Marine Spatial Planning for Kelp and Shellfish Aquaculture in Puget Sound

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Introduction

With a diverse range of competing uses in Puget Sound a functional marine spatial planning tool is critical to the success of commercial aquaculture operations. Marine spatial planning aims to compile spatial and temporal data relevant to the human uses in marine areas, with the goal of achieving ecological, economic, and social goals. Planners must incorporate the needs of stakeholders with federal, state, local, commercial, and environmental affiliations. Planners in Washington must also uphold Tribal treaty rights in this process, notably the right of Indigenous people to fish in Usual and Accustomed Areas (UAUs). This complex regulatory landscape has led to notable challenges in the expansion of aquaculture in state waters.

Kelp aquaculture is a nascent field in Puget Sound with potential to grow into a robust commercial industry. With a wide range of applications and low environmental impact, the kelp aquaculture industry is a progressively essential field. Despite the auspicious applications, there are few studies that examine viable sites for kelp aquaculture or the effects of farms on encompassing ecosystems.

Contrastingly, the shellfish industry in Puget Sound is well established, and the majority of farms exist in the southern basins. Tribes have farmed shellfish for thousands of years and shellfish growers have utilized intertidal lands to grow a variety of shellfish since the 1800's, producing the largest quantity of farmed shellfish in the United States and generating over one hundred million dollar in revenue annually (Pacific Shellfish Institute, n.d). Many species are cultivated in the Sound such as a variety of oysters including Pacific and Olympia, Mussels, Manila and Soft Shell Slams, and even Geoducks (Pacific Shellfish Institute, n.d).

Puget Sound's growing interest in commercial kelp farming and expansion of the shellfish industry demonstrates an increased need for adequate planning tools to reduce conflicts in a heavily utilized area. Appropriate tools for site selection will alleviate potential conflicts and result in greater opportunities for success. The marine spatial planning tool we have designed aims to provide potential farmers with useful information for success early on in the permitting and planning process.

Uses for Aquaculture

Kelp aquaculture has a range of applications extending beyond commercial food harvest. Kelp can be used for biofuel, natural kelp bed restoration, bioremediation, and carbon sequestration (Theuerkauf et al., 2019). Shellfish aquaculture is already a profitable commercial industry in Puget Sound, but similar to kelp, has applications outside of this realm. Below we detail these important uses and applications, and discuss how marine organisms, ocean water quality, and humans residing in the region can benefit from increased kelp and shellfish aquaculture.

Food Systems and Commercial Use

Humans can reap many benefits by incorporating certain species of farmed kelp into their diets. When grown as a commercial product, it can be incorporated in food products, cosmetics, animal feeds, and plant fertilizers. Compared to terrestrial agriculture, kelp is significantly less resource intensive, requiring no land, fertilizer, or irrigation (Blue Dot, n.d.). This makes kelp farming a highly sustainable option as a food production system. Additionally, adding this product to animal feed can lower emissions from cattle by reducing the amount of methane that is produced in the rumen and released into the atmosphere.

Unlike kelp, the commercial shellfish industry is already large in Washington state, and production through aquaculture plays an increasingly important role in domestic seafood production (The Pacific Shellfish Institute n.d.). Recreational shellfish harvest has a long and culturally significant history on the beaches of Puget Sound. Shellfish such as oysters, clams, and mussels provide an important source of food for Tribes and residents of the Puget Sound region (Pacific Shellfish Institute n.d.).

Restoration

Growing kelp for ecosystem restoration is highly effective, as kelp beds provide a productive coastal habitat as a complex three dimensional structure for a variety of invertebrates and fishes, including commercially important species in Washington such as rockfish. These highly productive kelp beds aid in nutrient uptake, carbon dioxide sequestration, and dissolved oxygen production.

Shellfish restoration is a primary area of focus in Washington state amongst scientists, farmers, and the general public, particularly when it comes to reestablishing once abundant native species. Through pollution, habitat destruction, and over harvesting, native species such as the Olympia Oyster became scarce. Organizations such as the Pacific Shellfish Institute, Puget Sound Restoration Fund, the Nature Conservancy, and NOAA had been working to restore native populations. Shellfish restoration can provide secondary benefits as well such as addition of critical habitat and water quality improvement.

Bioremediation

Kelp have the ability to extract harmful nutrients from the water column, such as nitrogen, phosphorus, and certain heavy metals (Langton et al., 2019). By removing nutrients from terrestrial runoff, storm water discharge, and sewage outlets, kelp aquaculture can aid in localized ocean clean up. While the amount of nutrient uptake varies depending on species and water quality of the area, kelp farms may be sited in polluted coastal waters to ease the polluting nutrient load while increasing oxygen through photosynthesis (Froehlich et al., 2019). This strategy was effective in the Bronx River estuary in New York (Kim et al., 2015).

Additionally, kelp has the ability to mitigate harmful algal blooms in localized areas by adding more habitat to the system for algicidal bacteria to thrive, as demonstrated in the Jiangsu Province in China (Grebe et al., 2019). In some cases if sited properly, kelp may offer a form of shoreline protection by dampening wave energy. This is an important application as storm intensity increases with climate change (Duarte et al., 2017).

One of the most widely applicable and well known uses for bioremediation potential is integrated multi-trophic aquaculture (IMTA), or polyculture. Co-production and integration of kelp with different species of shellfish and fin fish allows for waste products from fin fish to be recycled (Chopin et al., 2001). This sustainable approach to farming our oceans allows for the fed organisms to release waste matter which can be assimilated by the shellfish and kelp. Additionally, kelp releases detritus into the water column that can provide additional nutrients to shellfish and finfish.

Shellfish, acting as filter feeders, have the ability to uptake particulate organic matter (POM) while kelp as primary producers will uptake inorganic waste products, like nitrite, nitrate, phosphorus, and ammonia (Strand et al., 2018). Shellfish also have the ability to extract harmful nutrients like nitrogen from the water column. (Clements & Comeau, 2019). In areas of high run-off water, nitrogen can lead to eutrophication and subsequent harmful algal blooms. As shellfish absorb nitrogen, it becomes embedded in their shells then trapped in the surrounding sediment, thus cleaning the water column(Clements & Comeau, 2019).

Climate Change Mitigation

The concentration of atmospheric carbon dioxide continues to rise at a steady rate due to anthropogenic emissions. In 2019, the global average atmospheric carbon dioxide reached 409.8 parts per million (ppm), and daily levels in 2020 surpassed 410 ppm (climate.gov). The annual rate of atmospheric carbon dioxide increase is occurring approximately 100 times faster than any natural changes in history (climate.gov, Fabry et al., 2008). Kelp farming has the ability to help mitigate localized effects of ocean acidification through sequestration.

The global ocean absorbs approximately one quarter of anthropogenic carbon dioxide emissions, and the rapidly accelerating concentration comes at a cost to marine organisms. (Fabry et al. 2008). Ocean pH has decreased from 8.2 by 0.1 units since the beginning of the industrial revolution, which corresponds to an approximate 30% increase in acidity (Feely et al., 2004 and Fabry et. al, 2008). The mean surface ocean pH is projected to drop to 7.8 units by the end of the century (The Royal Society, 2005). This trend tends to be even more pronounced in coastal areas such as Puget Sound where upwelling and freshwater input are influenced heavily by ocean chemistry.

This decrease in pH has consequences for many forms of marine life with direct effects for calcifying organisms such as oysters, clams, and other species of shellfish which rely heavily on calcium carbonate to form shells and exoskeletons. Decreased ocean pH corresponds to decreased calcium carbonate saturation, leading to fewer carbonate ions available for the critical processes of shell and skeleton formation (Smithsonian and Porzio et. al 2011). Oysters are particularly vulnerable to ocean acidification at the larval stage as the energy expenditure to build shells under suboptimal conditions is taxing and can lead to increased mortality (UW, OA in the PNW).

Kelp forests are highly productive ecosystems with the potential to provide localized relief from ocean acidification (Hirsh et al. 2020). As it grows, kelp sequesters carbon dioxide from the ocean through photosynthesis, creating the potential for mitigation and offsetting in areas of kelp growth. This buffer zone can help organisms that exist within it, like shellfish, thrive. Kelp has been used in integrated multi-trophic aquaculture systems for precisely this reason.

Shellfish vulnerability to ocean acidification puts the shellfish farming industry in Washington at risk. Multi-trophic aquaculture operations and restoration of natural kelp beds are potential avenues for ameliorating that risk. Another long-term avenue for addressing this challenge comes from research into selective breeding of shellfish for strains tolerant to ocean acidification. The Puget Sound Restoration Fund (PSRF) currently has a number of projects dedicated to addressing the effect of ocean acidification on Washington's shellfish, including a conservation hatchery where acidification tolerant shellfish are cultured and studied (Puget Sound Restoration Fund, n.d). PSRF's work is in collaboration with universities, Tribes, governmental, and non-governmental agencies all dedicated to understanding shellfish adaptations and potential routes for resilience under climate change.

Current Aquaculture Farms in Washington

State of kelp aquaculture in Puget Sound

Despite the significant benefits of and uses for kelp aquaculture, there is only one commercial kelp farm in Puget Sound whereas on the East Coast, this is a well established commercial industry. However, recently in Washington there has been growing interest in expanding kelp aquaculture. This interest is evidenced by the case study below on Blue Dot Sea Farms and by the creation of the Washington Seaweed Collaborative, a forum for sharing information and resources for individuals interested in participating in the emerging kelp aquaculture industry in Washington.

As this industry grows, the need for public data sharing and information related to the permitting and environmental considerations of siting aquaculture are increasingly important. The marine spatial planning tool we have created is designed to provide potential aquaculturists with information about the uses of Puget Sound so they can identify and minimize spatial conflicts early on in the process.

Case study: Blue Dot Sea Farms

Blue Dot Sea Farms is currently the only commercial aquaculture farm operating in Puget Sound. It is a 5-acre suspension farm that grows sugar kelp and oysters. The site started as an experimental farm in 2013, funded by a 4-year grant from the Paul G Allen Family Foundation (Blue Dot Sea Farms, n.d). The scientists that proposed the idea wanted to test whether cultivating kelp for phytoremediation could be used to address the challenge that ocean acidification presents.

In the Pacific Northwest and Puget Sound, the effects of ocean acidification are especially pronounced where processes like upwelling, freshwater input, and respiration heavily influence ocean chemistry (Washington State Blue Ribbon Panel on Ocean Acidification, n.d). This puts a strain on marine organisms, especially shellfish who have difficulty forming and maintaining shells under the increasingly acidic conditions. With the robust commercial shellfish industry in Washington, this experimental farm was interested in testing the localized mitigation potential of kelp in a co-culture aquaculture farm (Blue Dot Sea Farms, n.d).

At Blue Dot they monitor the effects of growing kelp on pH, dissolved inorganic carbon, and other carbonate chemistry. They advocate for the importance of growing kelp for its phytoremediation properties, but also as a sustainable food source. Being a crop that requires no fertilizers or other inputs, it is both low cost and environmentally sustainable (Blue Dot Sea Farms, n.d).

In addition to the benefits that kelp provides to marine organisms and as a food source, the harvest can also be used for a host of terrestrial purposes. One alternative use that Blue Dot is exploring along with agroecologists at the University of Washington is composting kelp as a terrestrial fertilizer. Kelp is carbon and nutrient rich from sequestration in the ocean, and it releases these nutrients into the soil as it decomposes, effectively recycling the nutrients (Blue Dot Sea Farms, n.d).

Blue Dot is a guiding example of how kelp aquaculture farms can benefit the marine ecosystem by enhancing water quality and habitat for a number of organisms. Additionally, they demonstrate the important alternative uses of kelp as a food source and a nutrient rich terrestrial fertilizer. This co-culture aquaculture farm shows how kelp could be grown with shellfish in a single aquaculture farm in Puget Sound and the wide range of benefits this would have for the marine environment and humans who rely on it.

State of shellfish aquaculture in Puget Sound

Shellfish aquaculture is ecologically and economically important in Puget Sound. Shellfish are filter feeders, intaking water and straining out excess nutrients like nitrogen as they feed (Woods Hole Oceanographic Institute, n.d). Additionally, commonly grown species like oysters can provide habitat for forage fish, invertebrates and other shellfish (NOAA Fisheries, Oyster Reef Habitat n.d). In some cases, the larvae may even be food for other organisms (NOAA Fisheries, Oyster Reef Habitat, n.d).

Shellfish farming in Washington has a lengthy history and has been a successful industry for over one thousand years. The state is the largest producer of farmed shellfish in the U.S generating over 100 million dollars annually (Pacific Shellfish Institute, n.d). After the Olymia oyster fishery crashed in the 1900's, the aquaculture industry transitioned its focus towards restoration, in hopes of boosting the wild population of oysters. While the Pacific Oyster is arguably the most important species farmed in Washington, cultivation of mussels, clams, and geoduck are a significant part of the industry as well.

In 2011 the Washington State became the first in the nation to launch its own Shellfish Initiative. This partnership between the tribes, government and NGOs first focused on water quality improvements and permitting process reviews, then shifted focus to include research, improved permitting applications and processes, and restoring the Olympia Oyster and Pinto Abalone.

Methods

Literature review

We began this capstone project with a comprehensive literature review to familiarize ourselves with the permitting process, ecological benefits and applications of kelp farming, and to learn about other kelp farms operating in the U.S. During this process we were able to work with our advisor, Eric Laschever, to write and publish a paper entitled "U.S. Aquaculture's Promise: Policy Pronouncements and Litigation Problems" in the Environmental Law Reporter. This paper details the need for and regulatory challenges of commercial aquaculture in the U.S (Laschever et al., 2020).

From our literature review, we began to form areas of interest secondary to commercial kelp aquaculture. These areas focused on the applications of growing kelp in Puget Sound for restoration, bioremediation, and ocean acidification mitigation. These additional interests helped us to focus our data collection and create our final tool.

Through this research we were also able to gain a more in depth understanding of the critical need for comprehensive marine spatial planning in Puget Sound. Puget Sound is a large, complex estuary, which creates the potential for overlapping uses in the absence of thoughtful marine spatial planning. Washington State law defines marine spatial planning as a "public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives." (Washington MSP, n.d).

This type of planning relies on collecting and analyzing spatial data depicting a variety of uses to inform future management and use decisions (Washington MSP, n.d). Planners in Washington have to work to incorporate the needs of stakeholders with local, state, federal, commercial and environmental affiliations and we really came to understand how difficult this can be through our research. Additionally, planners must uphold and honor tribal treaty rights, such as the right to fish in UAAs in the Sound.

With all of these uses and interests, marine spatial planning is necessary to minimize spatial conflicts in Puget Sound. It allows stakeholders and farmers to identify and avoid potential spatial overlap related to the various uses of Puget Sound early on in their site selection process. Having spatial data like this available in a user-friendly tool is critical for the success of kelp growers in Puget Sound.

Data Sourcing

Using a framework analogous to the Ecosystem Approach to Aquaculture developed by the Food and Agriculture Association (FAO), we gathered data from multiple types of sources to account for the entire ecosystem and its services as well as the equity of stakeholders (Food and Agriculture Association, 2010). Some of our sources included the National Oceanic and Atmospheric Administration (NOAA), Washington Department of Natural Resources (WA DNR), Washington Department of Transportation (WSDOT), Bureau of Indian Affairs (BIA), U.S. Fish and Wildlife (USFWS), and the University of Washington (UW). The data used is all open-source, geospatial data that can be easily accessed by anyone who wants to utilize this tool.

Categorizing

As we collected our spatial datasets we checked them for accuracy and relevance and ensured we had the most up to date data before approving them for inclusion in our final tool. We then categorized our spatial datasets into three categories: existing human uses, habitat classifications, and critical species habitat (Table 1).

Table 1. Dataset categorization and abbreviated source information for geospatial data included in the marine spatial data tool.

Category	Datasets	Source
Existing Human Uses	Ferry terminal Ferry routes Aids to navigation Puget Sound fishing areas Tribal Reservations	WSDOT WSDOT NOAA NOAA BIA
Habitat Classifications	Exposure class Substrate Nearshore vegetation (kelp & eelgrass) Shoreline areas	DNR DNR DNR DNR

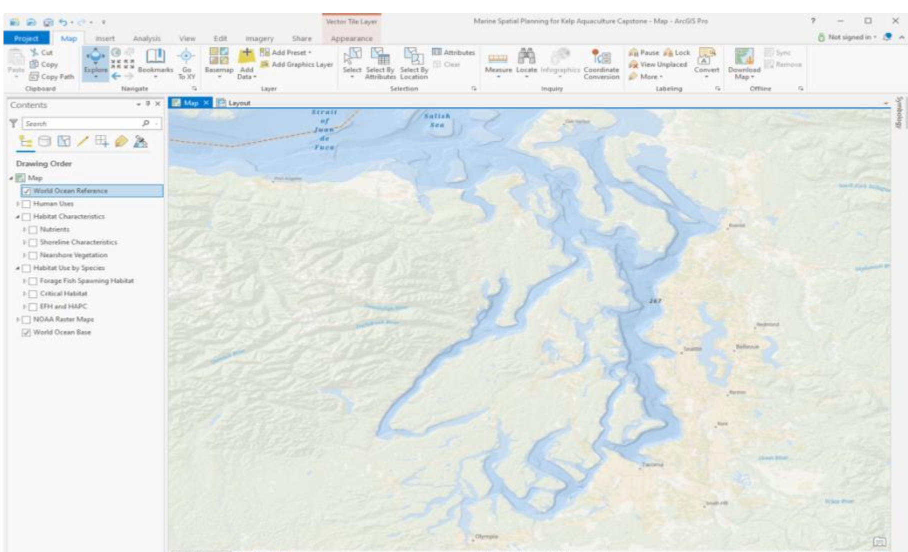
Habitat Use By Species (Critical habitat and Essential Fish Habitat)	Chinook Rockfish (Boccaccio & Yelloweye) Southern Resident Killer Whales Essential Fish Habitat Aquatic Reserves Wetlands	NOAA NOAA NOAA NOAA DNR National Wetland Inventory
Water Quality and Shellfish Specific Layers	Stormwater Discharge Areas Water Sampling Commercial Shellfish Growing Areas Commercial Harvest Sites Shellfish Closure Zones	WSDOT WADOH WADOH WADOH WADOH

Visualizing

After categorizing our data layers we imported them into Esri's ArcGIS Pro, the current standard GIS software for visualization and analysis of spatial data. Here we imported the various data layers to individually verify their applicability to this tool and vet their usefulness to potential kelp farmers. We draped our data layers over different base maps native to ArcGIS to inform the user in different ways throughout the planning process.

In Figure 1 you can see the extent of the planning tool to the Puget Sound waterway, a southern component of the greater Salish Sea that begins at the mouth of Admiralty Inlet and terminates south at the Nisqually delta near Olympia, Washington. On the left hand side you can see our datalayers in their nested categories. The three major categories are Human Uses, Habitat Characteristics, and Habitat Use By Species. There are a number of subcategories within these including: critical habitats of various listed species native to Puget Sound in the Endangered Species Act (ESA), shoreline characteristics, nutrient data, and nearshore vegetation.

Figure 1: The GIS tool showing the extent, bathymetry, and various nested datalayers (left).



Below in Figure 2 you can see the data layers that make up the Human Uses Category. Users have the ability to point and click various layers of interest on/off and clicking on specific icons within the map shows additional information in a popup window. Here we see tribal nations in orange, waterway access points in blue (triangles and diamonds), WA Department of Natural Resources aquatic reserves in purple, ferry lanes in red, and Puget Sound fishing areas in green. We also see additional information for a specific fishing area in the popup window. These are draped over a clean bathymetry ocean map with labels of various rivers and cities.

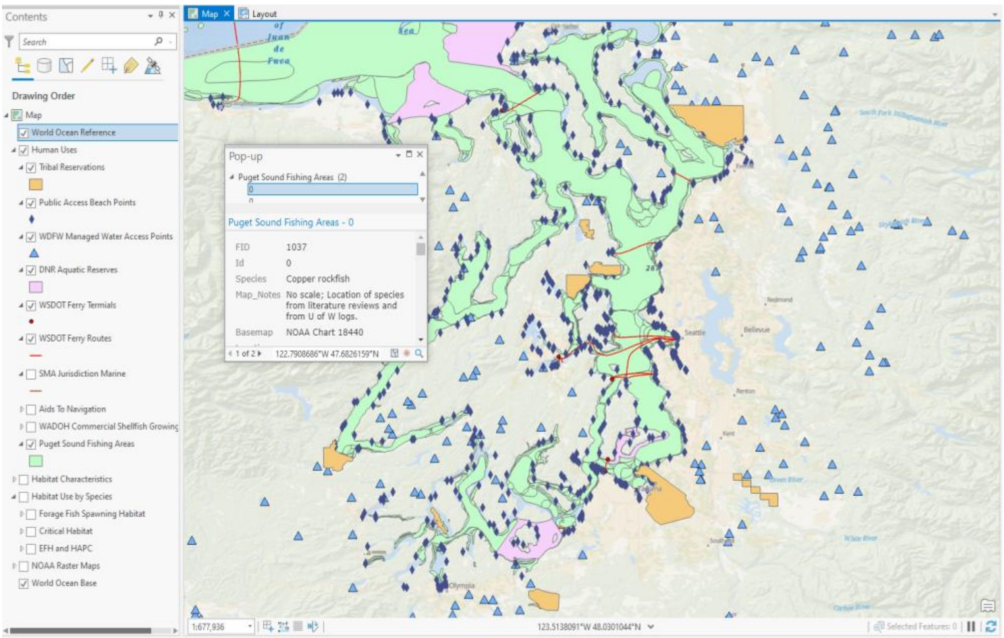


Figure 2: highlights the data layers in the human uses category and the ability for users to click on icons for additional information.

ArcGIS can also be used to create finished map products with standard scale bars, legends and north arrows. Here we see the second basemap of the tool; a hybridized satellite view that is useful when looking at the level of urbanization in a given area while taking into account proximity to roadways and towns. This could be useful when planning transportation routes for maintenance and finished product. Figure 3 also shows the various ferry lanes and aids to navigation that should be avoided when potentially siting a farm, but useful if transporting product via boat to be processed. This satellite basemap also gives a rough view of the level of waterfront property density and the potential amount of pushback from wealthy homeowners associated with "Not In My Backyard" syndrome. As we have seen in previous attempts to establish kelp farms in Puget Sound this potential barrier is not inconsiderable and should be carefully considered in the planning process.

Figure 3 also shows potential areas of forage fish spawning (e.g. smelt and herring) as managed by the WA Department of Fish and Wildlife that need to be taken into consideration when performing *in situ* habitat surveys for permitting process. Finally, we also see here the designated critical habitat for the Puget Sound Endangered Species Unit (ESU) of Chinook salmon in pink. This is important to know when preparing for a consultation with USACE on effects of a potential farm on locally listed species.

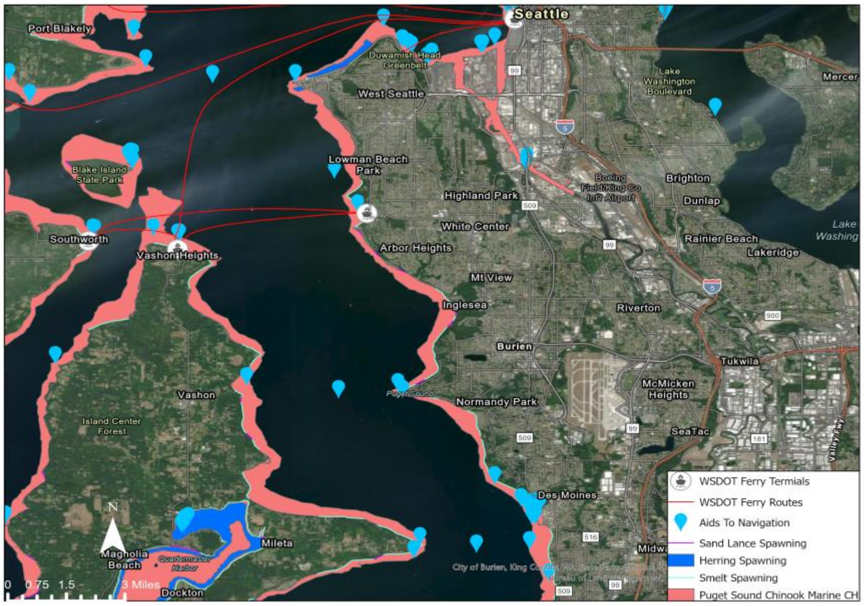


Figure 3: An example of a finished map product of the southern end of main basin that could be exported and saved as a JPEG or PDF

The last two figures show a zooming in on a particular area in the south end of the main basin in Puget Sound, opposite of Vashon Island. Figure 4 shows public access points for various recreational activities in the immediate area and the relatively undeveloped shoreline with few houses along the coast and less armoring along the shore zone. Just south we see a marina that likely has a boat launch, which is an important consideration for farm maintenance logistics throughout the growing season. The level of exposure is shown in blue with a semi-protected stretch of coastline shown just north of the marina. This is important because too much exposure could potentially rip kelp from seeded lines, while too little water movement could inhibit kelp growth. Finally, we see critical habitat for rockfish in the area. It is important to note that kelp farms may enhance critical habitat for rockfish since kelp has been found to be essential for the juvenile stages of various rockfish species like yellow eye and boccaccio. The yellow box represents a potential area that may be suitable for a kelp farm based on the datalayers we have examined.

Figure 5 zooms into this area further and highlights the level of information that can be gleaned from NOAA raster charts. Here we see depth contours in fathoms and relative steepness of the immediate coastline, potential underwater obstructions and cables, navigation aids, and major lanes of commercial traffic. This layer is often very detailed and informative in itself, and therefore slow to load when changing the current visual extent, so we recommend using this layer at smaller scales once a potential area of interest has been identified.

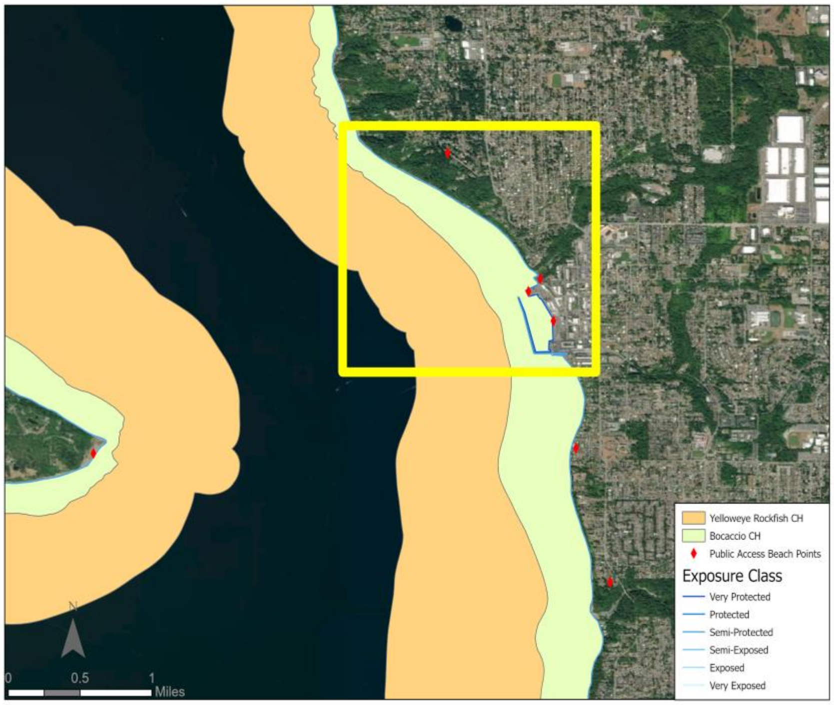


Figure 4: A potential area of interest within the southern portion of main basin opposite of Vashon Island

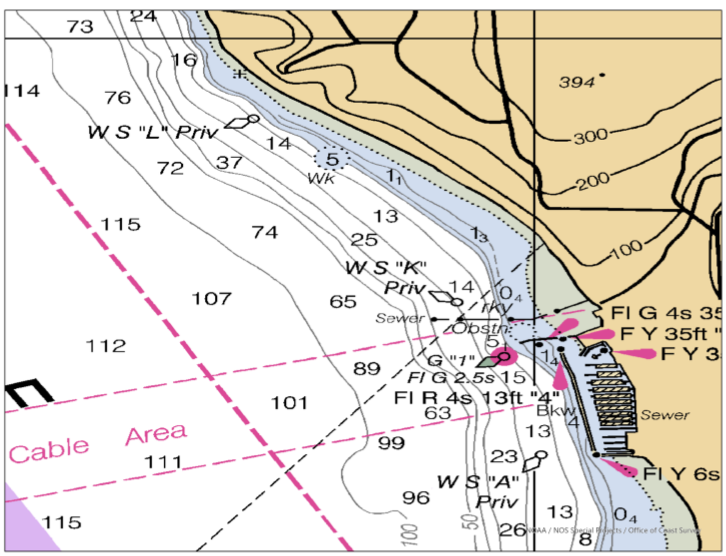


Figure 5: An example use of NOAA raster charts to further examine smaller areas of interest

Similar methods can be used for shellfish activities. Appropriate layers include current commercial growing sites, eelgrass presence, nitrate priority areas, and shellfish closure zones (Figure 6). As with previous data layers shellfish layers like the commercial areas and closure zone have additional information when clicked on by the user.

Maintenance

Regular maintenance will ensure the continued usefulness of this tool in the future. Over time data layers will be updated by the source agency and these new layers will need to be integrated into the tool manually. The frequency of updates varies from data layer to data layer, so it is recommended that monthly checks be conducted by the host admin. All current layers are open source and readily available online and relevant metadata for each layer can be found within the Tool's GoogleDrive and at the source Agency's website. These metadata data will indicate when they were last updated and by whom. Keeping an up-to-date roster is recommended to document which layers were updated and how frequently.

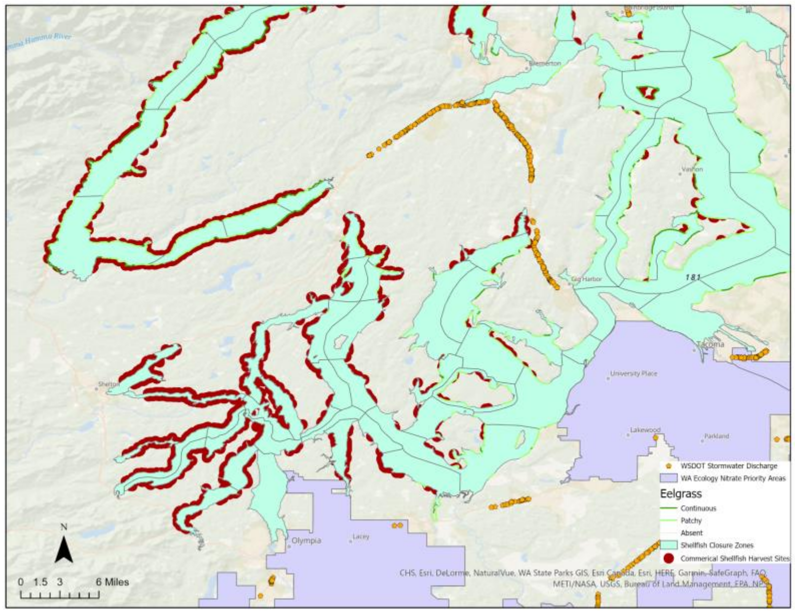


Figure 6: Example map with shellfish relevant layers in Sound Sound.

Regulatory hurdles

Leasing

The process of obtaining a lease site permit is long and arduous nationally, and each state has a different criteria and framework for permit applications and leasing. Here we focus our efforts to showcase the regulatory hurdles a potential applicant faces in Washington State. Leases for aquaculture operations in Puget Sound are issued by the Washington Department of Natural Resources (WDNR). These leases are based on the 1984 Aquatic Lands Acts to ensure protections of the environment where aquatic use practices are occurring. These leases are handled by the WDNR aquatic districts. For Puget Sound this includes the Orca Straits district and the Shoreline district. The revenue generated from leasing sites to users of these marine spaces goes towards management of state-owned lands and the Aquatic Lands Enhancement Account (Washington DNR, n.d).

Joint Aquatic Resource Permit Application

The state of Washington has issued a one-stop application, the Joint Aquatic Resource Permit Application (JARPA), created by multiple regulatory agencies in order to attempt to increase the efficiency of the regulatory process. Every applicant is required to fill out the JARPA. This application can be used for permits issued at the federal level, state level, and local level, including Section 10 and 404 permits, 401 and Aquatic use authorizations, and shoreline permits respectively (Washington State Department of Transportation, 2021). Due to the overlapping nature of federal and state core authorities there are instances where one permitting application process could inhibit the advancing of another, causing an overall bottleneck. This can be further exacerbated by "false start" events, where a specific aspect of a permit application is considering lacking, resulting in the invalidity of a second permit (e.g. Section 401 certifications issued by the Washington Department of Ecology in lieu of the Environmental Protection Agency and Section 7 consultations triggered by the Corps).

Individual and State Permits

Individual permits authorized by the United States Army Corps of Engineers (USACE) is the beginning of the regulatory process for applicants. Under the Rivers and Harbors Act, a Section 10 permit may be required for applicants to obtain. This Section 10 permit is required when regulated activities conducted below the high-water line of navigable waters (3 miles or less offshore) include activities such as excavations, dredging, filling, and sediment disturbance.

Additionally, a Section 404 permit under the Clean Water Act may also require authorization from the USACE to cover dredging and filling of materials into navigable state waters. At the state level, applicants must apply for a 401-water quality certification if they require approval from the USACE. Under the Clean Water Act, and specific to Washington State, a farmer will need to obtain a 401 WQC authorized by the Washington Department of Ecology (WDOE), stating the project is in compliance with the water quality standards in Washington State (United States Army Corps of Engineers, n.d).

Local Permits and Consultations

Narrowing in at the local government level, a shoreline permit may be necessary, allowing governments to implement their Shoreline Master Program under the Shoreline Management Act aimed at regulating development within the appropriate shoreline jurisdiction (Washington State Department of Ecology, n.d). In addition to these permits, a Section 7 ESA consultation is needed if the proposed farm may impact any listed endangered species and/or critical habitat. This requires either an informal or formal consultation to be conducted. Under Section 7 of the Endangered Species Act a consultation with NOAA is required from all federal agencies. If the proposed kelp farm is determined "not likely to adversely affect" endangered species or critical habitat then applicants are able to proceed with a letter of concurrence and there are no further actions required. However, if the proposed kelp farm is deemed "likely to adversely affect" endangered species and/or critical habitat a review process with a Section 7 biologist is triggered and the request and procedures may be time consuming (NOAA Fisheries, n.d).

Shellfish Aquaculture

Regulatory hurdles for shellfish aquaculture are largely based on the existing kelp framework described in depth above. The main difference is the new nationwide permit (NWP) for kelp aquaculture. The already existing NWP 48 for shellfish aquaculture was reauthorized by the USACE and NWP 55 was created specifically for kelp.

Litigation and need for Marine Spatial Planning

While the aforementioned permits and consultations are vital when siting kelp farms, this list is not exhaustive. There may be other documents that applicants must consider, such as the National Environmental Policy Act (NEPA), State Environmental Policy Act (SEPA), and later state Aquatic Farm Registration application. It is also important to take into consideration these regulatory hurdles are subject to appeal and litigation, being up for public comment.

With this in mind, the need and value for a robust spatial analysis is crucial. Both kelp and shellfish aquaculture planners and farmers in the United States must consider and analyze various existing constraints and water quality characteristics early in the planning stage to ensure a smooth permitting process down the road and subsequent successful and accepted farm. A user-friendly tool is critical for securing aquaculture sites that are suitable for kelp and shellfish to thrive with minimal impact to the surrounding environment and already occurring marine use activities.

Conclusions and implications

Importance

This tool provides users with a spatial analysis of many of the human uses in Puget Sound as well as important habitat designations and protected areas for ESA listed species. It is important to keep in mind that this is a planning tool to assist users early on in the site selection process, but this tool does not replace environmental review and cannot be used to circumvent the necessary regulatory processes required for site permitting.

Prior to this work there was no GIS tool that took into account all of these factors in a single, user friendly mechanism. Using GIS for marine spatial planning has proved successful in a number of studies; such as assessing seabird sensitivity to offshore windfarms (Bradbury et al. 2014), determining the impacts of shipping on whale migration (Redfern et al., 2013), and finding suitable areas for offshore aquaculture off the California coast (Lester et al., 2018). These studies and methodologies give us confidence that the spatial data layers integrated into our tool provide necessary and valuable information for decision makers.

While this tool provides information for citing commercial aquaculture, there are applications of kelp and shellfish aquaculture that fall outside this realm. Our focus fell on the potential for restoration, bioremediation, and ocean acidification mitigation when considering alternative applications for kelp and shellfish growing. This tool could be used by planners interested in growing kelp of shellfish for the purpose of water quality enhancement and ocean acidification mitigation. Planners interested in using kelp for this purpose could site farms in areas of high nutrient concentrations, such as areas where terrestrial runoff of stormwater discharge enters Puget Sound. Kelp sequesters carbon and nutrients as it grows, so farms sited in these areas could provide localized mitigation. Additionally, shellfish filters organic materials from the water, removing excess nutrients that cause water quality problems such as harmful algal blooms.

Furthermore, this tool can also be used for the purpose of kelp and shellfish restoration. As natural kelp beds decline in Puget Sound, scientists and planners can use this tool to identify priority areas where kelp and shellfish have persisted despite environmental stressors, like increased temperature. This can assist in determining suitable areas for replanting and restoring natural beds in Puget Sound.

Gaps and Next Steps

This tool primarily focuses on the ecological considerations and constraints for aquaculture site selection, but there are social considerations that could further its relevance and applicability. Of critical importance when planning in Puget Sound is knowledge of the locations of tribal UAAs Fishing Areas, which cannot be included in a publicly available planning tool.

Prospective farmers are expected to confer with tribes early on in the planning process before moving forward with site applications, as tribes are able to veto uses such as aquaculture in UAAs. Additional social considerations such as community receptiveness to aquaculture is important in determining feasibility of implementation and is an area where future research is needed.

Additionally, this tool could be co-expanded with a market feasibility tool for blue carbon. In Connecticut, where kelp aquaculture is a more established commercial industry, scientists have shown that kelp is a powerful tool for nutrient extraction and have proposed it be added to Connecticut's nitrogen credit trading program and carbon pricing scheme (Kim et al., 2015). This move would incentivize and compensate kelp growers while conferring environmental benefits.

This tool in its current capacity aids both shellfish and kelp farmers with the site selection process. Combining these two aquaculture practices in a co-culture of multi-trophic aquaculture farms, similar to Blue Dot Sea farms, could provide a localized solution to the negative impacts that ocean acidification has on shellfish production. The inorganic extraction provided by kelp can provide benefits to commercially valuable shellfish, in addition to the commercial value of kelp and environmental benefits that it provides.

The established commercial shellfish industry in Washington demonstrates that the state has a vested interest in supporting sustainable aquaculture practices. With the numerous benefits that growing kelp has on the environment and the commercial value of it as a crop, kelp aquaculture has the potential to become a robust commercial industry in Washington as well. This tool provides prospective farmers and planners with knowledge of the diverse spatial uses of Puget Sound as well as information regarding the permitting and regulatory process. With the demonstrated successes and widespread use of marine spatial planning tools, we are confident that this tool can aid in the continued success of sustainable shellfish aquaculture and help to build a kelp aquaculture industry in Washington state.

We hope to find a long-term online host for this tool so that data layers may be updated as new versions are released. An online host is a critical step in ensuring this tool reaches its intended audience and may be used widely by prospective aquaculturists.

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