the right type of aquaculture in the right conditions. Marine spatial planning incorporates and thereby mitigates many potential deleterious ecosystem-level impacts of aquaculture. For example, adjusting the mix of aquaculture types to enhance ecosystem function can only be done at an ecosystem level using a spatial approach, and with consideration of the background that the mix of aquaculture types is being added into.



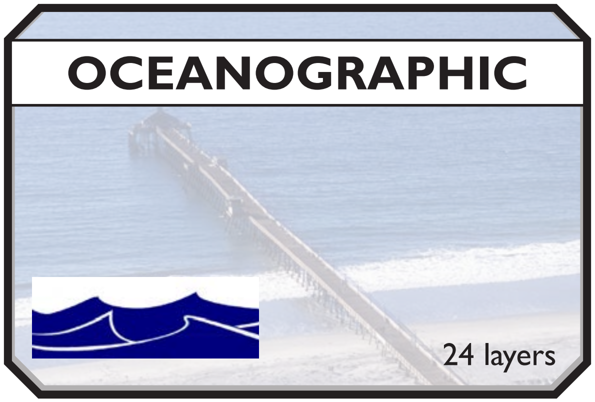
Marine Aquaculture Data Analysis Flow

Spatial planning generally begins with the data acquisition process, followed by QA\QC of the data, and any processing needed. After all necessary data have been obtained, then one can choose to use the exclusion analysis approach, whereby geospatial data associated with major constraining factors (e.g., military danger and restricted areas) within an AOI are used to exclude areas of known conflict from further spatial planning consideration. Constraints are removed from the initial AOI by: (1) removing the occupied or constrained area from the AOI, or (2) buffering the occupied areas based on safety considerations or other regulations and removing both the occupied and buffered area from the AOI. Once all areas associated with constraints are removed from the initial AOI, a suitability analysis can be conducted. These analyses can be completed with or without the exclusion analysis, for each final site selection. Suitability modeling refers to the spatial overlay and analysis of pertinent geospatial data layers within an AOI to identify and compare areas along a range of suitability (from unsuitable to highly suitable). This framework allows for identification of suitable potential aquaculture sites based on ecological, administrative, transportation, ocean industry, navigation, among other relevant factors. Here, we also consider various aquaculture gear and species thresholds together, to establish a foundation for the mix of aquaculture opportunities that may exist as well, through the use of an opportunity analysis.



Data Layer Themes

A total of about 170 data layers were included in a geodatabase to identify major constraints for aquaculture development in and around San Diego Bay. Data were acquired, vetted, and categorized into six major themes that inform major uses of coastal ocean space and inform potentially suitable areas for aquaculture development. Military data were layers are considered singularly in the layer count estimate.



*Photos courtesy of the Port of San Diego

Explanation of Data Layer Themes

Military

San Diego Bay contains several active military zones which should be avoided to reduce potential conflict with aquaculture operations. Areas such as the Silver Strand Training Complex, the Southern California Range Complex, and the Southern California Offshore Range are all accounted for in the geodatabase, as well as areas of unexplored ordnance, military danger zones, and restricted areas, and formally used defense sites.

Navigation

Transportation and navigation are routine operations in the Port and should be avoided when siting aquaculture to reduce interference with shipping channels and ensure a safe ocean space. Navigational data layers included shipping lanes, shipwrecks, navigational aids, vessel traffic, and maintained channels. In San Diego Bay, the Unified Port of San Diego provided specific areas to consider, such as the Port's jurisdictional boundary, marinas, mooring areas, buoys, wharfs, ferry paths, anchorage areas, and individual slips within the Bay.

Oceanographic

Physical oceanography, such as currents and waves, and the seafloor are important in determining if an area is suitable for aquaculture siting. The geodatabase for San Diego Bay included data on water currents, wave heights, water depth, sediment grain size, and pollutants. Water chemistry parameters which are important for shellfish and macroalgae growth, such as water temperature, conductivity, salinity, pH, turbidity, dissolved oxygen, light transmissivity, and chlorophyll α concentrations, were also included to identify areas better suited for production.

Biological

Possible interactions between aquaculture and any biologically relevant habitat, plants, or animals in the area must be examined to minimize potential conflict with protected areas. In San Diego Bay, species of particular concern include the Pacific Green Sea Turtle, seagrass habitats, and marine mammal activity in and around the bay.

Industrial

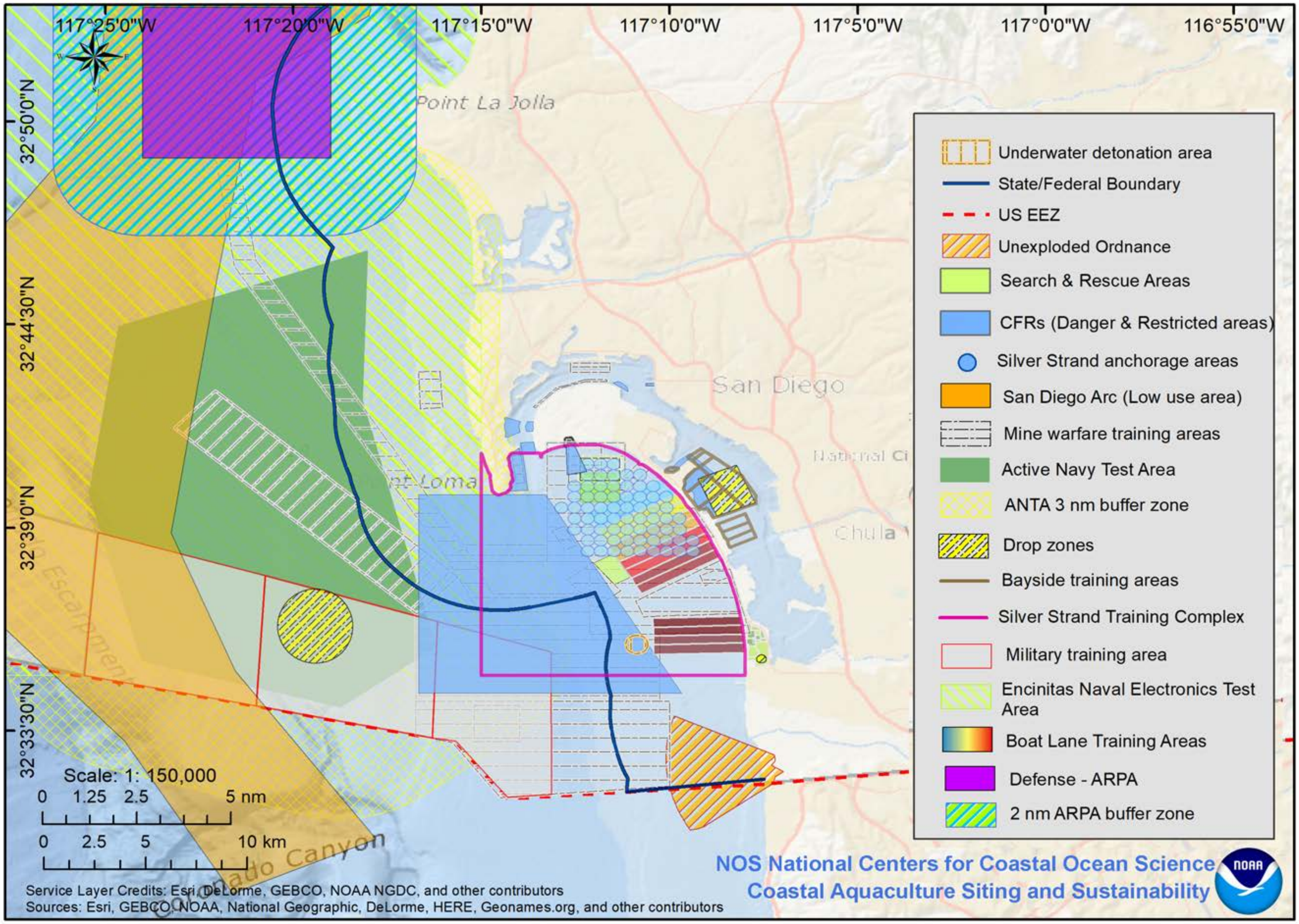
Industrial activities such as submarine cables, marinas, pipes, commercial fishing, and energy related activities may be avoided, or in some cases partnered with, to accommodate aquaculture activities. In San Diego Bay, the Port is working with numerous industries to accommodate and identify areas for aquaculture.

Administrative

Administrative boundaries are important considerations when it comes to permitting and planning for marine aquaculture. San Diego Bay is in state waters which are managed by numerous regulatory agencies, such as the Port of San Diego and the U.S. Department of Defense.

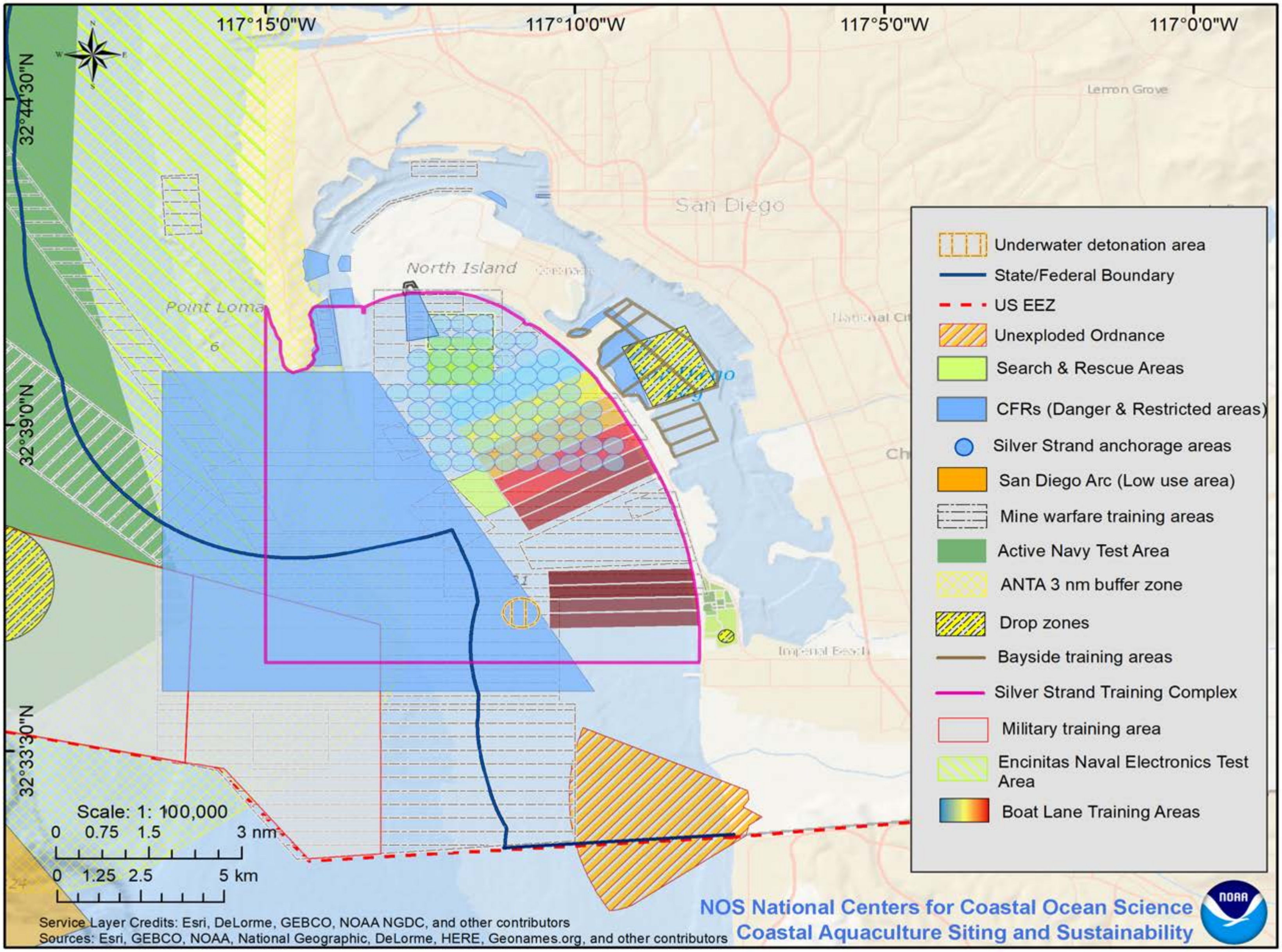
Military Use In and Around San Diego Bay

San Diego Bay is one of the most heavily militarized areas in the U.S., playing host to multiple strategically important training areas such as the Rim of the Pacific Multi-National Training zone and the Silver Stand Training Complex. Military areas are can be major barriers to aquaculture development and should be considered on a case-by-case basis when determining suitable areas for aquaculture development.



Military Use in San Diego Bay

This map is a closer look and better visualization of military operations within San Diego Bay. Inside the Bay area, several CFR areas (Code of Federal Regulations) exist, Bayside training areas for troops, and a designated military drop zone.

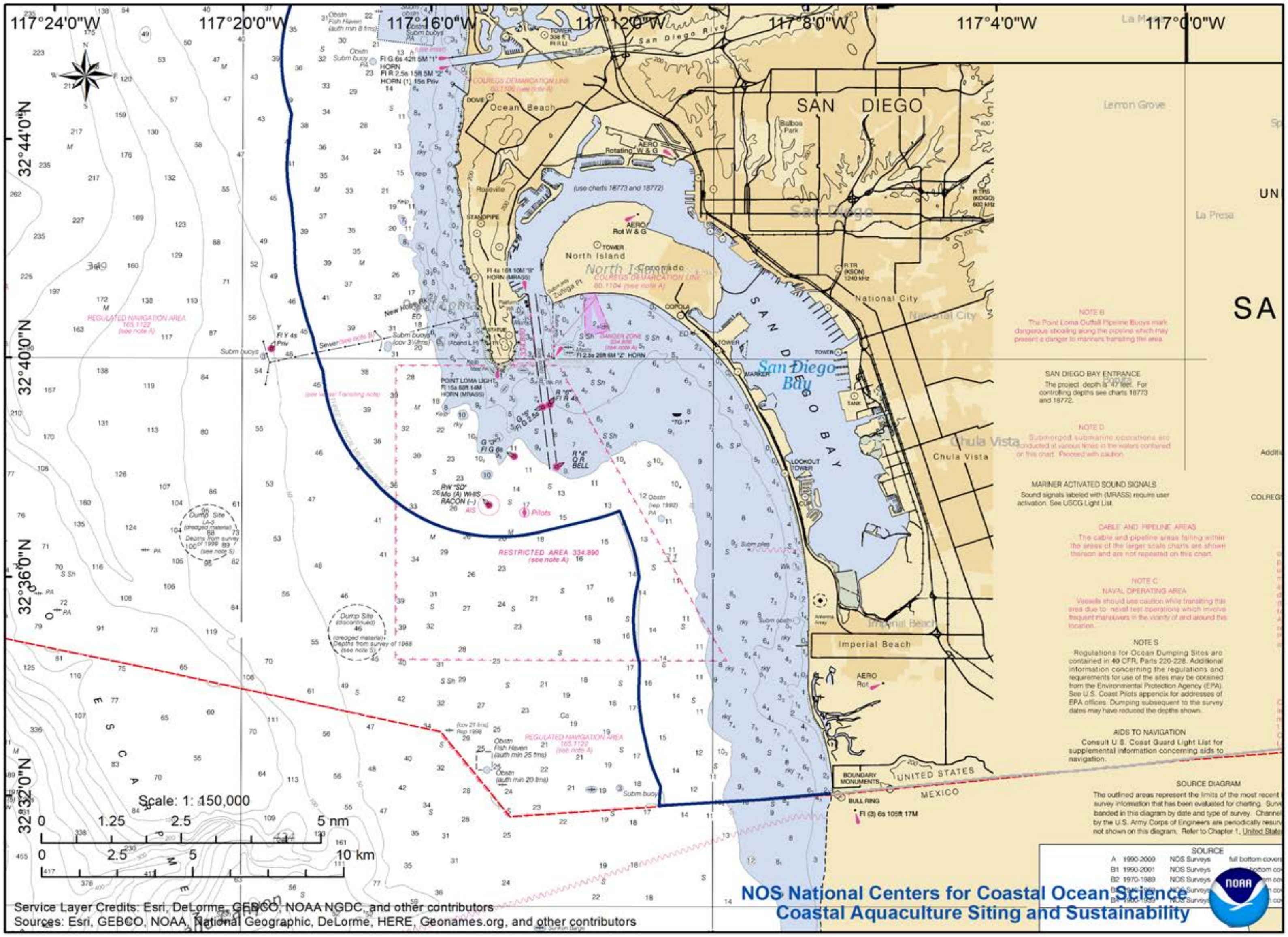


13| Photo of Pleasure and Military Craft Inside San DiegoBay

Photo | Arash Afshar, Port of San Diego

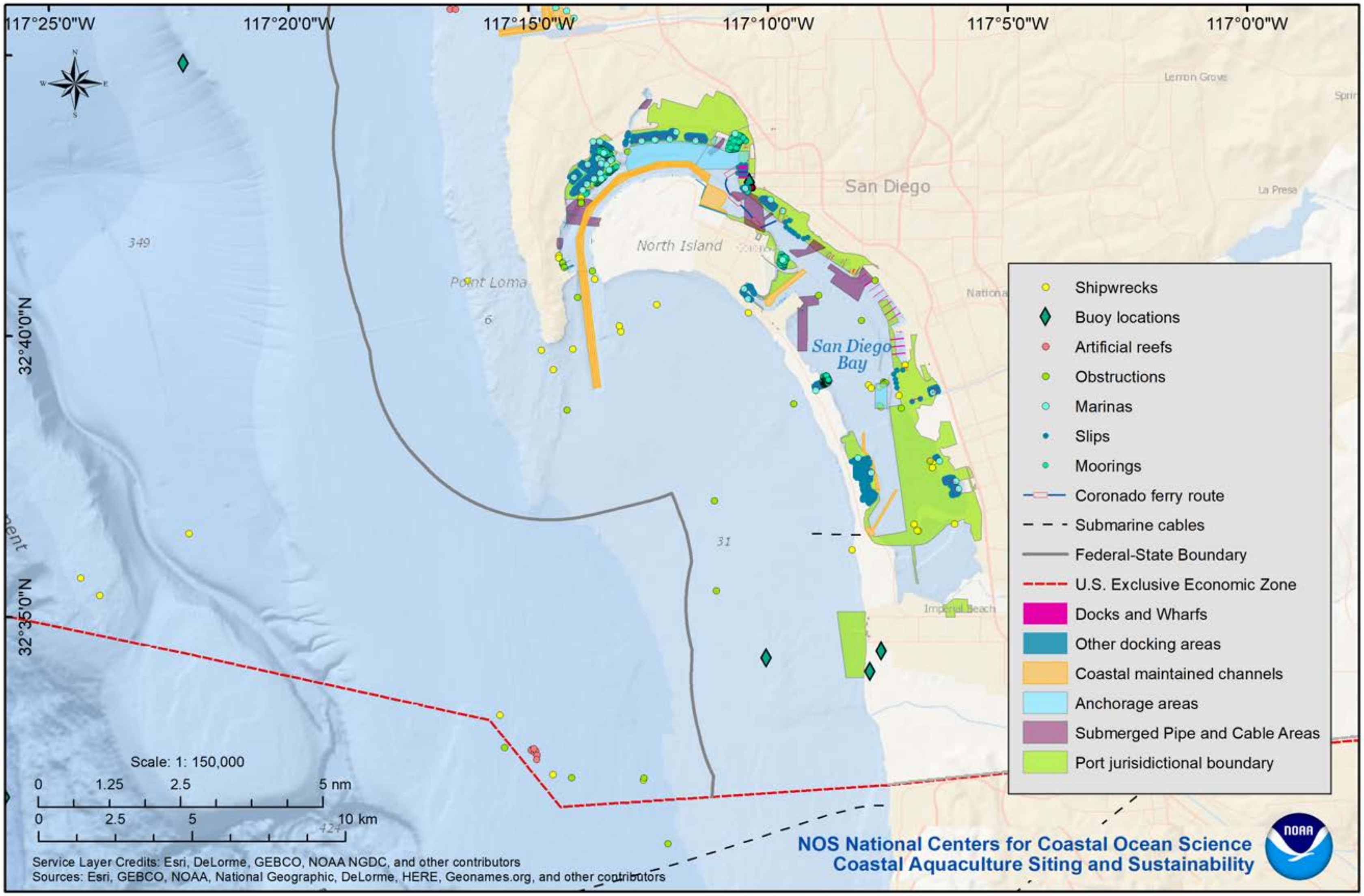
NOAA Nautical Chart

The NOAA Raster Nautical Chart (RNC), also called the Electronic Nautical Chart (ENC), is published and maintained by NOAA's Office of Coast Survey (OCS). All charts display water depths, coastlines, navigational hazards, aids to navigation, landmarks, and seafloor characteristics, as well as regulatory information. OCS updates the RNC on a weekly basis to make it one of the most up-to-date cartographic products for spatial planning of marine aquaculture.



Navigation, Transportation, and Industry Infrastructure

Navigation and transportation infrastructure are critical components of a port environment. Navigation infrastructure in San Diego Bay includes U.S. Army Corp of Engineers coastal maintained channels, anchorage areas, shipwrecks, artificial reefs, obstructions, marinas, slips, mooring areas, docks and wharfs, ferry paths, and the Port's jurisdictional boundary. All areas were considered constraints for aquaculture siting with the exception of the Port's jurisdictional boundary. Here, submarine cables and submerged pipeline and cable areas are also depicted, as these areas are constrained as well. Siting aquaculture requires avoidance of overlap with these features, as to not interfere with existing port operations.



Vessel Density

Dense ship traffic areas are important to avoid when siting for aquaculture to reduce conflict with existing navigation channels. The 2013 vessel traffic data represent the approximate number of commercial vessels using coastal waters within the U.S. Exclusive Economic Zone (EEZ) over the course of a year. Here, the 2013 data indicates heavy traffic in and out of the San Diego Bay. Largely driven by Port activities, the heavy vessel traffic areas were excluded as potentially suitable area for aquaculture.

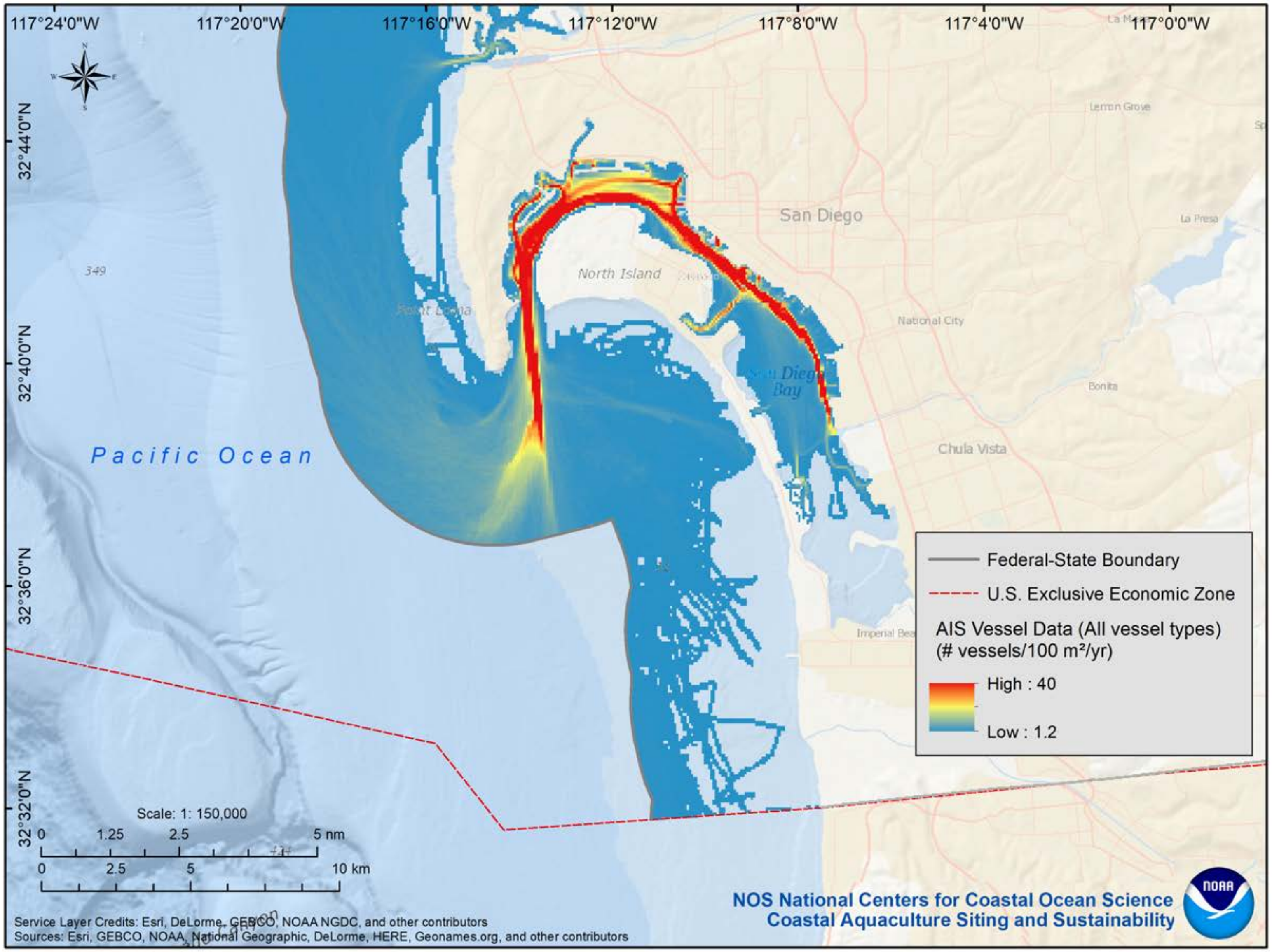
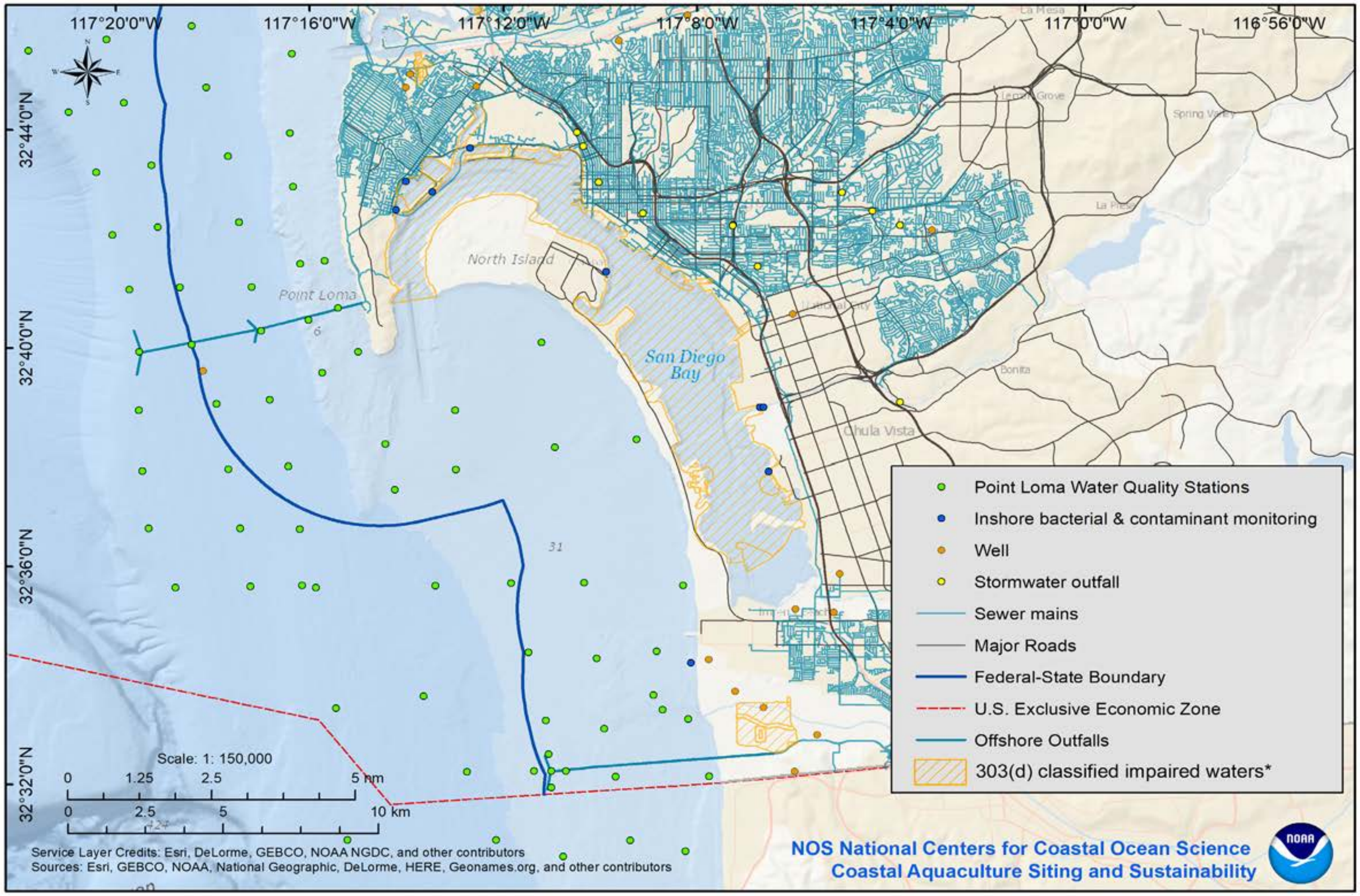


Photo | Port of San Diego

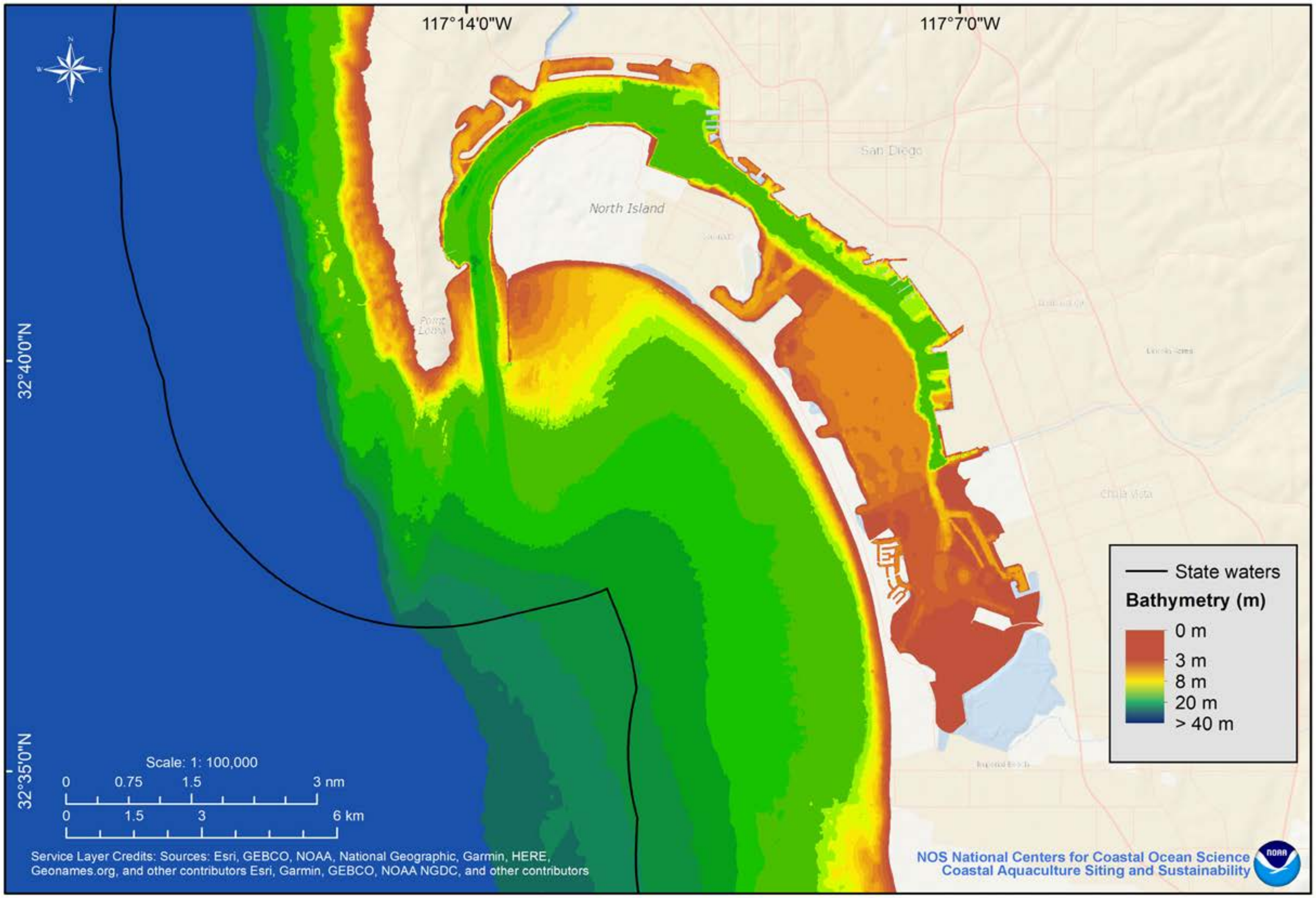
Water Quality

Water quality can be influenced by land use, stormwater runoff, wastewater treatment facilities, and numerous other natural and human-derived sources. In many cases, shellfish and macroalgae aquaculture can improve water quality by filtering the water and removing excess nutrients. Here, the sewer mains are represented in blue around the San Diego area. Water mains follow the same general schema, but are not shown. There are two main offshore wastewater outfalls in the San Diego Bay area - the Point Loma outfall (average discharge rate = 180.62 MGD) (Contreras et al. 2017), and the Tijuana outfall (southern most). The Point Loma outfall has an extensive monitoring program (green dots) to determine plume size and plume composition. Inside the Bay, 8 stations are in place for bacterial and contaminant monitoring. Ten stormwater outfalls are represented here (yellow dots), indicating points where excess rainfall will enter into the Bay. Sixteen oil and gas wells (orange dots) are located within the San Diego bay area, including 6 with listed status as buried, 8 are idle and have not been used in two years, and 2 are plugged and abandoned. 303 (D) areas in the Bay are being addressed by TMDLs.



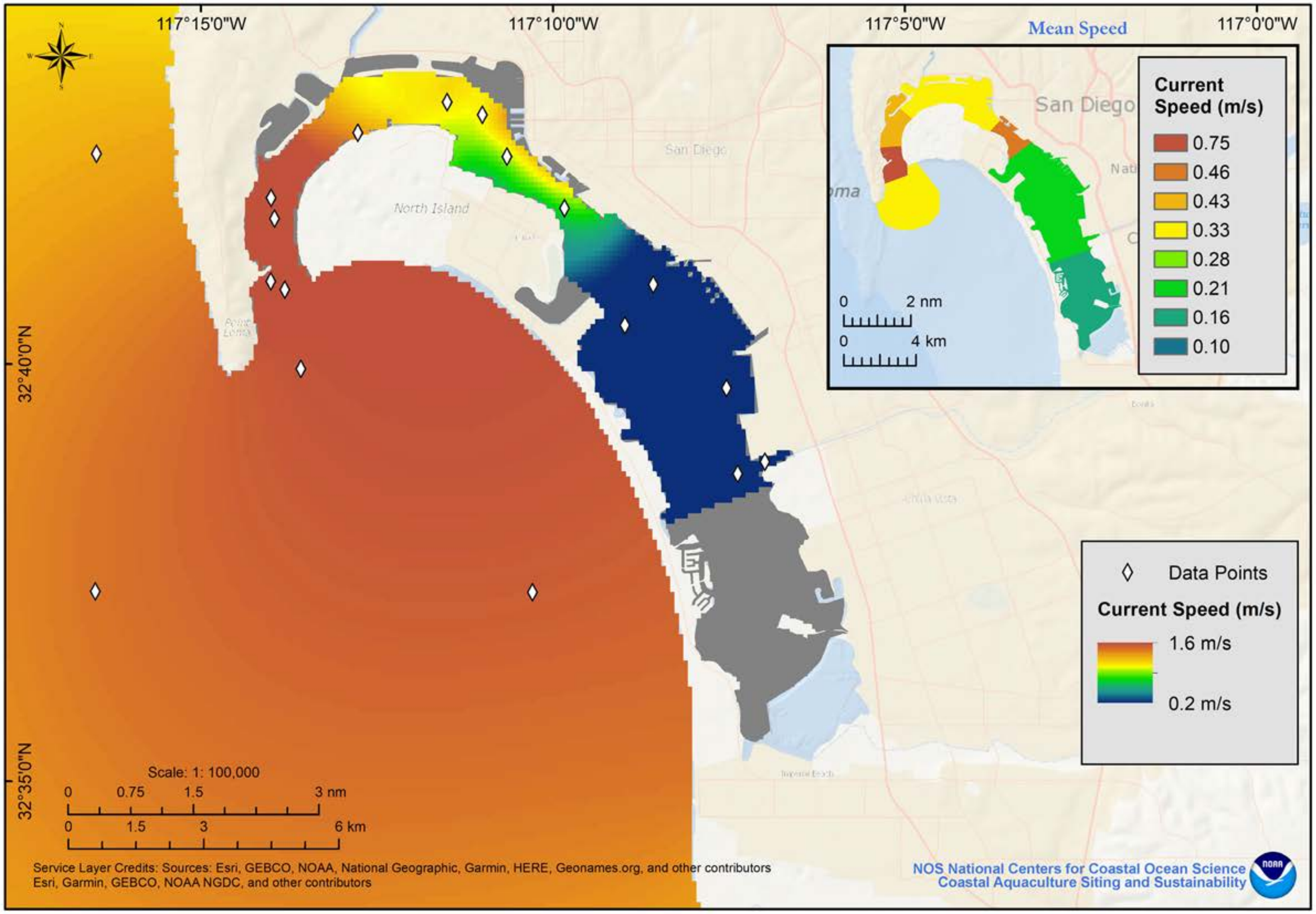
Depth (m)

Depth, or bathymetry, is important to consider when deciding which aquaculture species to grow as some species prefer deeper depths, while others grow better in shallow water. Depth was derived from a seamless, high-resolution (3 m) coastal digital elevation model (DEM) produced by the U.S. Geological Survey (USGS) for Southern California (https://pubs.usgs.gov/ds/487). The average depth of the bay is about 6.5 m (Wang et al. 1999). The southern portion of the bay is the shallowest water in the study area. Coastal maintained channels in the Bay can also easily be identified here, as the deeper, green-colored areas in the Bay. These depths are necessary for deeper draft vessels to navigate into and out of the Port area.



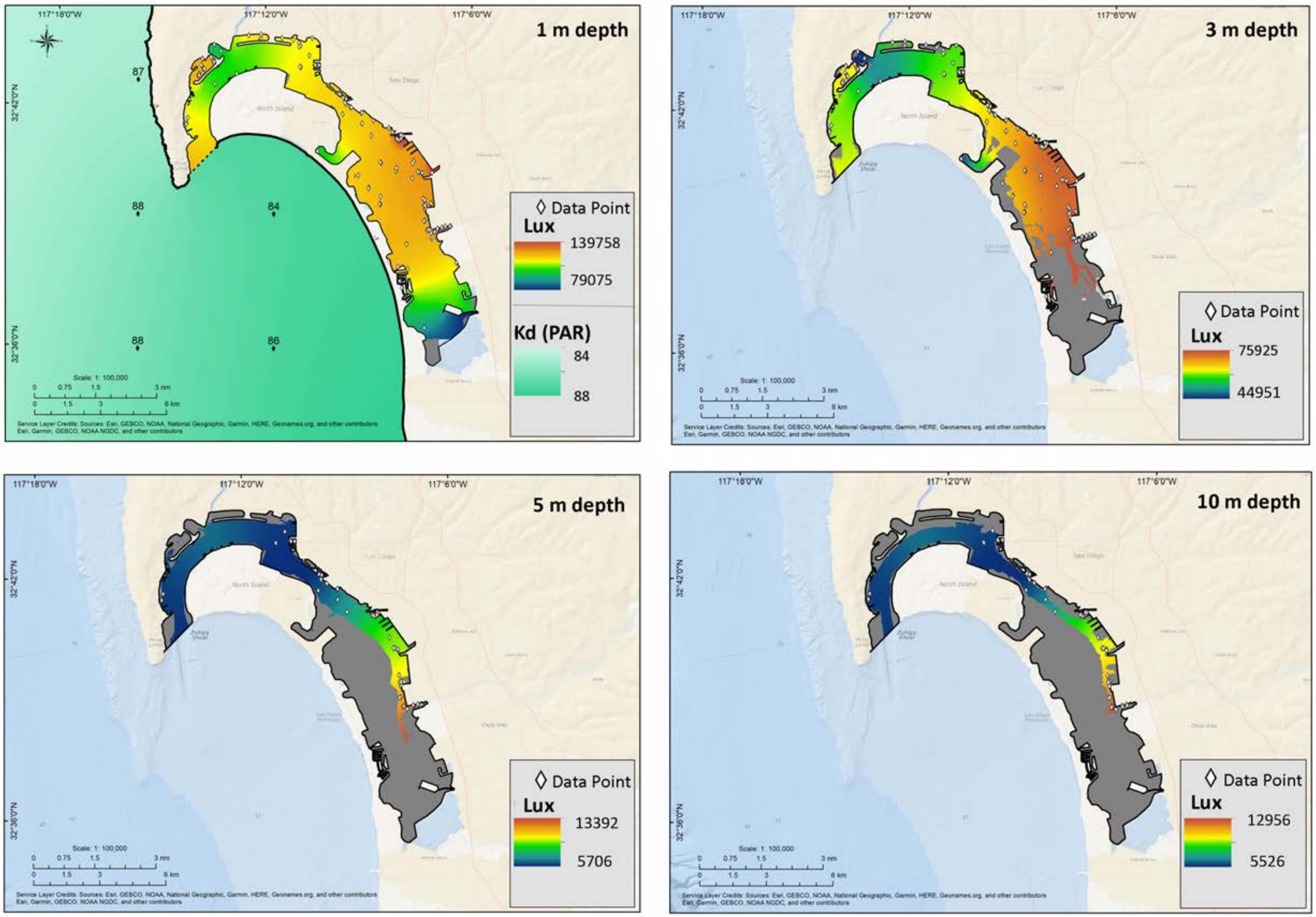
Tides and Currents

Currents that are too strong can weaken aquaculture gear over time, or currents too weak can limit aquaculture by not providing enough food for plants and animals to filter feed. The currents in San Diego Bay are primarily influenced by tides, with typical tidal current speeds between 0.3 - 0.5 m/s near the inlet and 0.1 – 0.2 m/s in the southern portion of the bay. Mean tidal range is about 0.85 m, with a maximum tidal range during spring tides exceeding 2 m (Wang et al. 1999). The interpolated surface was created from maximum current speeds, illustrating areas of episodic high flow. Data for the outside of the Bay were obtained from the HYCOM 4-km surface current model. Gray areas inside the bay represent areas where no buoy data were available or are sheltered areas with different flow regimes. The map inset illustrates estimated surface and tidal current mean values from literature, ADCP data from June through August of 2017 (UCSD), and imperial observations.



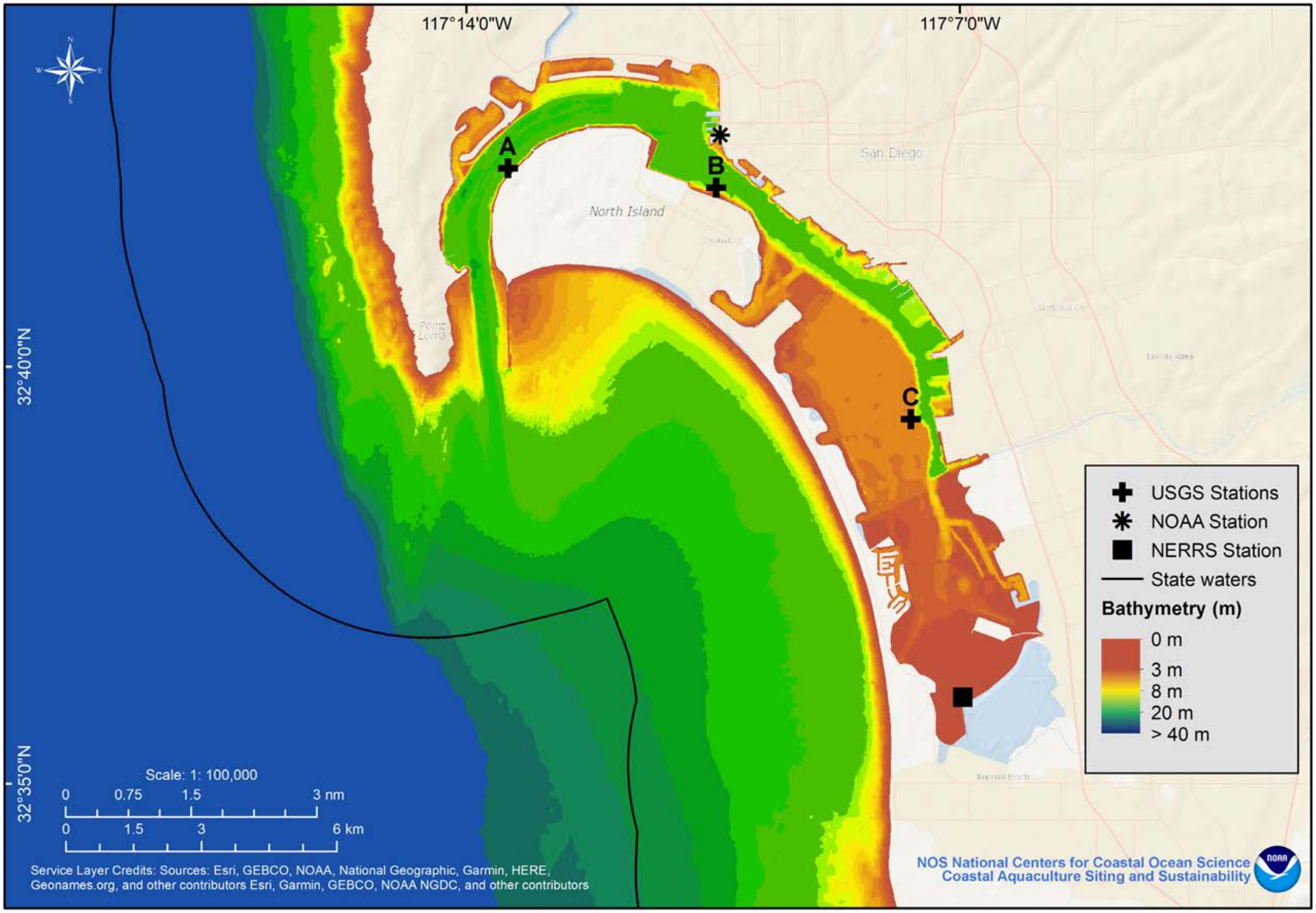
Light Intensity

Light intensity is important for micro and macro algae to photosynthesize, and was considered for the suitability analysis. The attenuation of light is the reduction or gradual loss in light intensity through a medium (water in this case). Light attenuation affects the production of photosynthetic organisms in the water column, based on the depth, water clarity, and photons reaching the plant. Gray areas represent areas that are too shallow to be characterized for that particular depth group. At one meter depth, Kd(PAR) data were used outside of the Bay, while Lux was used inside the Bay. Blue waters represent the lowest light levels, while orange and reds represent the highest level of light reaching that depth. Areas with low light are due to deeper depths, increased tidal and current action, as well as freshwater inputs.



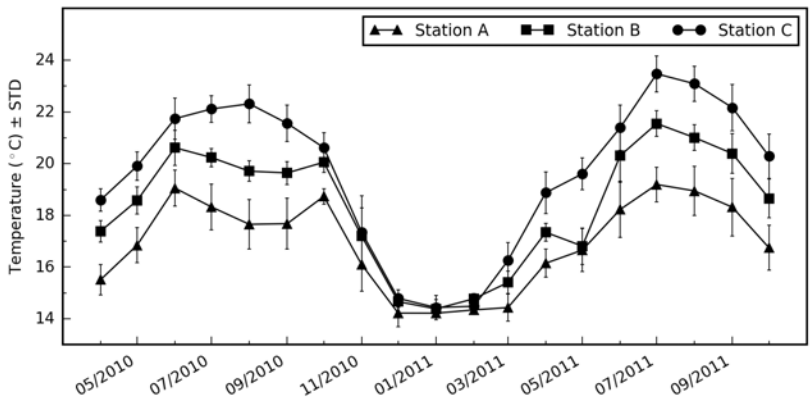
Environmental Monitoring Stations

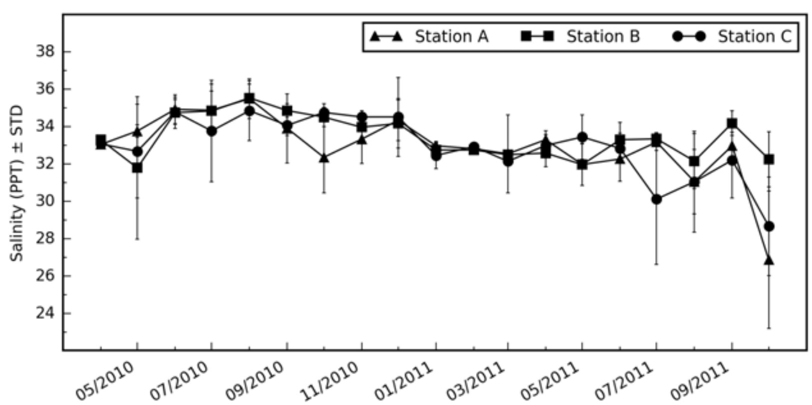
In order to determine which aquaculture species can be grown in San Diego Bay, as well as determining which gear types to use, oceanographic conditions (water current speed, depth, pH, salinity, temperature, dissolved oxygen, and chlorophyll concentrations) were obtained from monitoring data to identify areas that will offer aquaculture operations to experience the greatest chance of success. There are five environmental monitoring stations within San Diego Bay (see map below), and data from all stations were compiled and presented here to determine annual trends in oceanographic conditions to identify opportunities for different aquaculture species and gear types based on their respective thresholds.

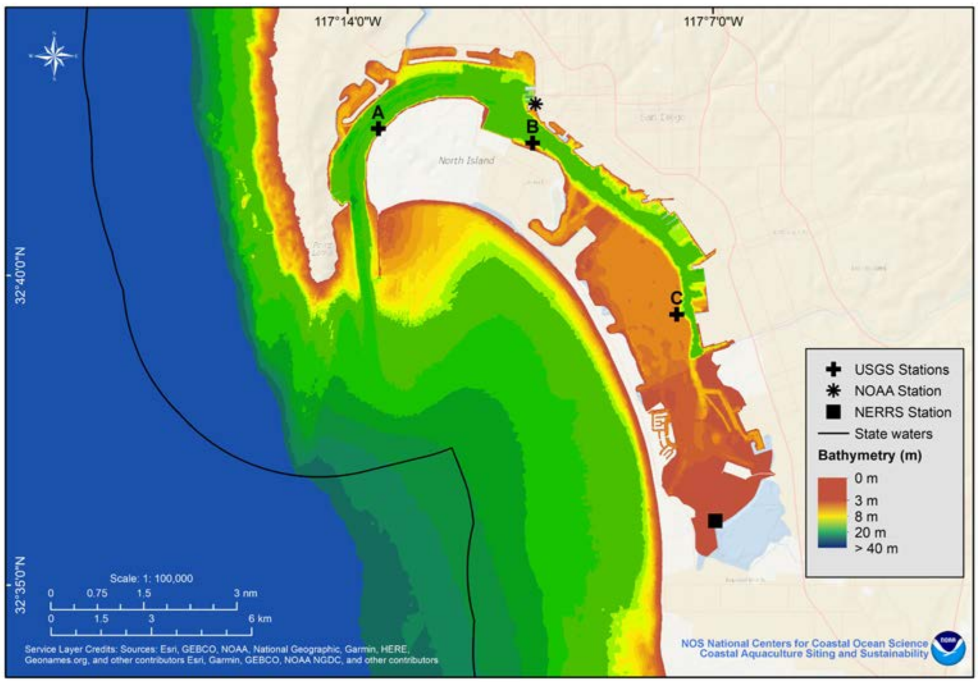


Temperature and Salinity

Trends in several oceanographic conditions (depth, water current speed, pH, salinity, temperature, dissolved oxygen, and chlorophyll a) were compiled from April 2010 to October 2011 to identify suitable combinations of aquaculture species and gear type in different sections of San Diego Bay. Temperature ranged from 12 - 24°C during the sampling period. Salinity in the Bay ranged from 32 psu to 36 psu.

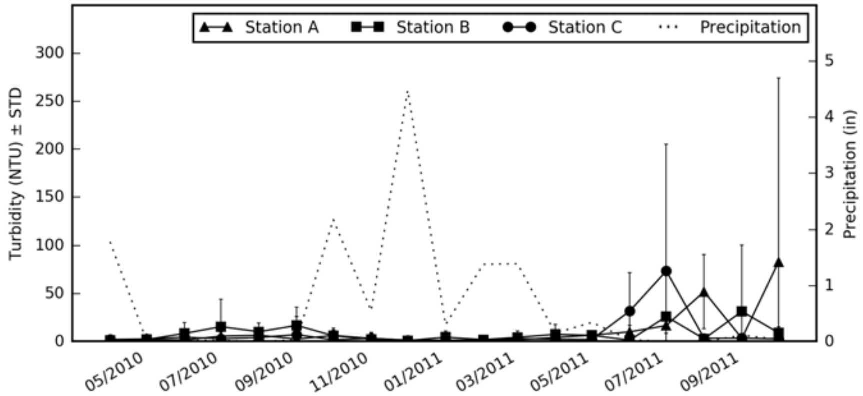


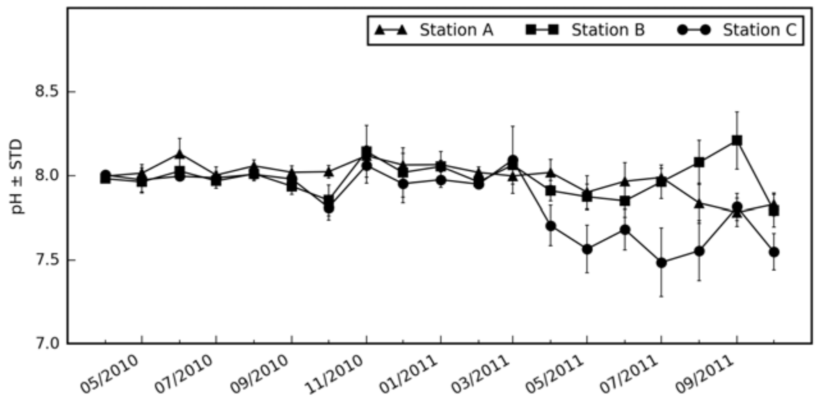


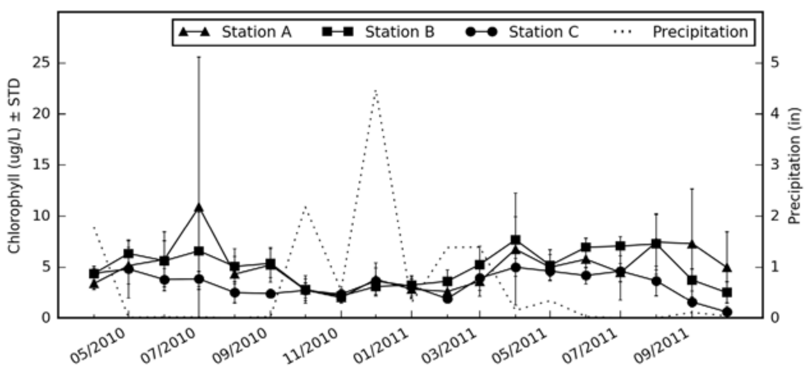


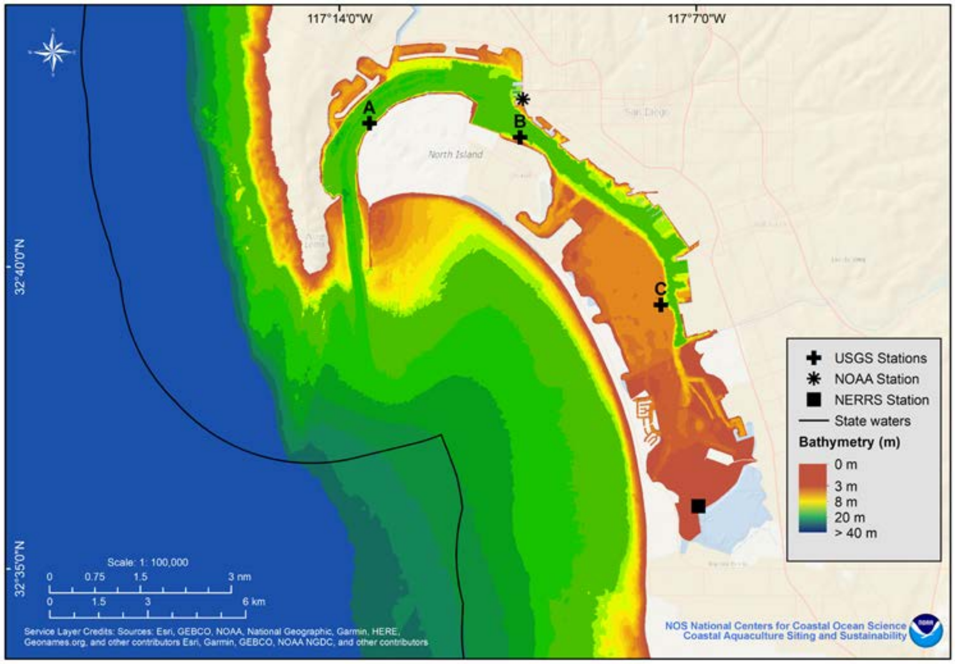
Turbidity, pH, and Chlorophyll a

Trends in turbidity, pH, and chlorophyll-a were compiled from April 2010 to October 2011 to identify suitable combinations of aquaculture species and gear type in different sections of San Diego Bay. Turbidity (NTUs) in the Bay is relatively low, even with increases in precipitation. pH stays relatively stable (8.0 - 8.2) throughout the Bay, based on the sampling station data. Chlorophyll-a also stays relatively stable (~5 µg/L).



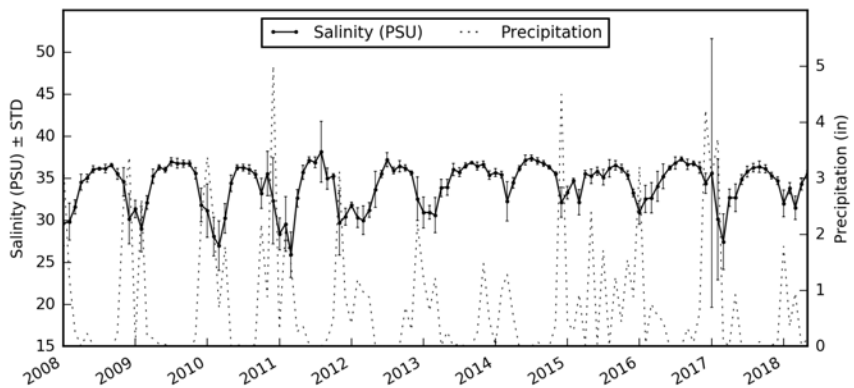


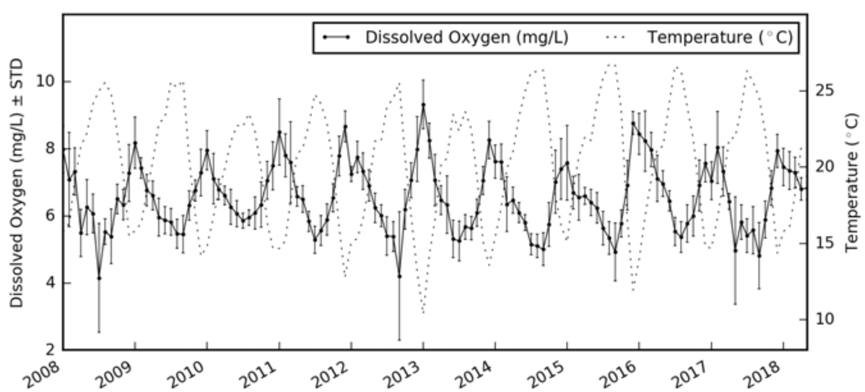


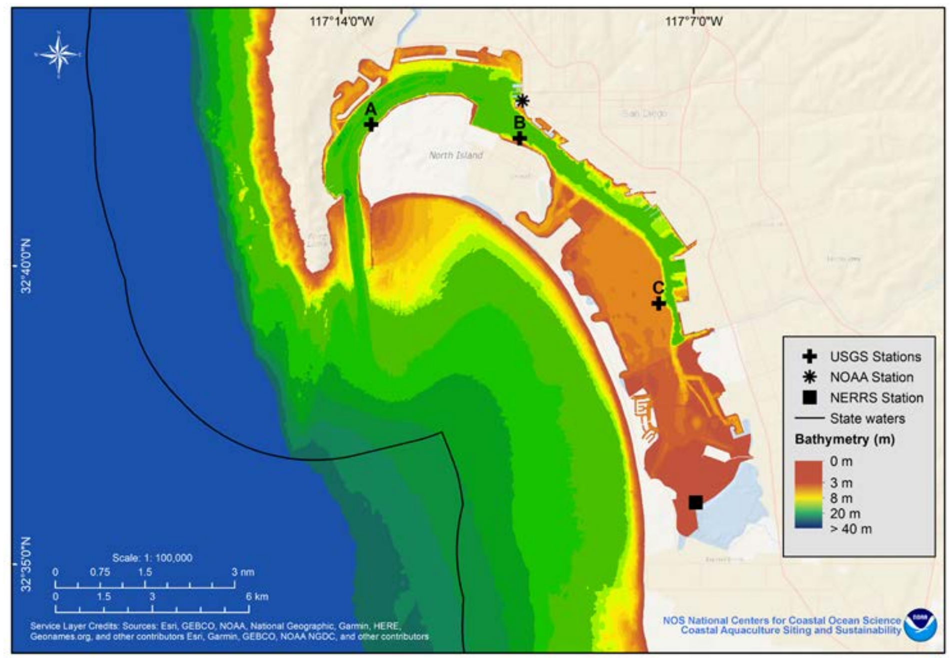


NERR Water Quality Station

The National Estuarine Research Reserve (NERRs) system monitors water quality in the southern part of San Diego Bay. Data for temperature, salinity, and dissolved oxygen (DO), and were compiled from 2008 to 2018 and represent monthly averages. Trends were analyzed to determine the accuracy of the data. The top graph indicates when precipitation occurs, salinity drops in the back, or southern portion, of the Bay. When temperature increases, dissolved oxygen decreases confirming general trends known to occur based on natural phenomena.







Important Areas for Marine Mammals

The migration and feeding behavior of marine mammals and protected species should be considered when siting aquaculture because these animals can get caught in certain types of aquaculture gear. Important areas for blue whale feeding and gray whale migration are present outside of San Diego Bay. A small group (n = ~60) Pacific Green Sea Turtles ave home ranges within the southern part of the bay. Deep sea corals are present outside of the Bay, but still within the area of interest. Seagrass, an important habitat for many species, is also present inside and at the mouth of the Bay.

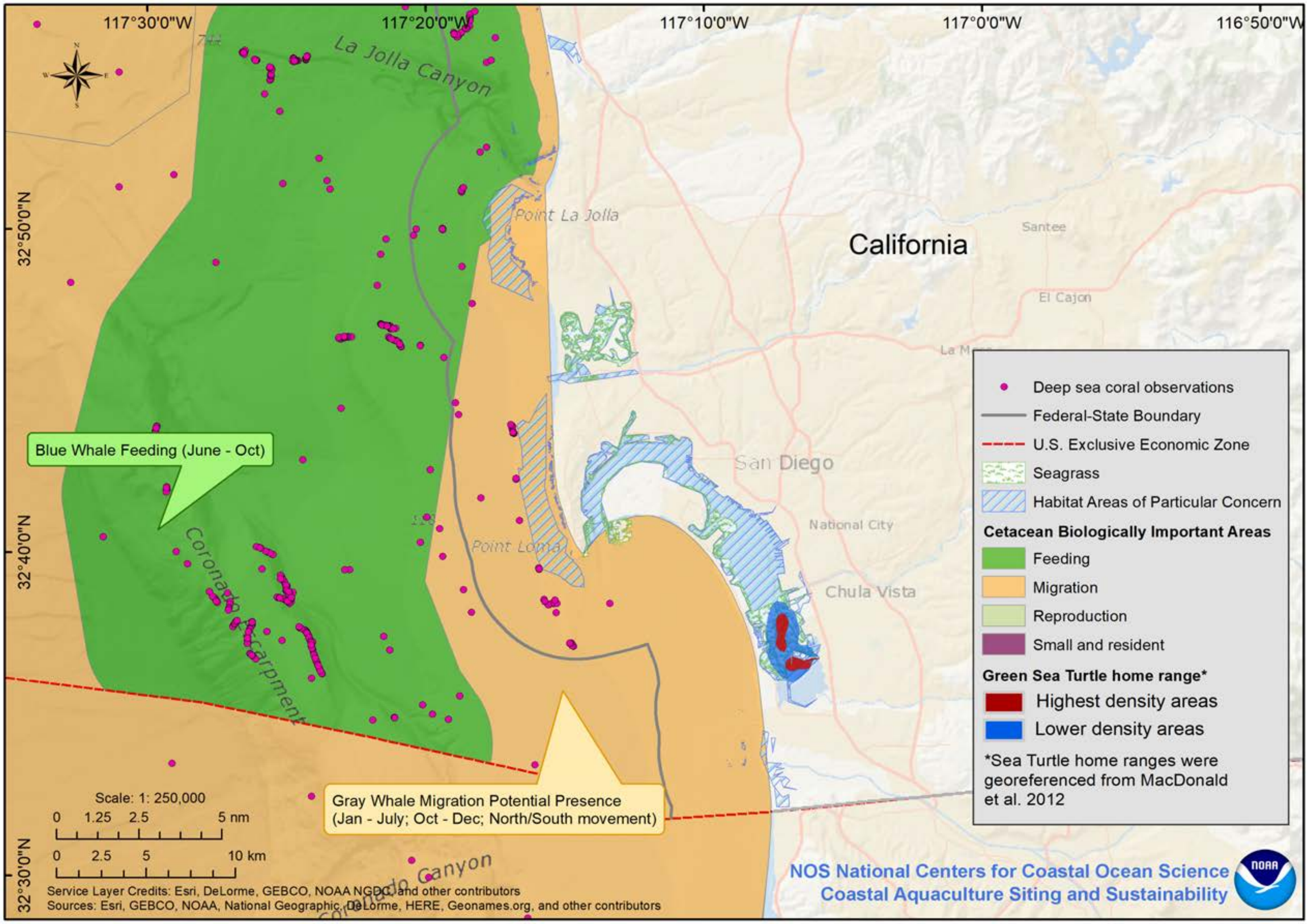
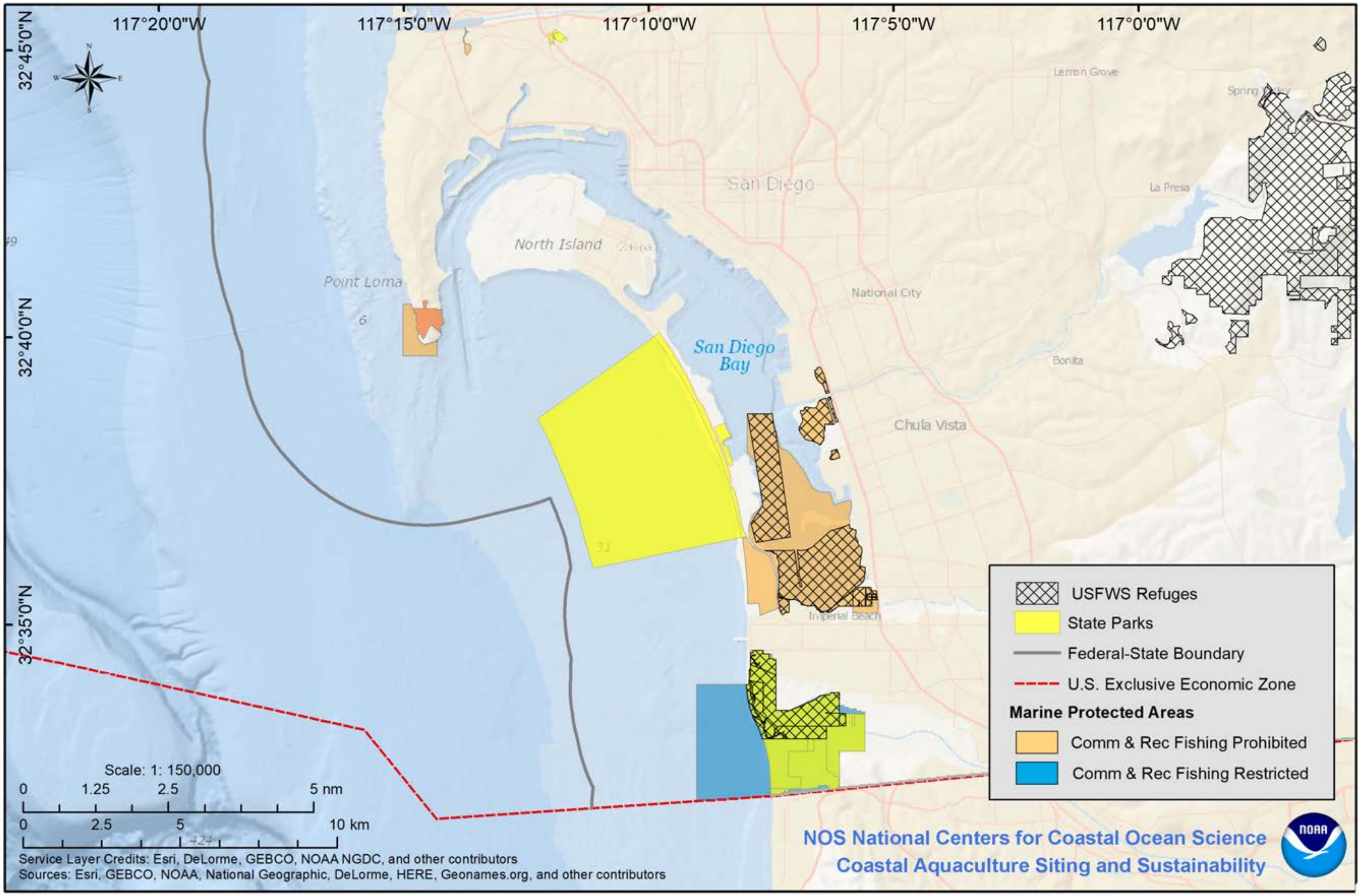


Photo | Port of San Diego

Marine Protected Areas

Marine Protected Areas could either benefit or constrain aquaculture production, meaning restoration aquaculture could be beneficial to a protected area, but commercial aquaculture could be hindered by a no-take zone. San Diego Bay contains a U.S. Fish and Wildlife refuge in the southern portion of the bay which overlaps with a marine protected area that prohibits commercial and recreational fishing due to the presence of protected Pacific Green Sea Turtles. State parks are present outside of the Bay, including Silver Strand State Beach and Border Field State Park.



Exclusion Analysis

This exclusion analysis identifies the greatest constraints from each data layer theme and removes areas from consideration that would prevent successful aquaculture development. The result is a more concise map that highlights all the usable area within and surrounding the San Diego Bay, minimizing conflict with other public trust uses and has suitable conditions for economically and environmentally beneficial aquaculture operations.

The exclusion process includes activities that are most limiting to aquaculture development in San Diego Bay.

First, the greatest constraint to siting for aquaculture is military operations. Military training areas were therefore the first to be removed from consideration.

Second, major constraints identified by the Port Authority such as heavily-used navigation channels for cruise and cargo ships, marine protected areas, and popular areas for socioeconomic activity were combined into a single exclusion map and removed from consideration.

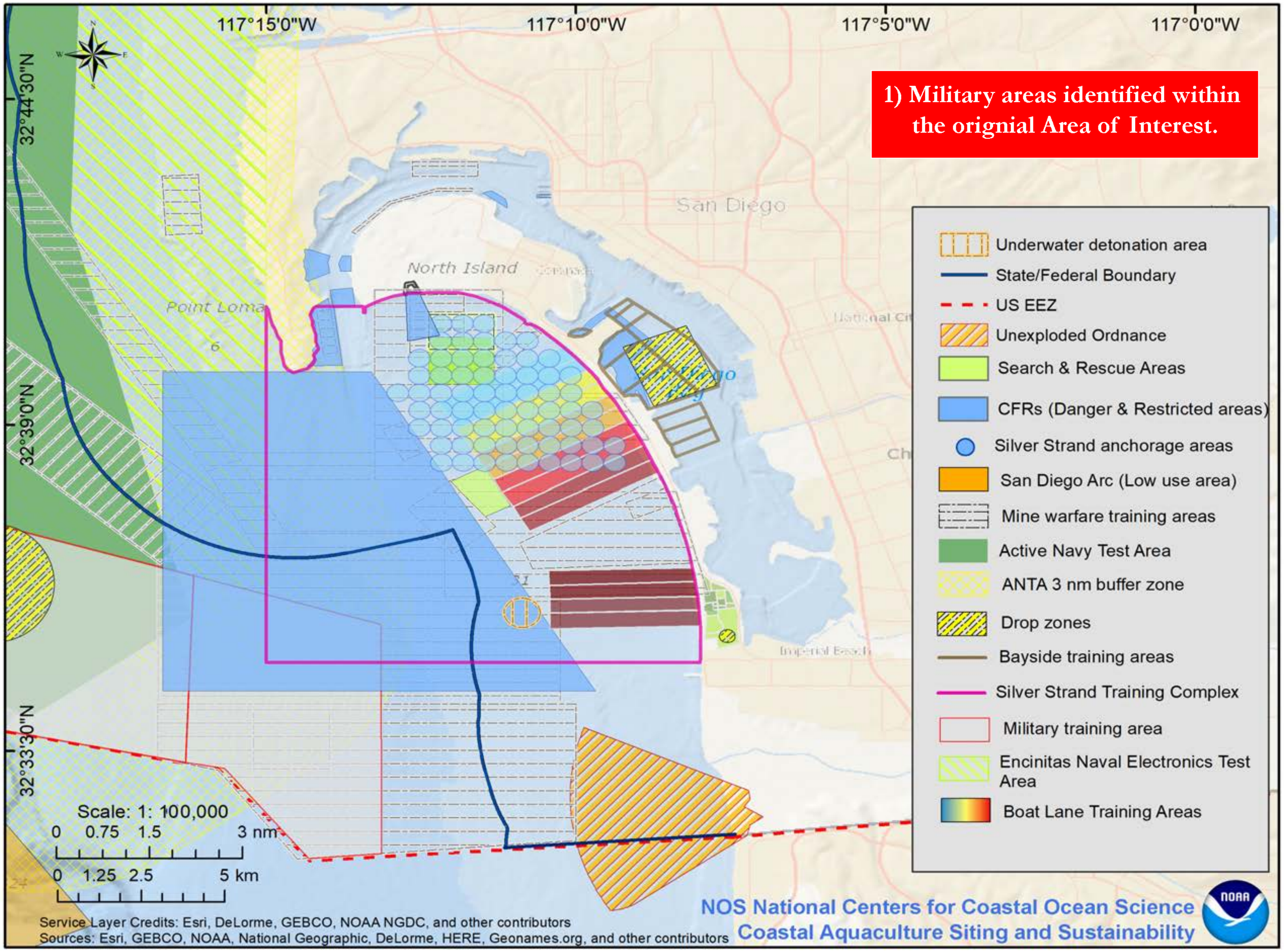
Third, areas that were considered too small or shallow for an aquaculture operation to be successful were manually excluded.

With all major constraints removed from consideration, the final map highlights only the areas with the greatest potential for marine aquaculture. Some of the data layers also included a buffer area to ensure aquaculture operations would be far enough away to avoid interference with activities such as military exercises or vessel traffic.

Photo | Arash Afshar, Port of San Diego

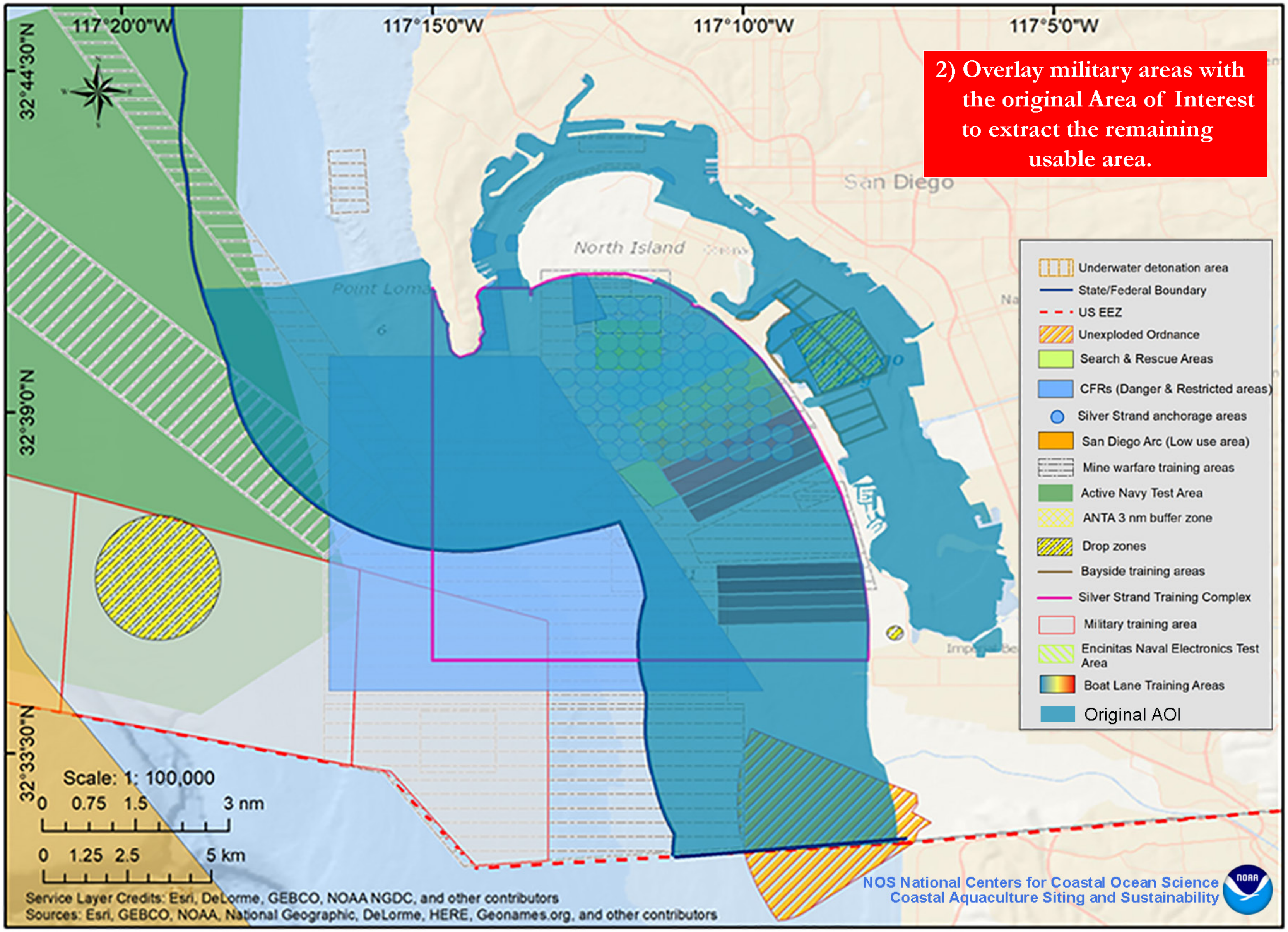
Military Excluded Areas

Military data layers were identified by and obtained from the U.S. Department of Defense for planning purposes only. All military operations within and around the designated areas were considered conflicting uses after conversations with the DOD.



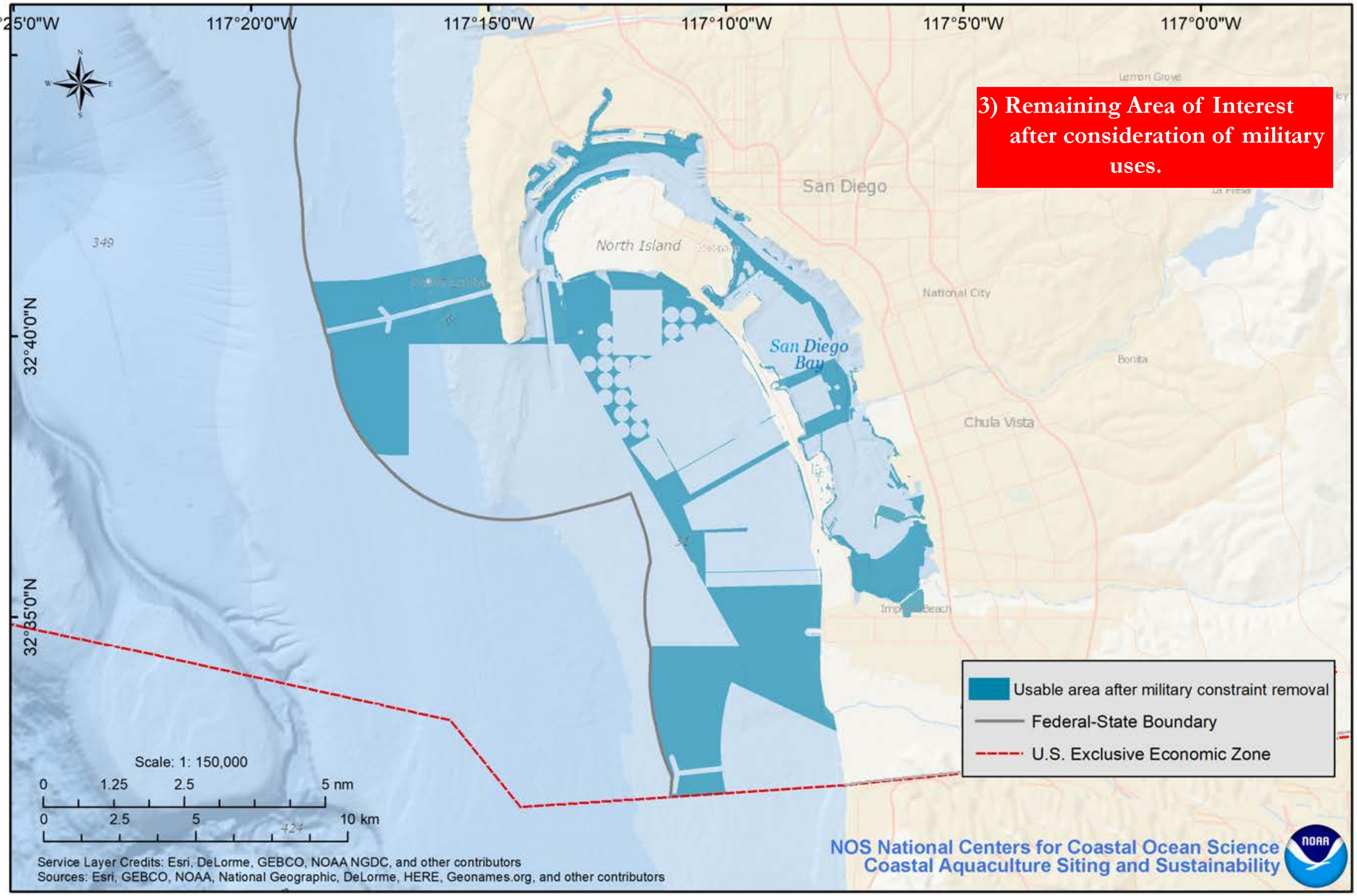
Military Excluded Areas

Military data layers were then overlaid with the original area of interest (blue overlay). We then removed the area where overlap occurred as these areas were considered conflicting uses and subsequently excluded from the usable area for aquaculture development.



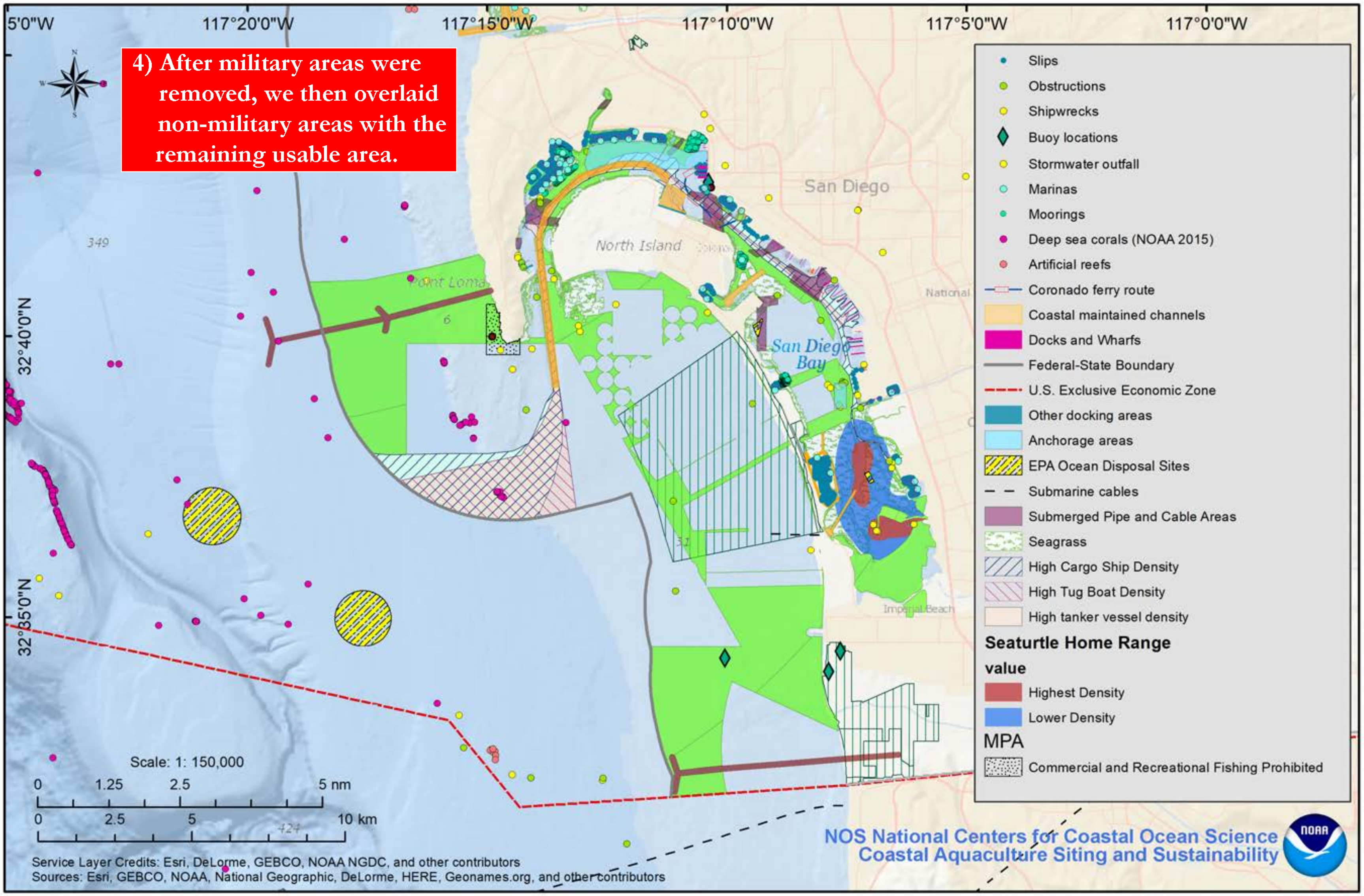
Usable Area after Exclusion of Military Areas

The usable area, highlighted in blue, after all military constraints were removed from the original area of interest.



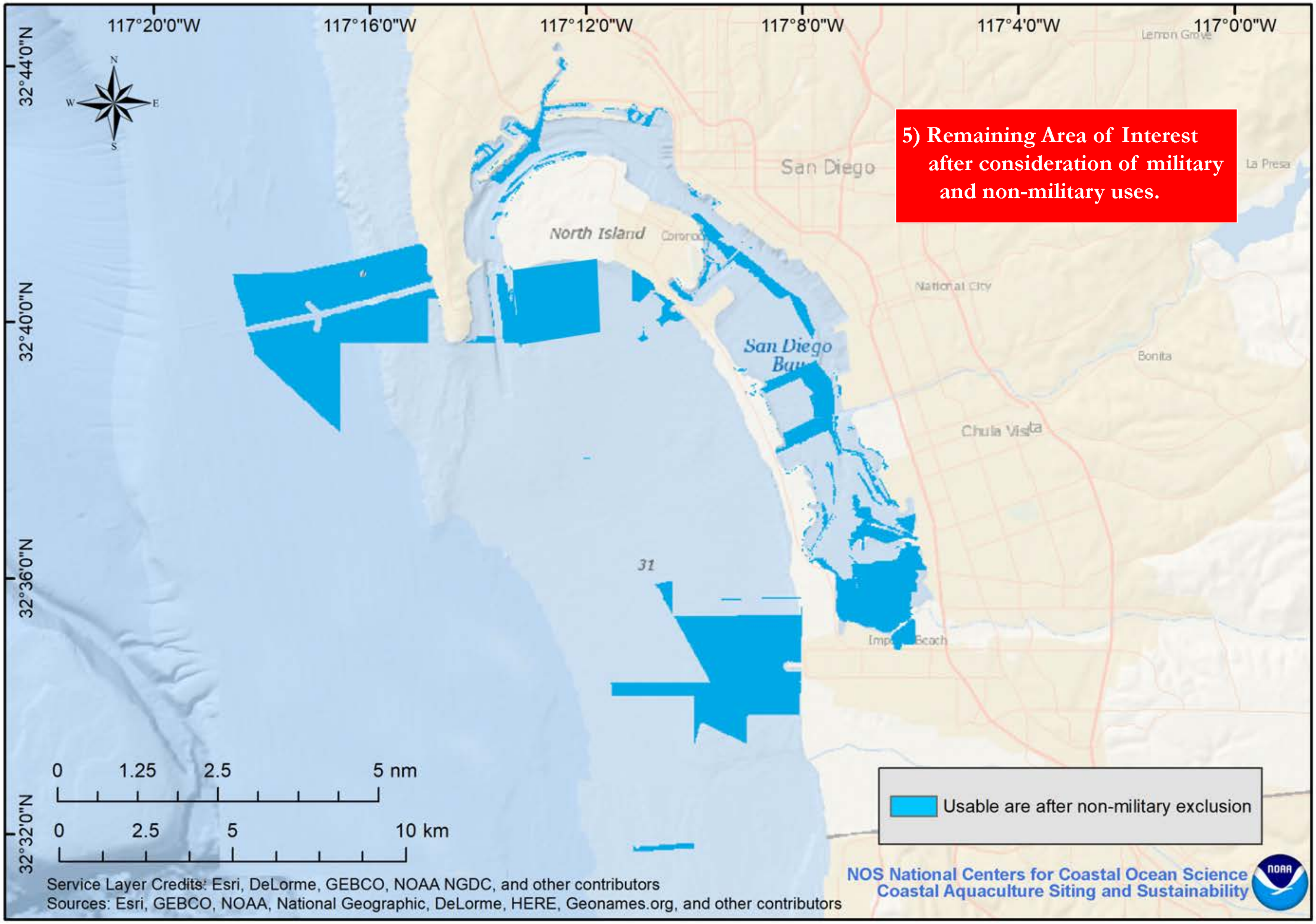
Non-Military Excluded Areas

After all military constraints were removed, non-military priority areas were excluded from the usable area for potential aquaculture development. These areas largely included navigational and industry constraints, as well as wastewater treatment plant outfalls, recreational areas, and important biological areas, such as those with submerged aquatic vegetation and in the southern part of the bay, those areas for the endangered Pacific Green Sea Turtles.



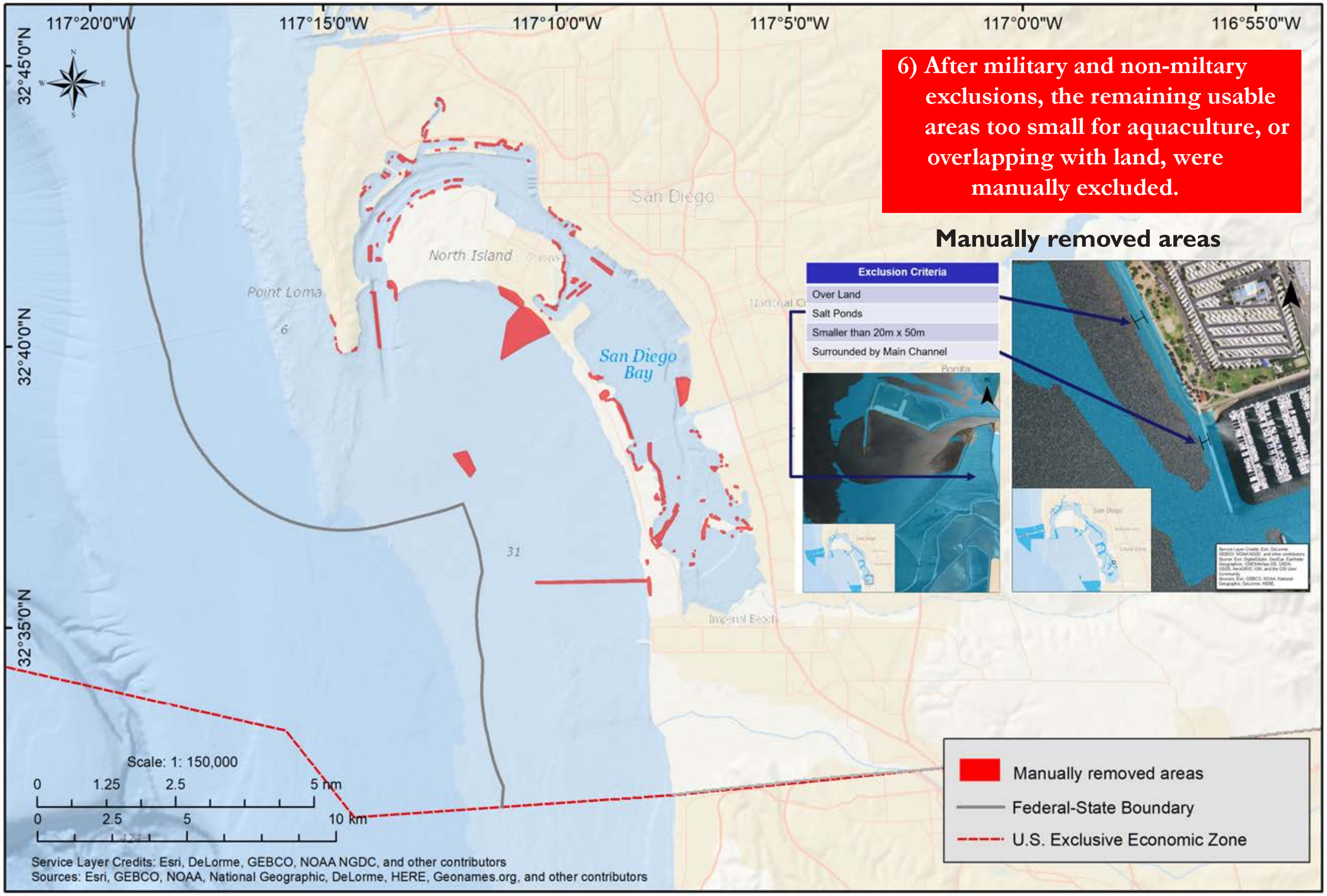
Usable Area after Exclusion of Non-Military Areas

The usable area, highlighted in blue, after all military and non-military constraints were removed from the remaining usable area.



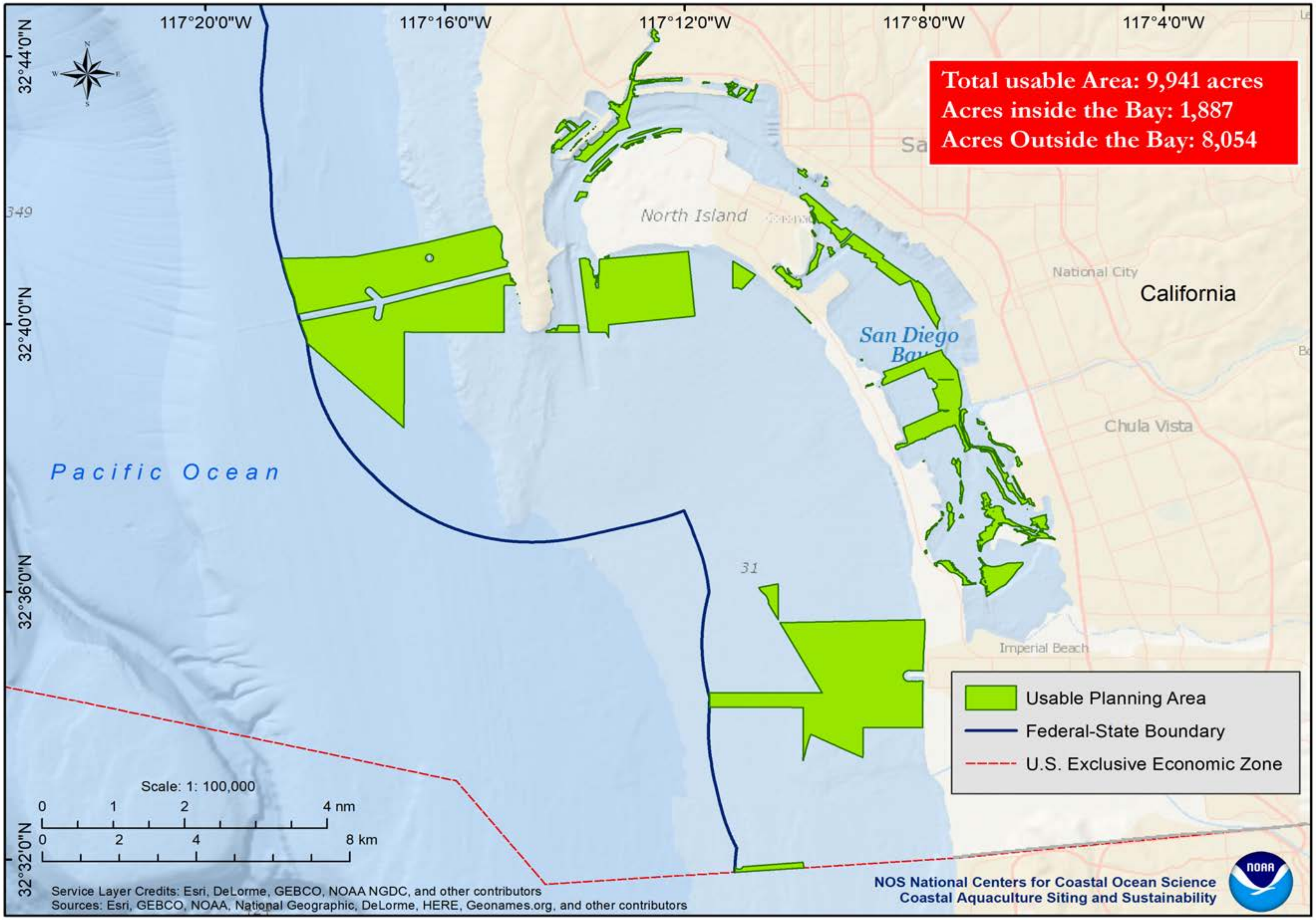
Manually Excluded Areas

Using the output layer from the previous exclusion steps, we overlaid satellite imagery to identify any portion of the usable area over land and removed them from the map. Next, we measured individual sections of the usable area, and identified areas that could not contain a rectangle of 20 meters by 50 meters (i.e. areas too small for aquaculture) and removed them from the map.



Final Usable Area for Aquaculture Development

The final usable area, highlighted in green, after all military, non-military and manually excluded constraints were removed from the original area of interest.



Suitability and Opportunity Analyses

A suitability analysis, a type of multi-criteria analysis, allows for identification of the most suitable areas from a set of candidate areas, as defined by applying a set of individually weighted criteria, for a specific purpose (Esri 2018). Here, reclassification of individual layers was completed according to defined thresholds derived from an extensive literature review, expert opinions, industry documentation, and empirical observations. All reclassified layers were weighted equally, as to not place more importance on one parameter over another.

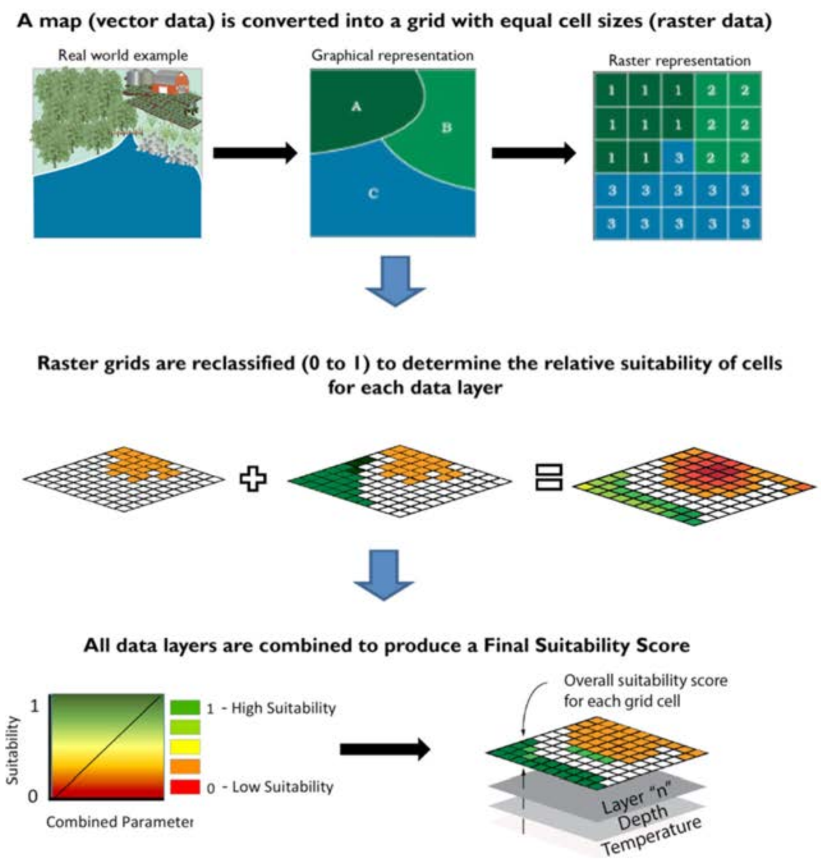
A suitability analysis can be conducted with or without an exclusion analysis conducted before hand. In this case, there were numerous constrained areas (e.g., military, transportation), and therefore an exclusion analysis was performed to remove areas with little to no compatibility with aquaculture infrastructure before suitability was examined. Also, because we are gauging opportunity, we included no additional buffers around military areas, and left the USFWS refuge in for analysis. Although conditionally constrained, the Port's strategic partnerships with these entities can lead to projects that may be restorative to the area. Once constrained areas were removed the suitability analysis examines and identifies areas suitable for numerous parameters (e.g. depth, water temperature, water current speed) based on relative compatibility.

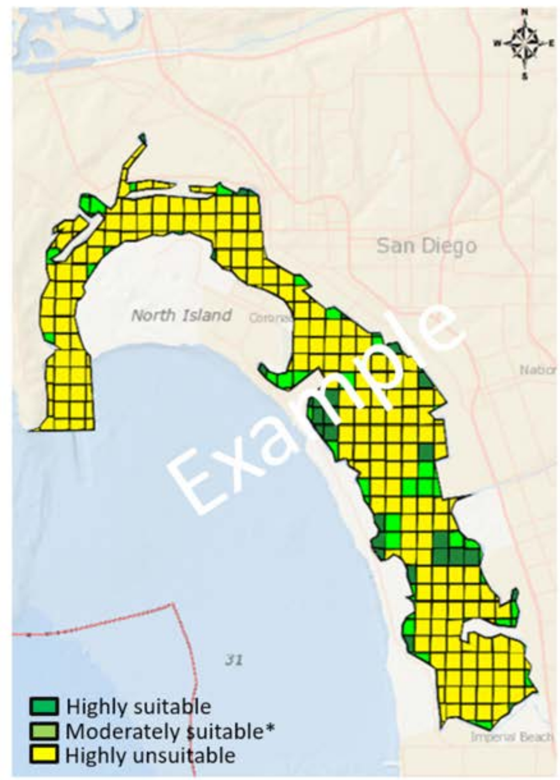
Using this approach, we formulated an opportunity analysis, a type of suitability analysis, for aquaculture siting. We examine candidate algae and shellfish species, in combination with associated gear types, to determine the potential opportunity for seventeen different candidate species (twelve species of shellfish and five species of algae) and gear types within and around the San Diego Bay. The opportunity analysis is an important step because areas may be suitable for candidate species, but not for a particular gear. We first conducted suitability modeling for species and gear separately, and then overlaid the results to determine where both the species and gear suitability overlapped. The end result is a map with areas of opportunity for a particular aquaculture species and gear type. The combination of the exclusion, suitability and opportunity analyses will allow the Port of San Diego to make informed decisions regarding the greatest opportunities for marine aquaculture in and around San Diego Bay.

Photo | Arash Afshar, Port of San Diego

Suitability Analysis Process

In order to develop practical operational constraints that could be applied to these species and gear types (pages 29-30) we surveyed existing scientific literature, consulted experts on gear types and species parameters, and reviewed industry recommendations. Environmental data were collected into raster files within ArcMap to be compared to the species and gear parameters. For each species and gear type, the applicable environmental variables raster datasets were reclassified to a binary system that reflects the practical operational ranges of each respective species or gear. Every cell in the reclassified datasets would contain a one if the respective species or gear could be successfully placed within it, or a zero if it could not. To determine the potential opportunity for a gear and species combination, we took all applicable raster datasets and added them together using the Raster Calculator tool in ArcMap. All areas in the resulting raster that have a value equal to the amount of layers included in the calculation (the maximum possible value) were considered to be suitable and to have potential opportunity. Due to the configuration of the data we had access to, the opportunity analysis was conducted separately for areas within the bay and outside the mouth of the bay. The suitable conditions for aquaculture opportunities were selected from limitations required by the cultured species or practical considerations of equipment. Cultured specie require water velocities ranging from a minimum for adequate oxygen, food, and flushing, to a maximum, beyond which can limit growth and survival. Suitable conditions with respect to equipment considerations are limited by wave energy and depth of the water column.





Aquaculture Species Thresholds

Specific shellfish and macroalage species were identified as potential candidates for aquaculture in and around San Diego Bay. Careful and deliberate literature searches, expert knowledge, and bioenergetics models were used to develop threshold values for several oceanographic parameters that are important for optimal growth for each species considered in this analysis. Threshold values could not be determined in all cases, and so values for related species were used when no information was available.

Common Name	Scientific Name	Temp. Min (°C)	Temp. Max (°C)	Current Min (m/s)	Current Max (m/s)	Salinity Min (PSU)	Salinity Max (PSU)
Pacific Oyster	*Crassostrea gigas*	8	40	0.05	1.0	25	35
Olympia Oysters	*Ostrea lurida*	6	38	0.05	1.0	25	40
Blue Mussel	*Mytilus edulis*	5	20	0.05	0.2	13	35
Mediterranean Mussel	*Mytilus galloprovincialis*	10	17	0.05	0.2	13	37
Manila Clam	*Venerupis philippinarum*	5	28	0.20	1.0	14	35
Geoduck Clam	*Panopea generosa*	8	19	0.10	0.8	26	34
Giant Keyhole Limpet	*Megathura crenulata*	11	26	-	-	30	36
Purple Hinge Scallop	*Crassadoma gigantea*	14	22	-	0.1	14	40
Red Abalone	*Haliotis rufescens*	14	18	-	-	27	40
Pink Abalone	*Haliotis corrugata*	18	24	-	-	27	35
Green Abalone	*Haliotis fulgens*	18	24	-	-	27	35
White Abalone	*Haliotis sorenseni*	18	22	-	-	27	35
Black Abalone	*Haliotis cracherodii*	14	18	-	-	27	35
Red Ogo	*Gracilaria pacifica*	13	34	0.05	0.5	20	40
Red Algae	*Gracilariopsis spp.*	20	30	0.05	0.5	25	40
Giant Kelp	*Macrocystis pyrifera*	5	21	0.20	3.0	15	33
Green Algae	*Ulva lactuca*	12	26	0.05	0.3	20	40

Notes: pH, Dissolved Oxygen (DO), chlorophyll a (checked for filter feeders), and light (checked for algae species) were examined for all species. Based on the best available data, species thresholds were within the range of values observed. pH generally ranged between 8.0 and 8.2, DO was almost always greater than 5 mg/L in areas measured, light was sufficient at siting depths, and chlorophyll concentrations (µg/L) were sufficient for filter feeders. Abalone and limpets actively feed on macroalgae, and therefore current speeds were not a concern.

Aquaculture Gear Thresholds

Specific gear types used for growing the target shellfish and macroalage species were also examined to determine suitable areas for aquaculture within San Diego Bay. Not all gear types can handle the same oceanographic conditions, and so literature searches, expert knowledge, and existing operations in other regions of the country were used to inform suitable gear type combinations with each species considered for marine aquaculture. Depth and recommended substrate were obtained from literature searches, whereas ranges for current speed were determined from an engineering analysis for each gear type, which included the mass of the species.

Gear Type	Tide Min (m)	Tide Max (m)	Current Min (m/s)	Current Max (m/s)	Depth Min (m)	Depth Max (m)
Covered In Bottom manual	0.13	-1.63	0.01	0.25	-0.03	-1.25
Covered In Bottom mechanical	0.13	-1.63	0.01	0.25	-0.03	-1.25
Floating Bags	0.13	+	0.01	2.20	-0.75	+
Floating Cages	0.13	+	0.01	2.20	-0.75	+
Hanging Basket	-1.63	+	0.01	2.20	-5.00	+
Horizontal Longlines	-1.63	+	0.01	1.50	-5.00	+
In Bottom	0.13	-1.63	0.01	0.70	-0.25	-1.00
Lantern Nets Cages	-1.63	+	0.01	1.00	-5.00	+
Line Cultivation	-1.63	+	0.01	1.20	-0.75	+
Planting Seeded Cultch manual	0.13	-1.63	0.01	1.00	-0.25	-1.25
Planting Seeded Cultch	-1.63	+	0.01	1.00	-0.25	+
Rack and Bag	0.13	-1.63	0.01	0.60	-0.75	-1.50
Raft Culture	-1.63	+	0.01	0.25	-5.00	+
Seabed Cultivation	-1.63	+	0.01	1.52	-3.00	+
Stake	0.13	-1.63	0.01	0.25	-0.30	-1.50
Substrate Nets	-1.63	+	0.01	0.60	-2.00	+
Supported Cages	-1.63	+	0.01	0.60	-3.00	+

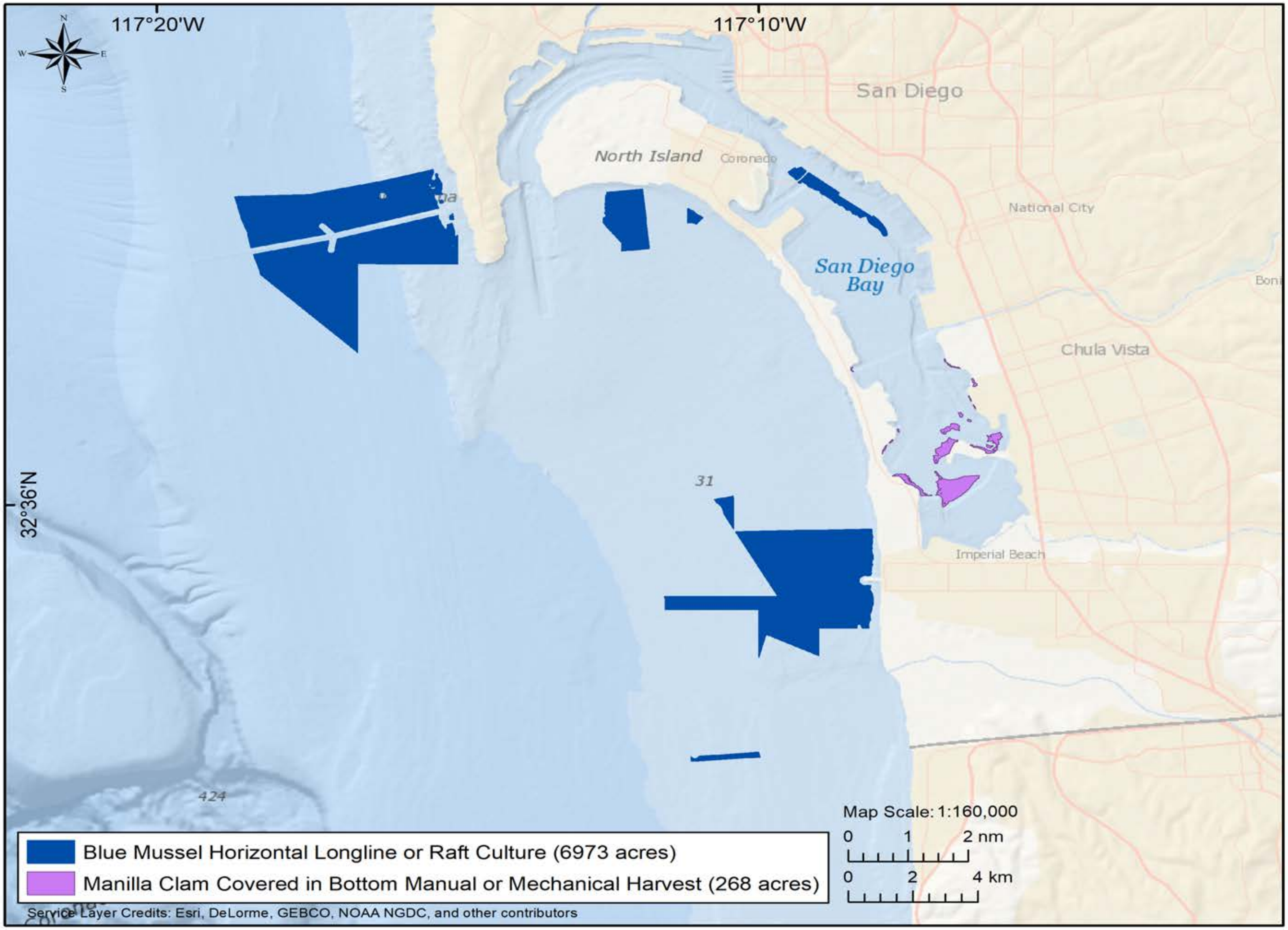
+ No maximum depth limit defined for gear type, the maximum depth of study area used

Spatial scientists used the CanVis viewshed simulator o visualize what a shellfish farm might look like from shore at Liberty Station and Glorietta Bay. They also simulated what an algae farm on the surface might look like from the pier at Imperial Beach and along side the Coronado Bridge, California.

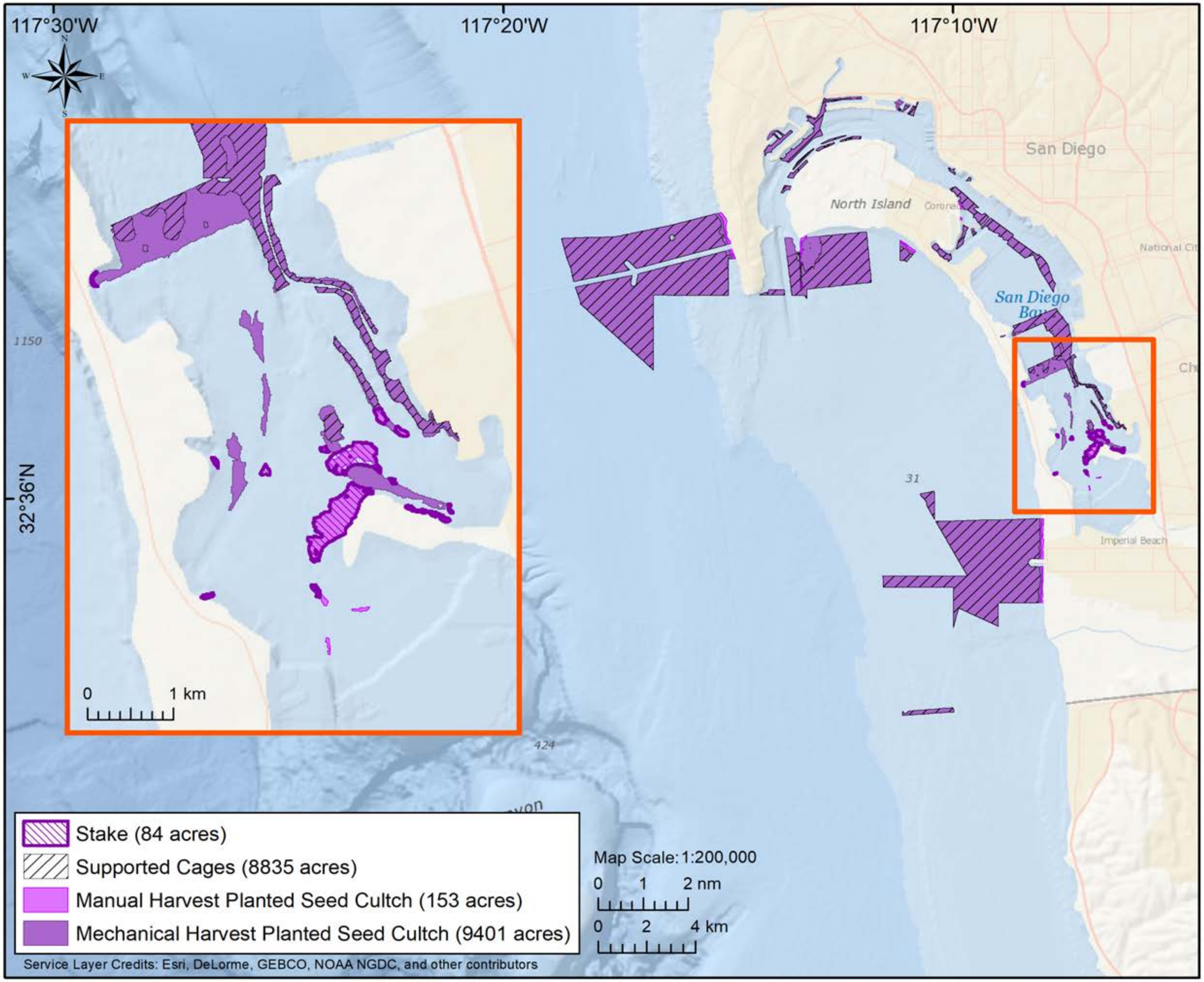
CanVIS gives users access to an aquaculture library to create simulated visualizations with aquaculture is added within a seascape. CanVis tools can help coastal managers better explain to stakeholders what the true versus perceived impact of aquaculture infrastructure has on the viewshed.

CanVis:
Creating Viewshed Simulations

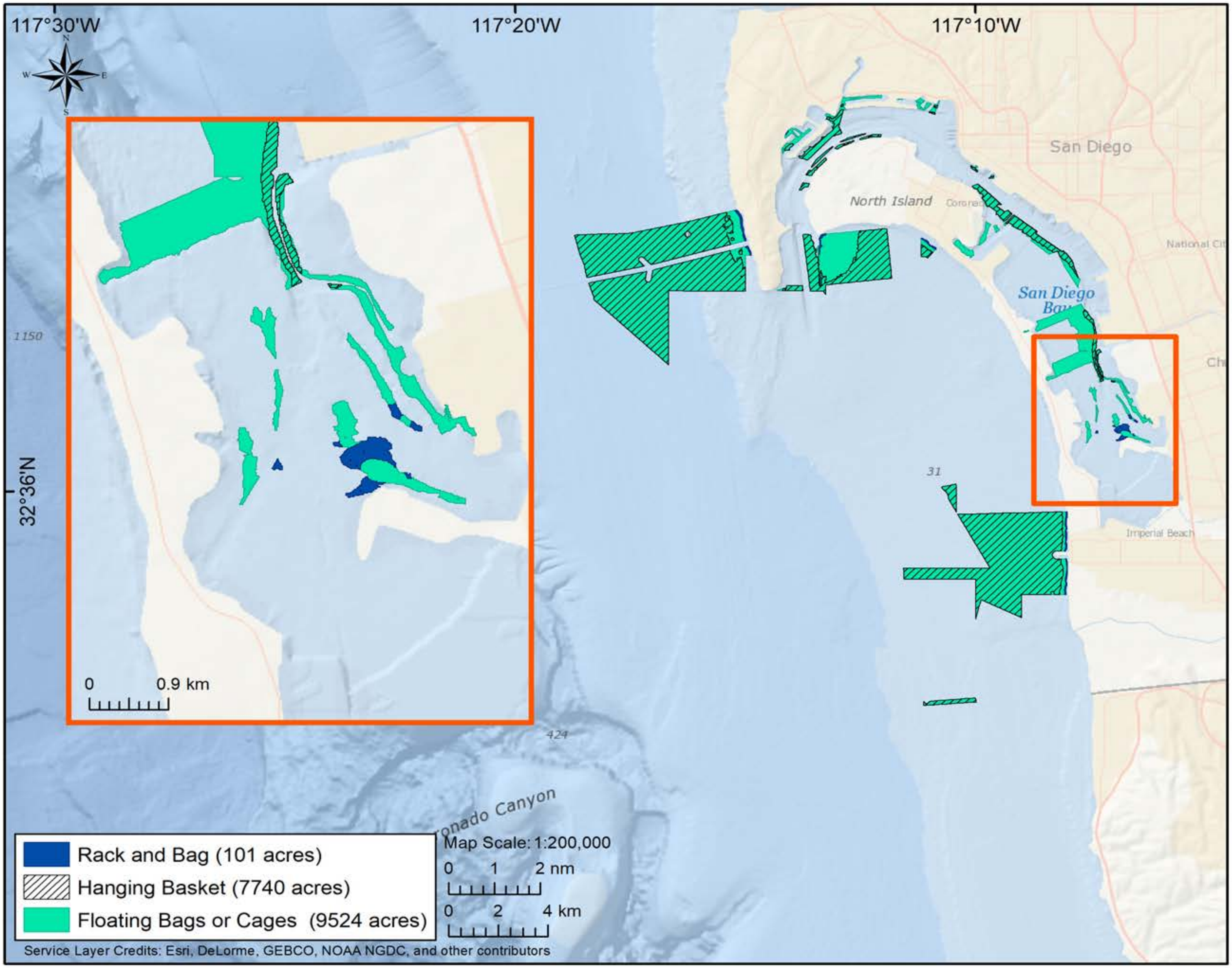
Manila Clam and Blue Mussel Opportunities



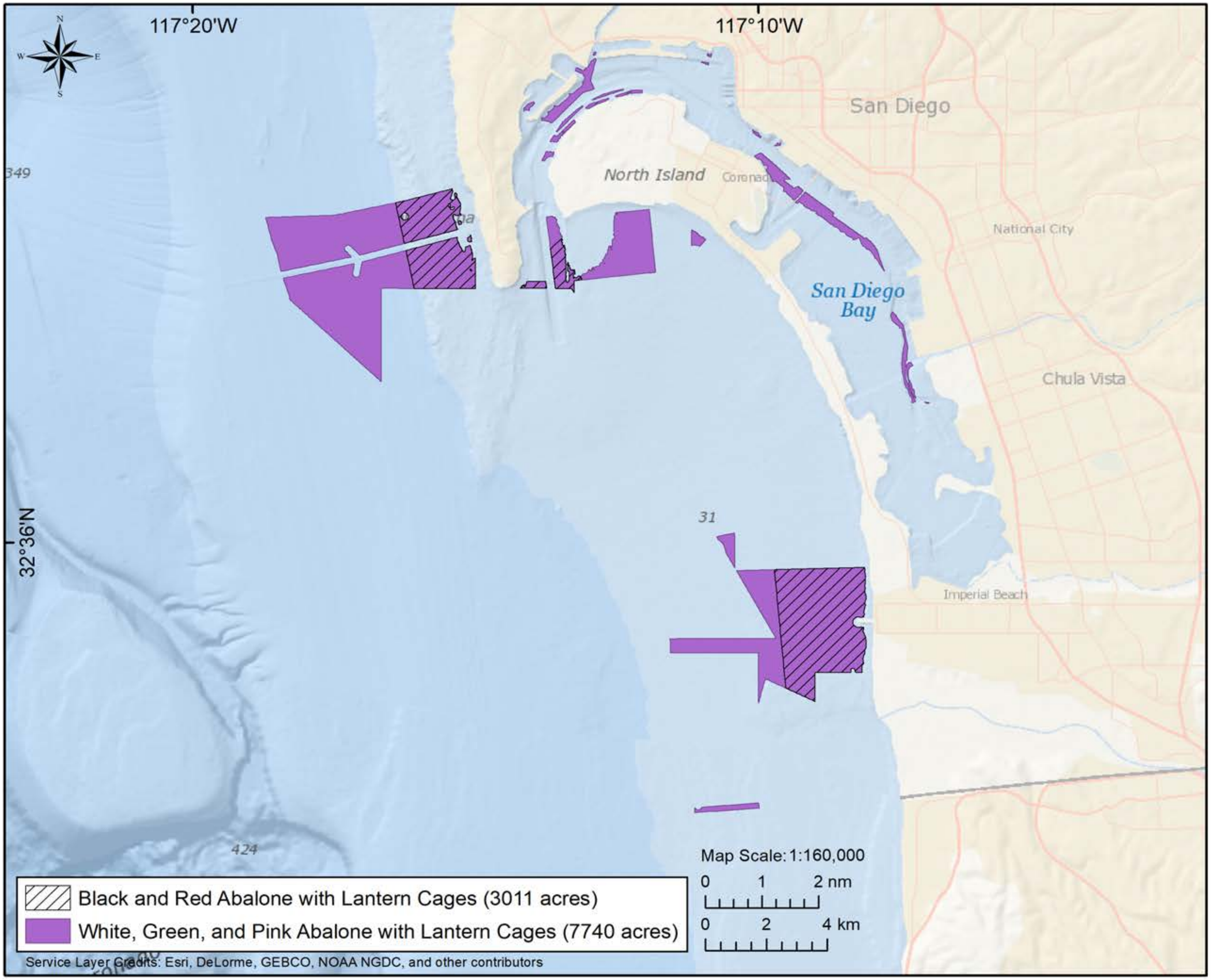
Oyster Opportunities



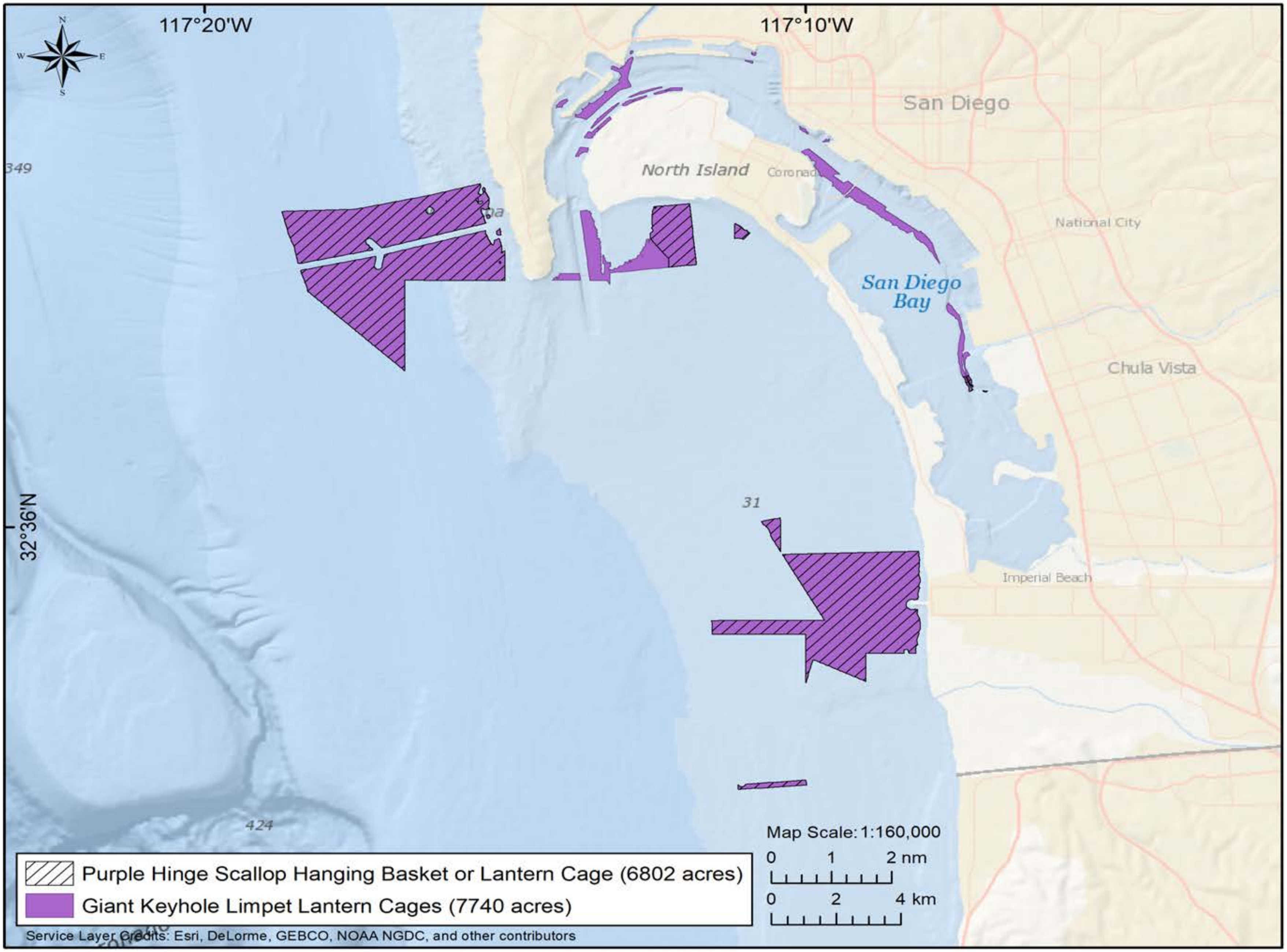
Oyster Opportunities



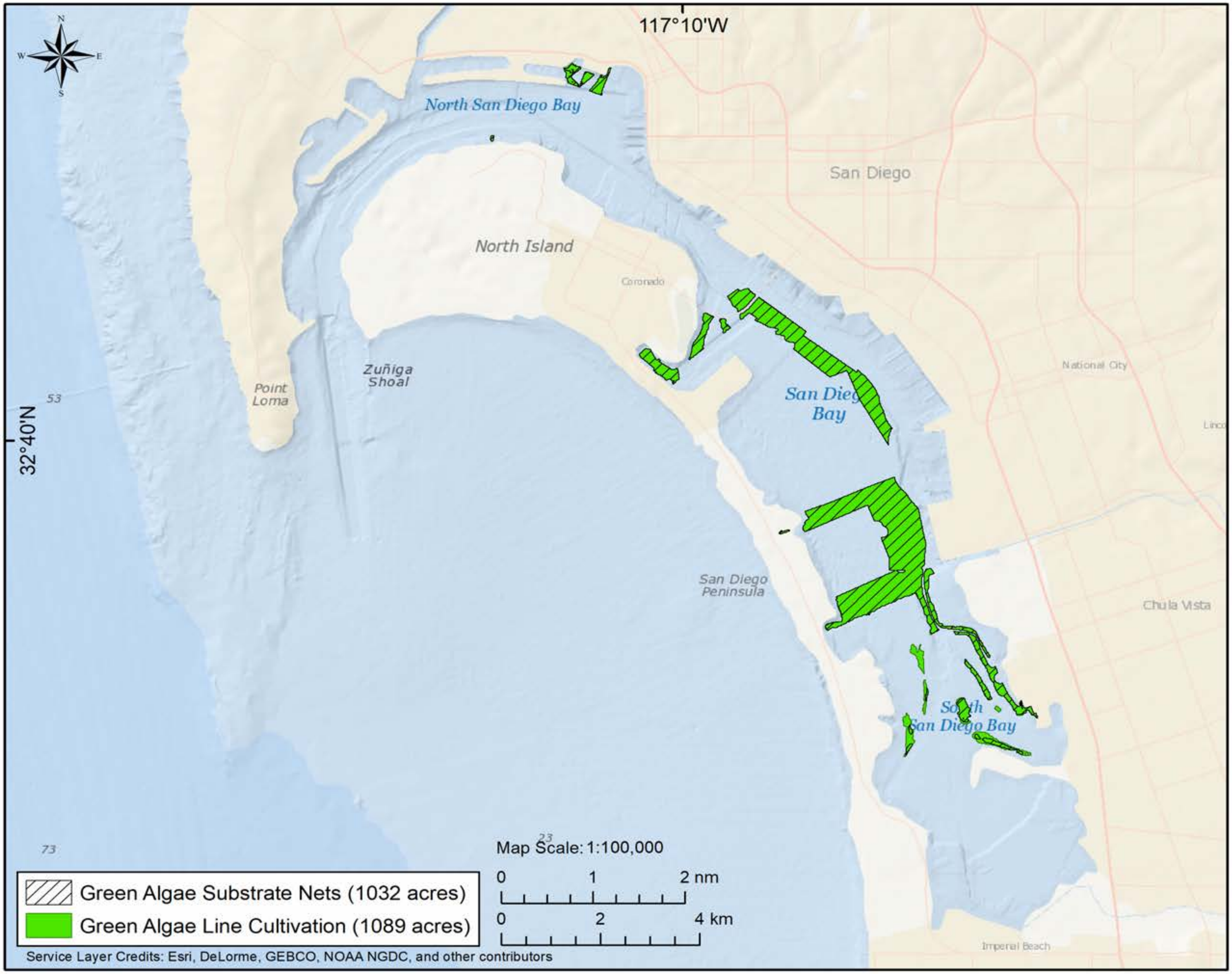
Abalone Opportunities



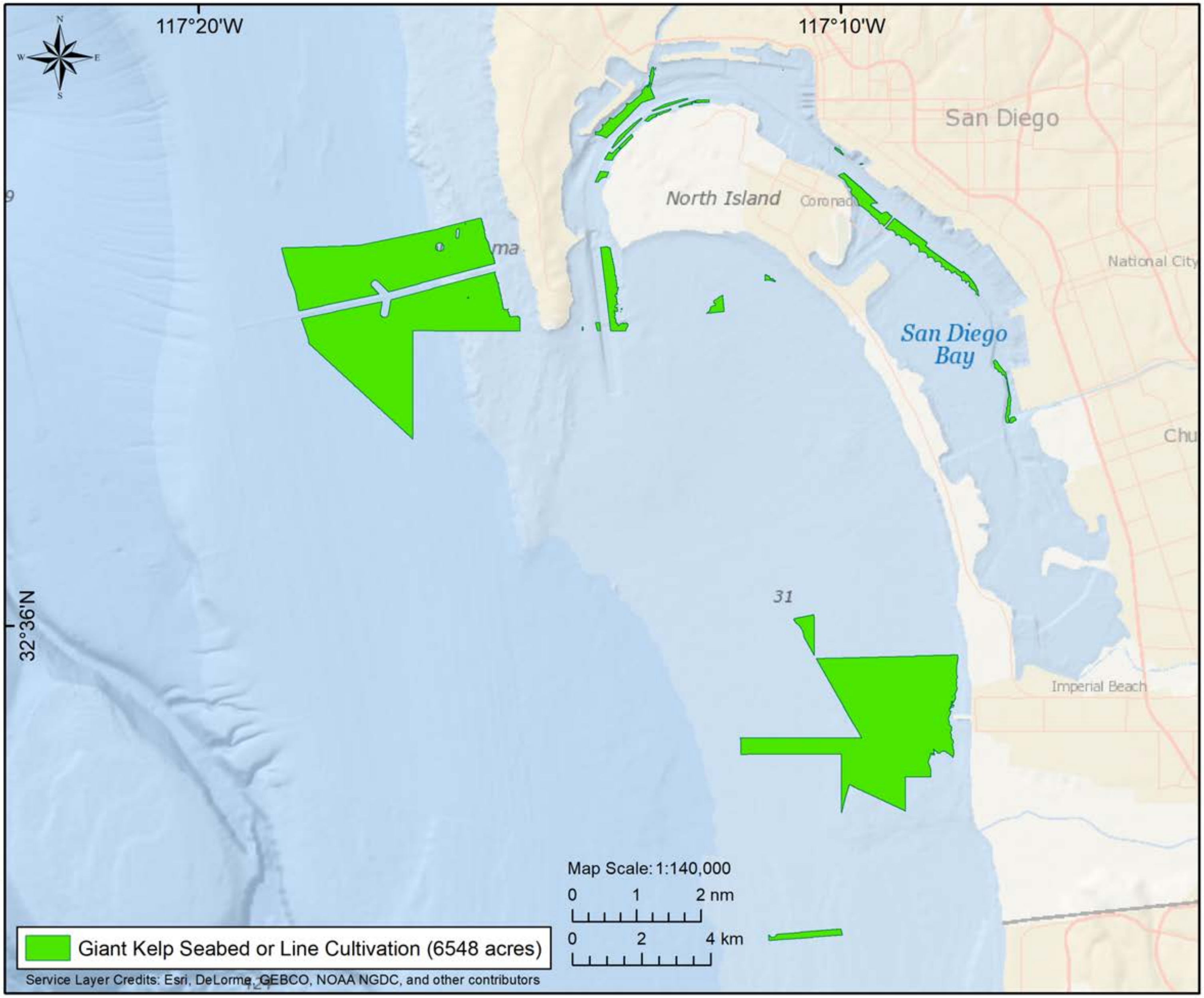
Purple Hinge Rock Scallop Opportunities



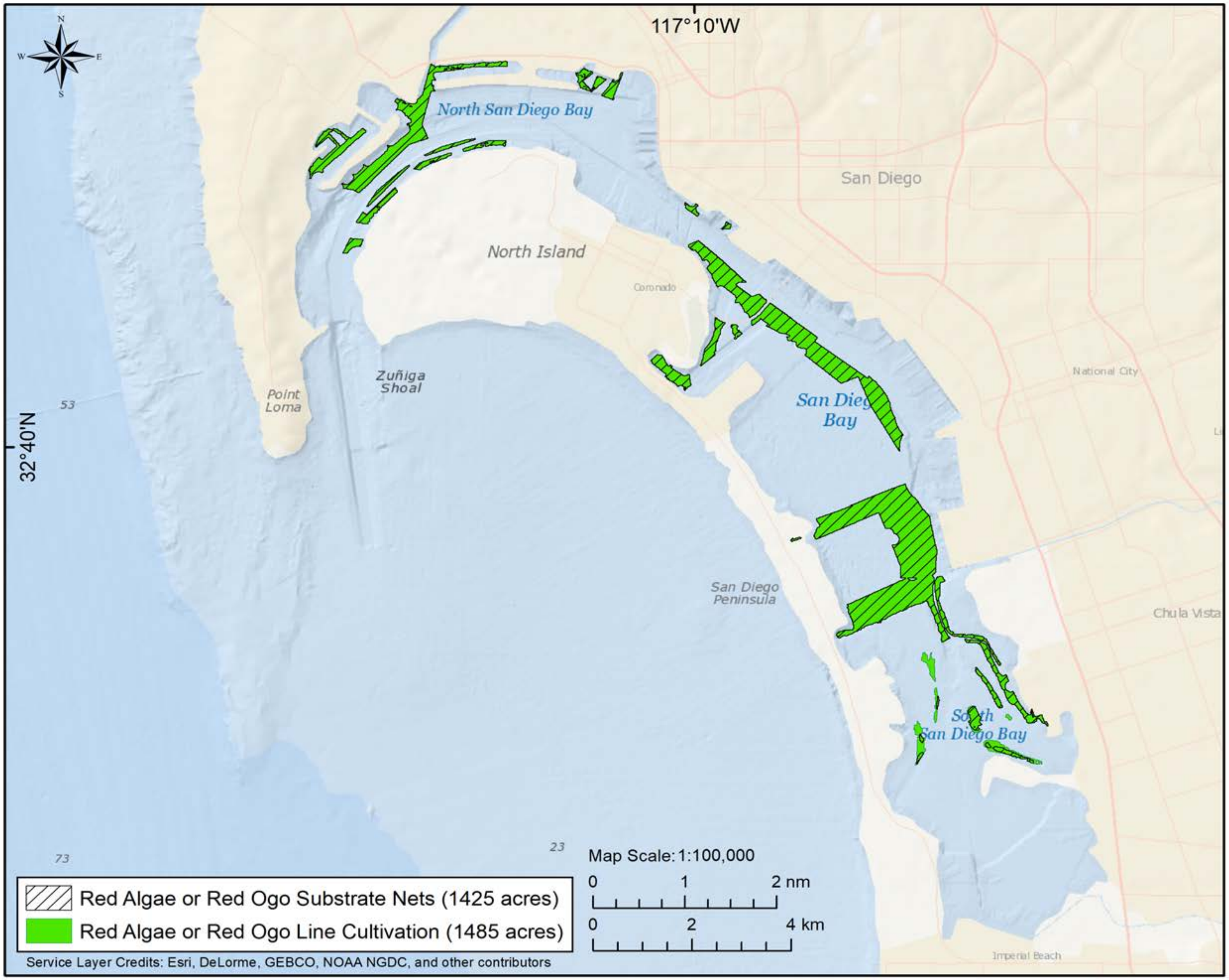
Green Algae Opportunities



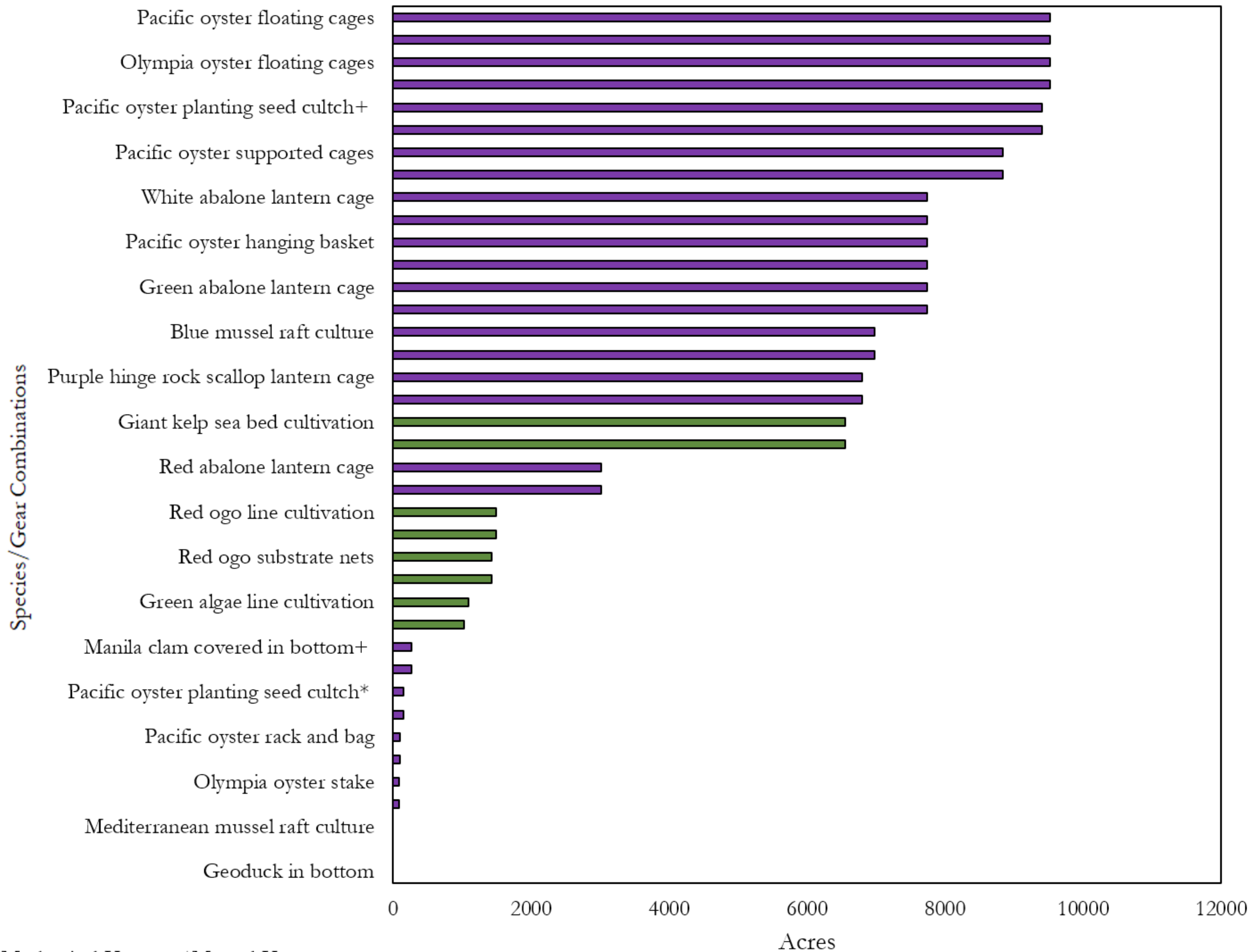
Giant Kelp Opportunities



Red Algae Opportunities



Summary of Overall Species/Gear Combination Opportunities



+Mechanical Harvest, *Manual Harvest

Overall Opportunity

Through the opportunity analyses, we provide an example of preliminary siting opportunities for various culture species, with consideration given to spatial use conflicts, gear thresholds, and biophysical needs of cultured organisms. Once the final usable areas for opportunity were established within the AOI, we then performed the opportunity analyses. Suitability was determined for each species and gear through reclassification of raster data using the established thresholds. For the shellfish and gear combinations, Pacific and Olympia oysters using either floating bags or floating cages, has the largest potential opportunity in the area of interest, with a total of 9,524 acres for potential development. This is largely driven by gear type, and the ability to culture these species at deeper depths, particularly if they are mechanically harvested. Pacific and Olympia oysters could also potentially be seeded on cutch material over 9,401 acres, if mechanically harvested. If manual harvest techniques are used, the potential opportunity drops to 153 acres for seeded cultch and only exist inside the Bay. For supported cages (8,835) and hanging baskets (7,740 acres), both species of oysters can potentially occupy a large portion of the usable area. The most limiting gear types for oysters were stakes (84 acres) and rack and bag (101 acres), due to the need to remain in the intertidal zone. Similarly, Manila clams using covered in bottom technique, with either manual or mechanical harvest, are limited to the intertidal zone. This is a species limitation as clams need substrate for growth. The purple hinge rock scallop (6,802 acres), giant keyhole limpet (7,740 acres), black and red abalones (3,011 acres), and white, green, and pink abalones (7,740 acres) in lantern cages all have ample potential for opportunity in the Bay. These species have long growth periods until harvest (~5 years), but are used for numerous purposes, such as medical research and stock enhancement, making potential aquaculture opportunity an important factor to quantify. Blue mussels grown on longlines or raft culture (6,973 acres) have great potential opportunity outside the Bay, as these species and gear types can withstand the currents within the ocean environment. Mediterranean mussels may also be used, but were excluded from this analysis due to temperature concerns.

For macroalgae species, the species with the greatest potential opportunity is Giant kelp (6,548acres) using either seabed cultivation or line cultivation techniques. Giant kelp can growth at deeper depths, withstand higher current speeds, and can use blue light (penetrates the water column deeper than red and green light) and uses chlorophyll-c to photosynthesize. All other species are only found within the Bay proper, as wave and wind action and current speed are a predominant concerns for species growth. Green algae using substrate nets (1,032 acres) and line cultivation (1,089 acres) are limited to the south and central portions of the Bay, with a small potion of the northeast portion of the Bay deemed suitable. These areas are all defined as having enough light at depths grown, and are relatively sheltered from high wave and current action. Red algae species, and Red Ogo specifically, have a wider potential distribution and therefore opportunity within the Bay, using substrate nets (1,425 acres) and line cultivation (1,485 acres). These distributions are greater depth can be used and current speed is not as limiting.

In total, there is potential opportunity for bivalve shellfish and macroalgae aquaculture in and around the San Diego Bay area. Some gears and species offer greater spatial opportunity then others, and some species gear combinations had no opportunity (e.g., geoducks). Finding the right balance for aquaculture will be critical to maintaining a resilient Port infrastructure, while also balancing ecosystem needs and trade-offs.

Conclusions

San Diego Bay is one of the first US Ports to conduct an opportunity analysis for multiple aquaculture species and associated gear types in the United States. Planning for future uses and activities in and around the San Diego Bay helps ensure sustainable ecosystems remain, and that future ocean industry does not substantially affect sensitive habitats, protected species, or other important ocean uses (e.g., homeland security, shipping routes). Here, we have provided an example of preliminary siting opportunities for various shellfish and macroalgae culture species, with consideration given to spatial use conflicts, gear thresholds, and biophysical needs.

Siting aquaculture requires considering operation constraints (exclusion analysis) in order to identify usable space for aquaculture. Exclusion analysis allows for consideration of multiple ocean space uses within and around the San Diego Bay, and where compatibility with aquaculture may be low or non-existent. This defines the total allowable space for planning within a given area that can be used for opportunity analyses. Moreover, the quality of that space must be quantified to determine relative compatibility. Although an opportunity may exist, further considerations, such as economic feasibility, must be accounted for before any aquaculture operation is initiated.

In this study, all gear types were considered after examining gear constraints for depth, tidal zones, and current speeds for use in and around San Diego Bay. Depth was the most limiting factor for the different gear types associated with each species. The species biophysical needs of temperature, salinity, current speeds, and sediment revealed only four species were constrained to a high degree. Red and black abalones were constrained by high water temperature, while Mediterranean Mussels were deemed unlikely cultivators due to high water temperatures. Geoducks were found unsuitable as given the sediment in and around San Diego Bay. All other species biophysical needs were met, with only a few being constrained in certain areas. The depth, specifically those species and gears limited to the intertidal zones had the smallest areas of opportunities in and around San Diego Bay.

The best available oceanographic and water quality data were used for this analysis, however short time frames, few sample sites, and data limitations may further constrain the areas identified as being suitable. The final areas of opportunity should be viewed as potential areas, as additional constraints may be present or other areas may possess the capacity for aquaculture. Therefore, thorough on site validation of physical and oceanographic conditions should be performed to confirm suitability for a type of aquaculture.

Next Steps and Limitations

These series of analyses are the first step towards gauging the potential for shellfish and macroalgae aquaculture in and around San Diego Bay. It establishes a foundation for future research needs, and has aided in defining usable space. Next, researchers should conduct small experiments with gear and species combinations to determine if each option is truly viable in the potential opportunity areas. Once experimental harvests have occurred, then depuration rates of certain contaminants can be conducted.

Having only a hand full of water quality monitoring stations in the Bay restricted the analysis. Therefore, a greater number of oceanographic and water quality buoys needs to be established inside the Bay area. Further, around the Point Loma and Tijuana offshore outfalls, plume trajectories need to be calculated, on a monthly or seasonal basis, to determine movement of wastewater effluent from the diffusers into the ecosystem. In these cases, macroalgae and shellfish aquaculture may play a restorative function for nutrient removal outside the Bay area.

Next, trace metals, PAHs, and other known contaminants distributed in the San Diego Bay, need to be characterized, so mitigation through aquaculture can occur, or these areas can be avoided for other types of aquaculture. Habitat also needs to be better characterized for the potentially suitable aquaculture opportunity areas. Sensitive habitats (e.g., native seagrass and kelp beds) need certain protections, while others (e.g., soft sediment) are compatible with aquaculture gear types and species. This is a critical step in siting aquaculture.

Additionally, an economic model (risk-cost benefit analysis) should be conducted for potential opportunities, taking into account the cost of gear, workers, maintenance, current price per pound of chosen culture species, time to harvest, risk of disease or farm loss, harvest costs, time until return on investment, as well as others should be accounted for before siting occurs for the investor.

From a coastal manager standpoint, this analysis shows both areas where aquaculture is constrained (i.e., exclusion), and areas where future permits may be sought after (opportunity). This analysis provides guidance to the Port to continue to grow the Blue Economy initiatives and will further guide future activities and industry in and around the Bay area. The next step is extending the analysis into the Federal waters of Southern California, exploring an expanded area for potential aquaculture production.

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