John Marshall
MGIS

Geography 568 - Spring 2018
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Sustainable Development and Sustainable Management:
A Puget Sound Oyster/Eelgrass Case Study

Introduction and Problem Statement

The larger system whereby natural resources provide a foundational platform for the sustainability of the planet Earth through its fundamental elements (e.g., physical, biological, and chemical) has been verified and semi-quantified by human beings. Also, to a significant degree, the human devised psychological and sociological abstract constructs aimed at making sense of the world have been verified and semi-quantified. This means there is likely adequate information available to create a conceptual framework analysis (CFA) for:

- 'Sustainable Development' (SD), which reflects the paradox of two diametrically opposed human goals of environmental protection and economic development by representing development that is purported to be possible while allowing the maintenance of the environmental conditions necessary for human life support on our planet for both present and future generations (Madu and Kuei 2012); and

- 'Sustainable Management' (SM), which reflects the plethora of human strategies purported to result in SD (Madu and Kuei 2012).

The missed anthropogenic nature of SD/SM in the literature appears to be obscuring if not outright masking the most critical epiphanies necessary before SD/SM can be brought into fruition. But before elaborating on this 'perception dilemma', it is necessary to add a few constraints on our conceptual framework to make it more manageable and ultimately more obtainable:[1]

- SD/SM is only valid if it occurs for all people no matter where they are physically located;
- SD/SM is only valid if it persists through all foreseeable generations;
- SD/SM can occur along several pathways (Figure 1):
    1. Society changes its definition of SD/SM to match a collective sense of what is feasible based on natural resource constraints[2];
    2. Society changes its behavior to alter what is feasible based on natural resource constraints;
    3. Society changes its technology to alter what is feasible based on natural resource constraints; or
    4. Society uses a combination of the above cited pathways to achieve a state of SD/SM.

[1] It is highly unlikely a 100% level of sustainable development is achievable. But that doesn't mean we should not constantly strive to obtain it.

[2] When conservation measures are already being judiciously applied, this pathway is potentially the proverbial 'slippery slope.' How much risk of chronic disease from exposure to toxic pollutants is acceptable? On the other hand, if entitlement is a significant influence, it may be a logical 'greater good' solution. How many cars does one working family need in a city with multi-modal and alternative sources of public transportation?

- SD/SM is only valid if the least entitled people (not the most entitled) agree that it is valid; and
- For many natural resources sustainability thresholds have already been exceeded, making past historical benchmark targets for a minimum partial recovery necessary before a state of SD/SM can be achieved in the present and future.

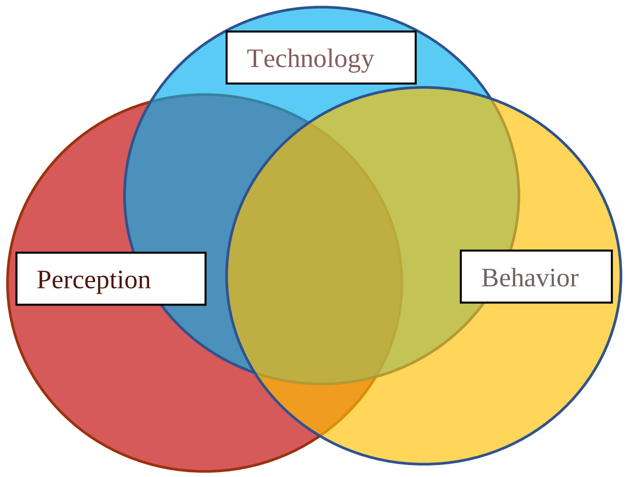

Figure 1. Pathways for Sustainable Development/Sustainable Management.

Problem Statement

Most of the earth's citizens have a view of reality (ontology) that is propagated by a kaleidoscope of overlapping human constructs of socio-political and economic systems devised over the ages of our developing civilizations and inherited by each successive new generation. These constructs were devised and are periodically modified primarily to help us to make sense of and manage our interactions with our surrounding environment and each other. While this collective view of reality has been built with overall noble and utilitarian intent, its true nature as layers of human constructs is obscured because over time it has been so effectively etched into our collective socio-economic psyche that we imbue upon its attributes a sense of substance and behavior not unlike a phenomenon of nature, like the ocean tides or the collective processes that manifest in our weather.

This in of itself would not necessarily be considered a problem, but the fact is the system works fine up until the point it doesn't. It is beyond the scope of this CFA to address all the potential failure points of these systems. It is probably fair to say the failures can stem both from system design flaws and from the less than benign disruptive actions by individuals or organizations such as corporations (Madu and Kuei 2012).[3] The fundamentally more important message is that these overlapping human constructs are essentially self-imposed illusions based on several highly influential erroneous assumptions. The objective is not to say these illusions are unnecessary, but to emphasize if their

[3] System malfeasance is often made possible through selective information management, populations chronically manipulated through 'fake news' and information saturation, populations with compromised information screening tools, and population apathy precipitated by constant diversions and escapist focused mindsets.

underlying assumptions are flawed, they cannot adequately serve their intended purposes. Even more to the heart of the matter, they are our own constructs. Therefore, as such we should never feel compelled to allow their failures to harm us (*do not let the tail wag the dog*). Instead we should view system failures as red-flag signals warning us that it is time for an intervention. The question then becomes at which level in the system is an intervention needed? This CFA postulates that at this point in history, the failure is at the base-level and the resulting false ontology permeates the Environmental, Socio-Political and the Economic-Domains and severely impairs our chances of achieving SD/SM.

The first erroneous assumption is that:

"Currency used in economic transactions is separate from environmental capital."

This assumption is the primary problem inhibiting SD/SM and, therefore, SD/SM will not be completely achievable until this assumption is collectively abandoned worldwide. Simply put, currency has no meaning outside the context of the foundational existence of the natural resources it represents. Any exchange of currency will have both direct and indirect effects on natural resources. This does not dismiss the value of manufactured goods and services (Petersen 2017) but emphasizes these goods and services are intermediate and interdependent manifestations of the natural resource base.

The second erroneous assumption is that:

"Evolutionary-Darwinism" inherently justifies a paradigm of social-Darwinism."

This assumption is used to justify winners and losers in natural resource allocations and permeates out of our tribal ancestry, which basically facilitates a human condition that is predilected toward each human demographic feeling they are superior to every other human demographic and therefore "*more entitled."* Entitlement seems to be a hard-coded human attribute.

The third erroneous assumption is that:

"As our knowledge and technologies improve, our efficiencies and overall abilities to develop more environmentally compatible economies will also improve."

This is probably the most insidious assumption of the three because it has some historical evidence of having occurred on more than one occasion and, in fact, it may hold the key to some of our best chances for achieving SD/SM. However, overall its historical track record is not all that impressive for several reasons, including but not necessarily limited to the following:

- Legacy special interests and their related markets resist innovation and transition;
- Knowledge and technology are not universally distributed and applied;
- Environmental consequences of legacy practices are not universally accepted;
- The largest beneficiaries of legacy practices may be leading transition efforts after they have already reaped massive '*rewards*' from their legacy practices at the '*expense*' of those they now persuade to follow their transition objectives, raising questions of equity and fairness;
- Unrealistic expectations of the rates and levels of new knowledge and technical innovations;

- Societal expectations of an acceptable environmental sustainability threshold are not universally shared; and
- Each new technical innovation is generally followed by its own unique set of direct and indirect environmental effects which are often, if not usually, unforeseen at the onset of its emergence.

Analysis Methods

The first step in developing a Conceptual Framework Analysis (CFA) for SD/SM was to group all the primary components or entities considered important in framing the overarching traditional paradigm of SD/SM (Figure 2). The next step was to devise and graphically display a comparison between two separate sustainability management paradigms, one devised for the traditional systems that typically do not internalize market externalities in market transactions and one that does routinely internalize market externalities (Figures 3 and 4). Finally, the critical components of the latter sustainability management paradigm were itemized so their primary relationships could be cross-matched with the focal SD/SM problems and constraints to help postulate a more refined CFA alternative for a natural capital driven SD/SM paradigm (Figure 5).

Narrative and Graphic Analysis Outcomes

Traditionally natural resource values were valued using market criteria propagated by a neoclassical economic theory based on a teleology of utilitarianism and human preferences (Victor 1979). In this tradition there was an acknowledgement albeit discounting of costs and benefits resulting from natural resource management decisions that were intangible to the market. In other words, since they could

Ecological Domain Socio-Political Domain Economic Domain Natural Resources Renewable Resources Finite Resources Ecosystem Services Remote Sensing GIS RDMS Geoprocessing Data Mapping Internalize Externalities Entitled Population Niches Non-Entitled Population Niches Resource Allocation Sustainable Development Present Generations Future Generations Real Debt Thought Debt Human Rights Socially Desired vs Politically Feasible Levels of Sustainability Human Homeostasis / Greed Scale Wealth Illusion vs Wealth Reality Social-Political Illusion Acceptance Scales Thresholds Defining Systematic Function and Dysfunction Social Equality Thresholds Social Diversity Thresholds Safety Democracy Poverty Health Education Capital Work Escape Artist Mindset Denial Acceptance Commitment Self-Awareness Police Social Change-Awareness

Figure 2. Entities Populating Sustainability Management Paradigm.

not be measured by a market currency, they were considered 'externalities' to be ignored in market transactions (Marshall 1985). So, for example, clean air, water, and fish and wildlife habitat were externalities that were regarded irrelevant in a market transaction. Generally, the overarching result was that while each transaction benefited a select set of individuals or corporations financially, there were varying degrees of environmental costs that could also be considered as a loss of natural capital. But these costs accrued to our society (e.g., air and water pollution, open-space loss and degradation, increased frequency and amplitude of storm related damages, etc.).

Over the course of the past several decades, this has been changing dramatically world-wide across broad economic bands of wealth and poverty. Now there is a trend is to expand the focus (Boyd et al 2007) (Costanza et al 1998) (Daily 1997) (Daily et al 2009) (Díaz et al 2015) (Gómez-Baggethun et al 2010) to encompass externalities (aka 'natural capital') as essential integral parts of market transaction decisions (Daily et al 2011). Figure 3 represents a CFA where natural capital is not considered in market transaction decisions and Figure 4 represents a CFA where the natural capital is considered.

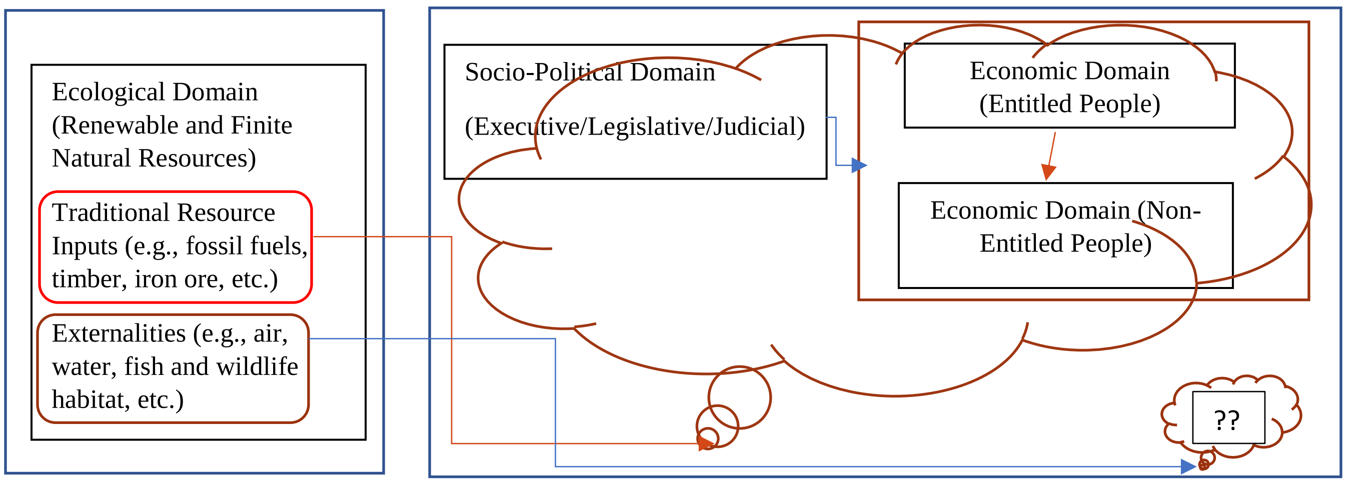

Figure 3. Sustainability Management Paradigm In Traditional Ecological, Socio-Political, and Economic Domains.

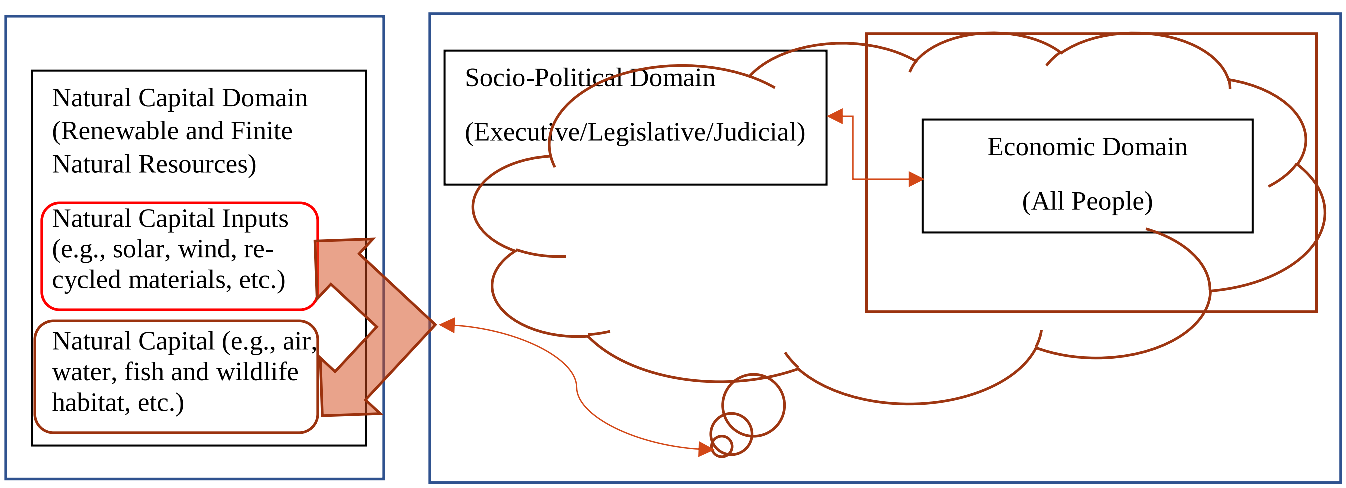

Figure 4. Sustainability Management Paradigm In Natural Capital, Socio-Political, and Economic Domains.

Investigation, Classification, and Synthesis of Results

The primary domains in the natural capital driven SD/SM paradigm are distilled into critical components (Figure 5) contributing to the dynamics of the ideal CFA illustrated in Figure 4. The domain components are applied at the global, regional, and local scales and are temporally informed by past and present conditions to assist meeting future goals and objectives. The Socio-Political Domain acts as a transactional framework linking the Natural Capital and the Economic Domains. All domains have interactive feedback loops but overall the relationships are viewed as hierarchical with the Natural Capital Domain acting as the parent to the Socio-political Domain and the Socio-political Domain acting as the parent to the Economic Domain.

Overarching CFA Presumptions

Looking back to the initial SD/SM constraints imposed for this CFA and considering them in relation to the domain components in Figure 5, most of the critical components become ideal focal points from which to address potential interventions necessary to construct a natural capital driven SD/SM system. First, renewable and finite natural resources (aka natural capital) comprise the foundational wealth that supports all other wealth. Therefore, currency that ignores all or any part of natural capital is no longer considered adequate to fully represent all the benefits and costs of any given market transaction. Second, the predilection of humans to gravitate toward entitlement must be tempered by a collective view of what is homeostasis relative to human needs vs a state where a human greed threshold is exceeded, with emphasis being it must be simultaneously obtainable by all the people in the world in the present and future generations. If this is done using a decision system using natural capital-based transactions, the determined state of human homeostasis should adequately address and balance all human needs with their overarching environmental needs. Once this state (SD/SM) is democratically determined, the exercise of police powers will likely be periodically necessary to support the practices necessary for acquiring and maintaining it.

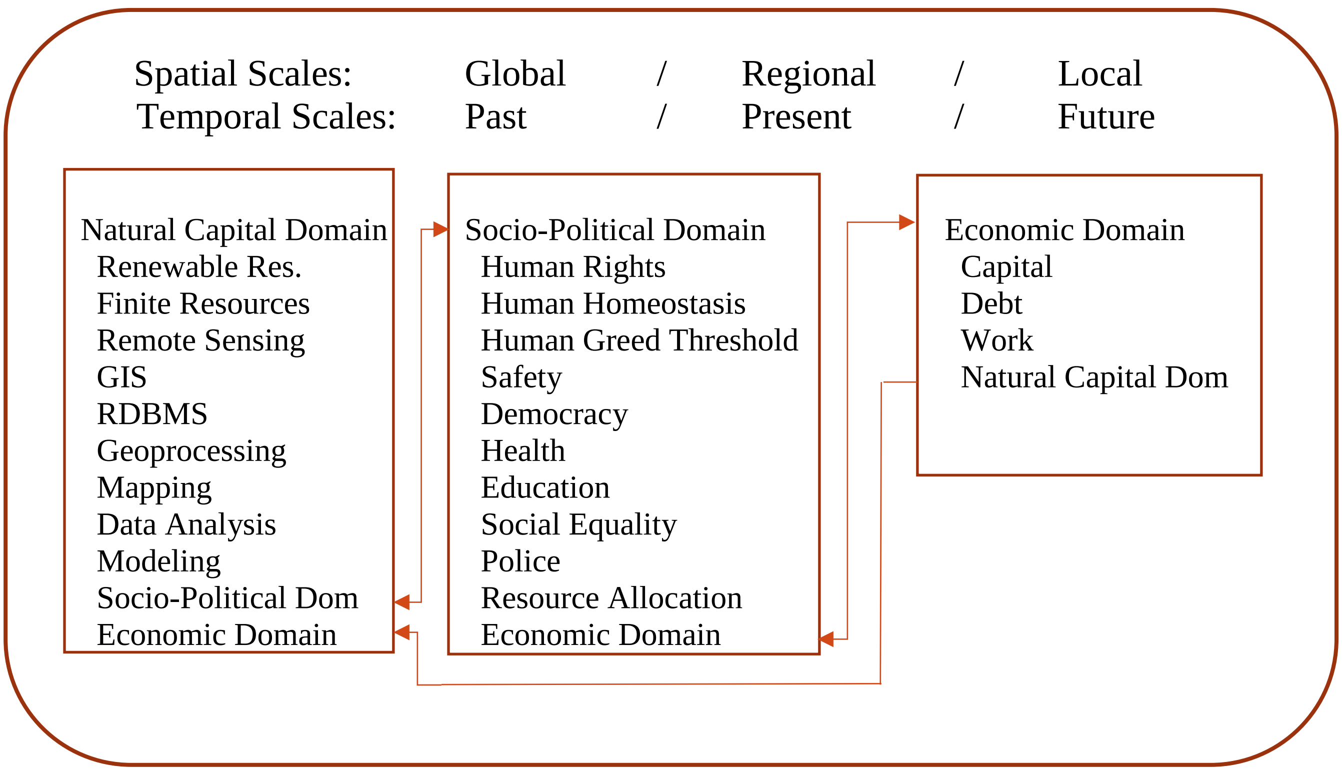

Figure 5. Environmental, Socio-Political, Economic Domain Relationships.

To ensure such a system is sustainable, it is imperative that what is judged to reflect homeostasis relative to human needs while protecting the environment is in fact acceptable and embraced by most people. To gauge whether this is true, focal questions should be formulated and routinely asked and answered by the people and the answers should then be reviewed by the policy makers. For example, most people queried should answer ‘yes’ to each of the following questions:

- Do you have enough to eat?
- Do you have an adequate supply of clean freshwater?
- Do you have adequate shelter?
- Do you have adequate healthcare (medical, dental, mental)?
- Do you have access to an education in the subjects / field(s) that interest you?
- Do you have a job or advocation that you look forward to everyday?
- Do you have a work or school environment that is safe and free from discrimination or harassment of any kind?
- Does your work / school allow you to have adequate time to relax by yourself and / or to be with your family and /or your friends?
- Do you have adequate opportunities to engage in the social and recreational activities you enjoy?
- Do you feel free to practice and express your non-violent religious and / or social beliefs without fear of discrimination or reprisal?
- Do you have adequate clothing to meet your personal and professional needs?
- Do you have access to adequate transportation to get you to the places where you need to be in a reasonable amount of time?
- Are you able to manage your debt and still have enough financial resources remaining to meet your basic needs and still do the things you enjoy doing?
- Do you feel protected and safe?
- Do you feel that your neighborhood, city, state / province, and country are safe and supportive of you and your family?
- Do you feel your natural environment and its natural resources are being properly managed and protected for future generations?
- Has the best available science been used to establish SD/SM benchmarks in your local area and surrounding region?
- Has the best available science been used to monitor and determine whether these SD/SM benchmarks are being met and, if not, routinely set into place the interventions necessary to bring the problem areas back on track?
- Do you feel that any of your basic freedoms (freedom of speech, freedom of religion, etc.) are intact and are not being denied or unduly restricted in any way?
- Do you feel that you have access to a political process that allows your concerns, views, and ideas to be heard and to be given a fair chance for enactment?

At the risk of being tagged a skeptic by researchers advocating a more volunteer oriented approach toward achieving SD/SM (Whitney 2014), in my opinion government oversight will likely be necessary to ensure empirical monitoring, analyses, and documentation of environmental (natural capital) resources and conditions are routinely conducted and reported to the people and the decision / policy makers. Any indications that SD/SM benchmarks are not met or are not on a targeted trend toward being met should be carefully evaluated and reported to ensure any necessary interventions are initiated when needed.

Linkage to Case-Study Level SD / SM

Up until now the entire discussion has been more or less conceptual and potential applications have been highly generalized. However, it is important to display the link between the conceptual SD / SM framework as it characterizes all SD / SM projects and the SD / SM frameworks characterizing specific projects or case-studies. Basically, for the purposes of this CFA a specific project only qualifies as a SD / SM project if it shares all the primary entities, attributes, and relationships used to characterize the over-arching SD / SM framework (Figure 6). In other words, the SD / SM case-study inherits the entities, relationships, and methods of the SD / SM CFA and in a sense can be considered an instantiation of the larger CFA. In this stage of the case-study characterization, the CFA might be best considered an ecological socio-political aspect and an intermediate phase of a more optimistic view of the 'micro-macro' linkage problem as compared to Coulter 2001. Since all real-world problems and related entities manifest in space and time, and since a GIS can be interpreted very broadly as any information system which tracks and analyzes phenomena both spatially and temporally, a GIS is considered to be an inherent technical apparatus dedicated for deployment in all SD / SM case-studies.

A GIS-Ecology Fitness Test: A Case Study

The case-study applied CFA in Figure 6 essentially begins to unwrap and develop the GIS-ontology and GIS-ecology[4] (Burgin and Zhong 2018) within the context of the research philosophical ontology (Smith 2003) the GIS is designed to help represent. Figure 6 also identifies native eelgrass as the natural capital characterizing this applied case-study. Figure 7 provides a theoretical basis for the currency of the natural capital as credits and debits and Figure 8 provides a preliminary measurement scheme for the currency for logic testing.

Case-Study Problem Ontology/ GIS-Ontology. Significant portions of intertidal habitat in the Puget Sound are dedicated to oyster aquaculture operations under the premise that they are biologically and ecologically compatible with undisturbed estuarine and marine structure and function. However, history informs us that aquaculture is a type of agriculture that can have serious direct and indirect adverse impacts on native species and the natural habitats they depend on.

Eelgrass Ecology. In the Pacific Northwest bays and estuaries, eelgrass (*Zostera marina L.*) provides spawning grounds for Pacific herring (*Clupea harengus pallasi*), out-migrating corridors for juvenile salmonids (*Oncorhynchus spp*.) and important feeding and foraging habitats for water birds such as the black brant (*Branta bernicla*) and great blue heron (*Ardea herodias*) (Thom et al 2014). Because of its

[4] The term GIS-ecology is differentiated from the word ecology. The former refers to existing relationships between information knowledge, data, and information processing systems, while the latter refers to those entities, relationships, and functions that contribute to a sustainable biosphere, ecosystem, or habitat. However, for the purpose and content of this particular case-study and its subsequent GIS, there is a significant overlap between the two terms.

ecological importance and its rapid response to environmental degradation, eelgrass has been identified as a Vital Sign of ecosystem health, and a 2020 eelgrass recovery target was adopted by the Puget Sound Partnership, which is a public program dedicated to restoring the Puget Sound ecosystem's health (Thom et al 2014).

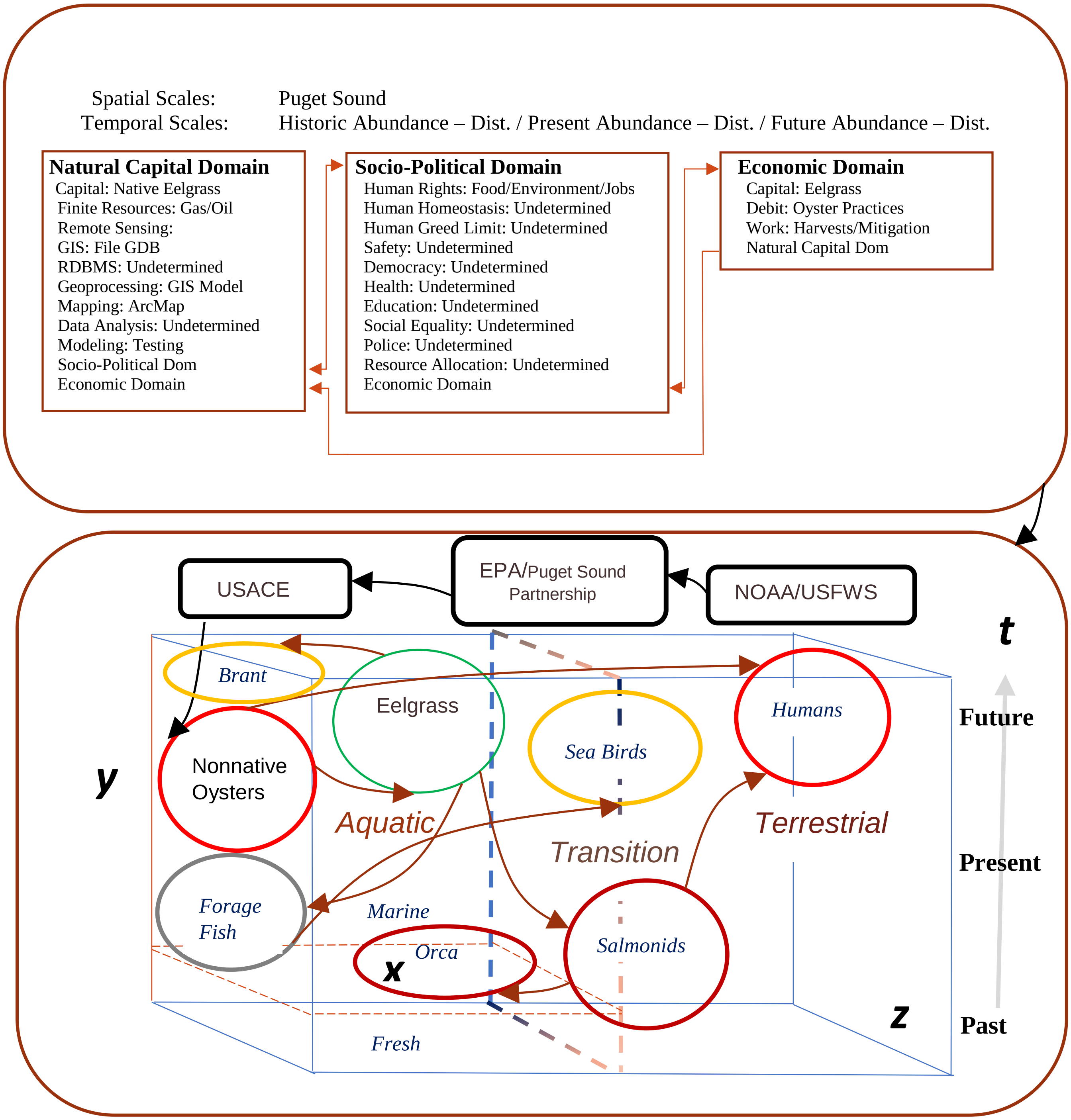

Figure 6. Environmental, Socio-Political, Economic Domain Relationships at a Specific Case-Study Level.

Credits

Production	Native eelgrass provides spawning substrate for Pacific Herring.	
Food Chain	Pacific Herring are forage fish for sea birds and marine mammals. Wintering Black Brant feed almost exclusively on eelgrass	**Diatoms**, bacteria, and detritus gathers **on eelgrass** leaves providing **food** for many invertebrates; including some clams.
Cover	Juvenile salmon use eelgrass to avoid predators.	Native crabs use eelgrass to avoid predators.

Debits

Structural Displacement	Oyster bottom culture, longline, and rack and stake can result in mechanical tearing of fragile eelgrass blades eliminating them from an entire plat. The reduction in light from shellfish bed structures can be associated with reduced eelgrass presence.	Oyster bottom culture, longline, and rack and stake can result in prevention of new eelgrass growth over an entire plat. High-density structures may increase sediment deposition, reducing eelgrass growth. Digging and dredging activities immediately reduce eelgrass presence.
Structural Impairment	Oyster bottom culture, longline, and rack and stake can result in mechanical tearing of fragile eelgrass blades decreasing blade density or eliminating it from entire sections of a plat.	Oyster bottom culture, longline, and rack and stake can result in prevention of new eelgrass growth over significant sections of a plat.
Lethal Direct	Pesticides used to control native burrowing shrimp kill these important estuarine species utilizing areas inside oyster plats.	Pesticides used to control burrowing shrimp likely expose and kill other 'non-target' native species (e.g., juvenile salmon and crabs) when they use eelgrass in oyster plats.
Lethal Indirect	Pesticides can persist and drift from the application areas into other estuarine areas indiscriminately killing many organisms in its path.	Nonnative parasites on native burrowing shrimp hosts may be decimating their hosts over large areas in Pacific Northwest estuaries.[i]
Sublethal Direct	Oyster boats transporting growers and growers walking in their plats tending and / or harvesting oysters disturb black brant off their feeding areas diminishing their winter reserves for the spring migration.	Pesticides used to control native burrowing shrimp may impair these important estuarine species utilizing areas inside oyster plats and make them more susceptible to disease and predation.
Sublethal Indirect	Oyster boats and growers travelling to their plats and walking on their plats disturb nearby black brant off their feeding areas diminishing their winter reserves for the spring migration.	Pesticides can persist and drift from the application areas into other estuarine areas indiscriminately impairing numerous organisms in its path, making them more susceptible to other perturbations.

[i] This is highly speculative consequence of oyster culture.

Figure 7. Natural Capital Rationale as Credits and Debits.

CREDITS

Production: 0 to 500
+
Food Chain: 0 to 500
+
Cover: 0 to 500

DEBITS

Structural Displacement: 0 to -300
Structural Impairment: 0 to -300
Lethal Direct: 0 to -250
Lethal Indirect 0 to -250
Sublethal Direct: 0 to -200
Sublethal Indirect: 0 to -200

= Total Potential Credit (1500) x Acres | = Total Potential Debit (0 to -1500) x Acres
= Total Potential Credit Value | = Total Potential Debit Value

NET CREDIT: Total Potential Credit Value + Total Potential Debit Value

Pre-Record Net Credit Classification Table

Range	Value
<=500	Low
> 500 and <=750	Moderate Low
> 750 and <=1000	Moderate
>1000 and <=1275	Moderate High
>1275	High

Figure 8. Credit and Debit Measurement Scheme for Logic Testing.[5]

Burrowing shrimp are native species in our west coast estuaries and can often be found associated with eelgrass populations. They contribute to intertidal and shallow-subtidal ecosystems as important components of estuarine food webs, providing forage for many species of birds, fish, and other shellfish. Their burrows also provide temporary refuge for small fishes and crustaceans, such as gobies, shore crabs, and juvenile Dungeness crabs (WDOE 2017).

Eelgrass Stressors. Aquaculture practices result in tradeoffs with natural systems, but the magnitude of those tradeoffs is strongly dependent on the management practices employed at a given aquaculture operation site. For example, research informs native eelgrass density declines with increases in oyster density on oyster plats (Tallis et al 2009) and mechanically harvested oyster beds contain significantly less native eelgrass than oyster beds harvested by other methods (Dumbauld and McCoy 2015).

[5] All credit and debit measures currently applied to oyster plat polygons in this case-study are hypothetical. There are no field data collected to calibrate the oyster plat credit and debit measurements at this time. Therefore, the credit and debit ranges used are only helpful in testing the case-study model logic.

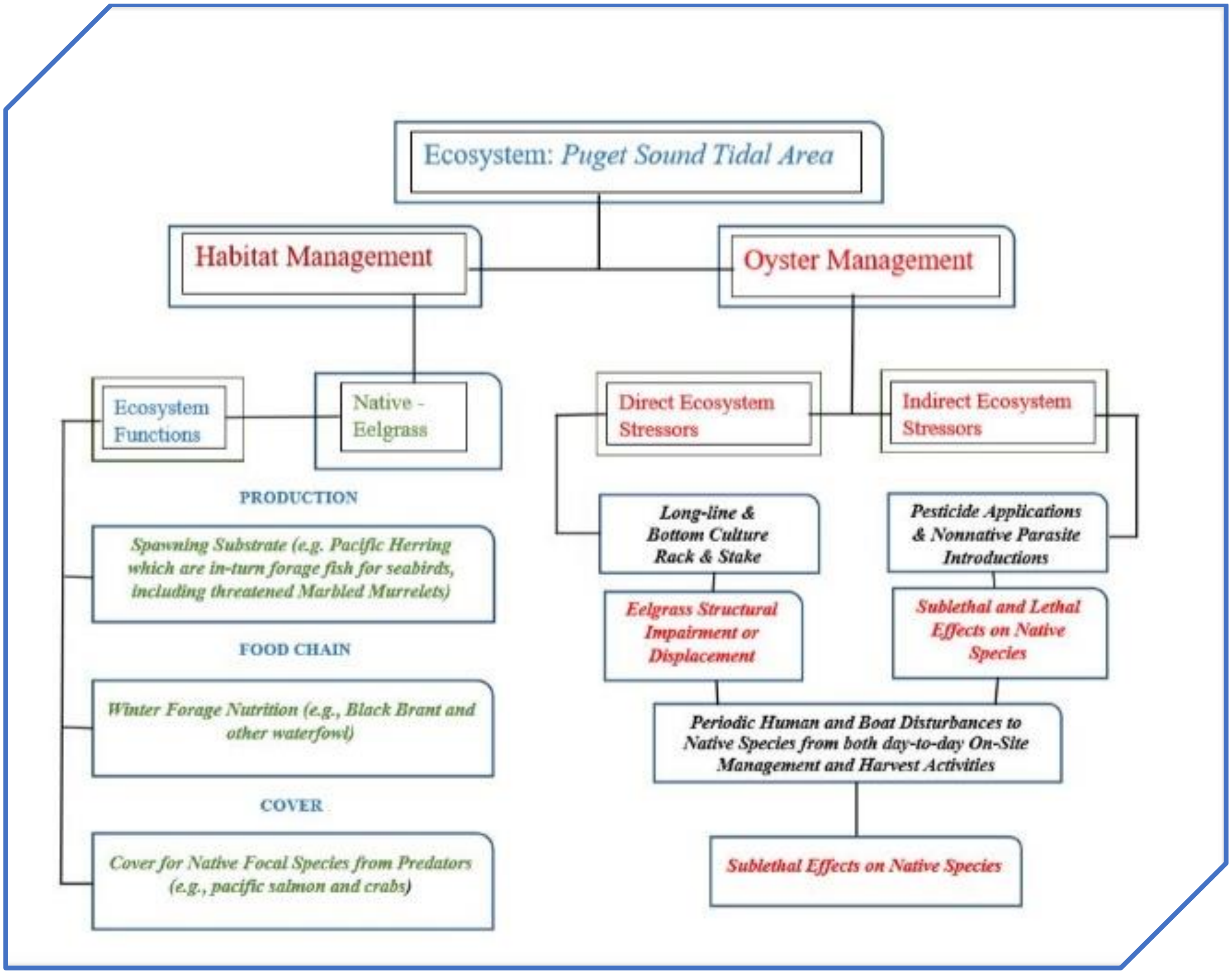

Figure 9. The Case-Study GIS-Ecology Foundation Diagram.

Rack and stake oyster culture (primarily introduced *Crassostrea gigas*) can cause reductions in eelgrass density, primarily through shading (USFWS 2009) (Rumrill and Poulton 2004). Stake culture also results in algae increases such as Ulva (sea lettuce) and Enteromorpha. These species compete with eelgrass and are suspected of having an adverse effect on eelgrass survival (USFWS 2009). After disturbance, a reduction in eelgrass density can persist for some time. Oyster culture rack and stake structure eelgrass density reductions have been severe in many areas, in some cases up to 75-percent if stakes and/or racks are positioned too closely to allow adequate light penetration (USFWS 2009). The reduction in eelgrass percent cover and shoot density on oyster plats can persist for over a year or result in eventual complete elimination of eelgrass from oyster plats (USFWS 2009). Fisheries biologist have understood for some time that ***management actions at the oyster plat level have a range of potential impacts*** depending on the type of culture, intensity, longevity, and timing of management actions:

> *"Acute disturbances that produce large-scale changes in community dominants, such as manipulation of burrowing shrimp or eelgrass with pesticides or mechanical harvesting and*

manipulation of oyster grounds, strongly influence the carrying capacity for many fish and macroinvertebrates. Ensuring that estuarine ecosystems are sustainable for the breadth of processes and resources requires a comprehensive assessment of both natural and anthropogenic disturbance regimes, landscape influences, and the effects of local management for particular species on other resources (Simenstad and Fresh 1995)".

There remains a certain level of uncertainty about how oyster culture and other stressors affect eelgrass habitat and eelgrass interdependent species. Eelgrass genetic variability likely plays a role in its resilience to stress, but it is not well studied in this region. Research does show it tends to adapt to local conditions. Local adaptation may lower subpopulation genetic diversity while increasing diversity overall in the Puget Sound. This fact makes general assessment of the effects of eelgrass stressors more difficult, because ironically local adaptations may make local eelgrass populations more or less vulnerable to changes in conditions at a given site (Thom and Judd 2011).

In another example of uncertainty, black brant wintering populations feeding primarily on eelgrass (Ganter 2000) in west coast bays and estuaries along the Pacific Flyway have declined significantly along the United States portion of the coastline since the 1960s (Pitkin and Lowe 2000). But as late as 2002, data were insufficient on the extent and quality of eelgrass habitats at major staging and wintering sites, carrying capacity of primary staging and wintering sites and the effects on brant distribution were poorly known, habitat loss from coastal development and associated disturbances at primary brant staging and wintering sites was not quantified, and the effects of contaminants on eelgrass and brant were unknown (Pacific Flyway Council 2002). Nevertheless, personal communication with U.S. Fish and Wildlife Service biologists responsible for monitoring coastal waterfowl populations inform oyster culture operations have likely played a significant role in wintering black brant population declines in west coast estuaries and bays in the United States (Pitkin and Lowe 2000).

Two species of native "burrowing shrimp" [Mud shrimp (*Upogebia spp*) and Ghost shrimp (Neotrypaea spp)] are considered pests by oyster growers because their burrows soften the substrate beneath the introduced commercial oysters and cause them to sink into the mud and perish from lack of oxygen (Griffin 1997). Consequently, there have been extensive efforts by commercial oyster growers to remove these species from their plats (Dumbauld et al 2006), ranging between mechanical removal to highly toxic nontarget pesticide (e.g., neurotoxins such as carbaryl and Imidacloprid) applications (Griffin 1997) (WDOE 2017). At the same time oyster growers have been working to "control" these species, an Asian invasive parasite (Orthione) infestations appear to be driving local Upogebia populations to collapse and near extinction by preventing reproduction (Chapman et al 2011). Upogebia is a critical ecosystem engineer due to its historical abundance and extensive suspension feeding and burrowing activities which influence nutrient flux, benthic community structure and functioning of estuaries (Chapman et al 2011).

Case-Study Research Question. What are the focal stressors on native eelgrass (*Zostera marina*) and associated native eelgrass dependent species that stem from oyster aquaculture operations in the Puget Sound and what is the ordinal magnitude and geographic distribution of these stressors?

Case-Study Research Task. This project attempts to isolate one key habitat type, native eelgrass, itemize focal stressors, and use a Geographic Information System (GIS) based ecology to spatially evaluate the geographic distribution and relative magnitude of these stressors in the Puget Sound area of Washington State.

Case-Study GIS-Ecology. It was deemed that the GIS should be organized into a set of entities and relationships (Figure 9) that reflect the nature of the research problem and question(s) to enable it to implement the research tasks. An underlying assumption presumes a yet to be determined carrying capacity threshold for the natural capital (native eelgrass) in the area of concern (AOC). As a GIS-ecology, it requires a geographic extent. The problem statement identifies intertidal and shallow subtidal habitat in the Puget Sound and the GIS-ecology adopts much of this area in its extent. It should be noted that while the focal natural capital extends to shallow subtidal areas along many Puget Sound bathymetric gradients, the indirect effects of oyster culture plats likely extend past those limits. Since the focus of the problem addresses oyster culture direct and indirect impacts to native eelgrass *and the species with life-cycle requirements dependent on eelgrass*, the geographic extent of hypothetical indirect impacts by oyster plats was adopted to delimit the extent of the AOC (Figure 10).

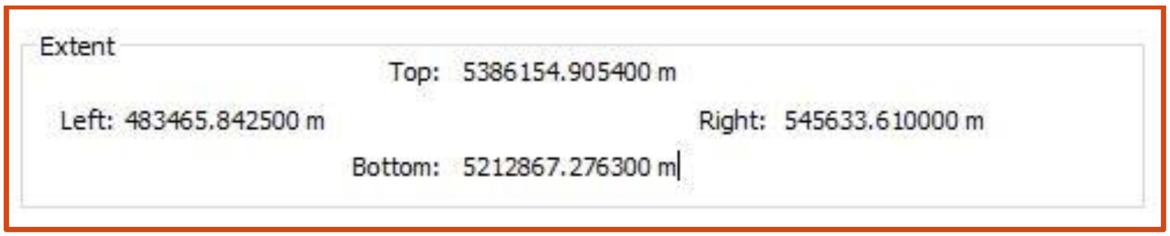

Figure 10. Extent Of Hypothetical Indirect Impacts By Oyster Plats.

A testing file geodatabase (Figures 11 and 12) is used to organize the structure of the GIS-ecology entities and relationships as well as the geoprocessing methods employed using ESRI Model Builder (see Python Code in Appendix 6).

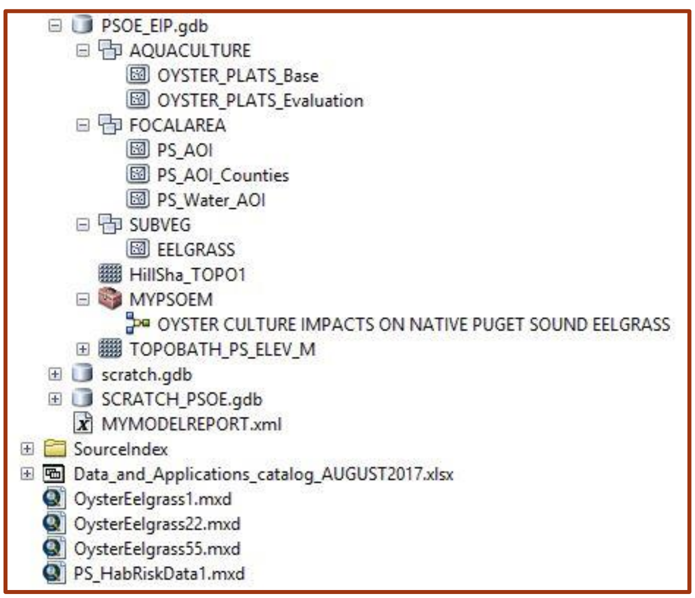

Figure 11. Case-Study Testing File Geodatabase with Input and Output Objects.

Feature datasets (Figures 11 and 12) were used to organize thematic data and to establish a common projected and geographic coordinate system (Figure 13) to project the spatial data.

Model Application in ArcGIS Model Builder. The first steps in developing the model (Figure 14) in ArcGIS Model Builder required two versions of the oyster plat data to be created, a base layer to calculate credits and an evaluation layer to calculate debits. Both datasets were pre-prepared for use in the model by adding them to an ArcMap project and then opening their attribute tables and using the add field function to create the necessary data fields (float data type/scale = 2). The field calculator was used to populate both the field input and calculated field records (Table 1 and 2).

Feature Datasets	Feature Classes	Definitions of Feature Classes	Data Sources
Aquaculture	Oyster Plats	Polygons delineating oyster culture operations.	Washington Department of Natural Resources
FocalArea	Puget Sound Area of Interest, Counties, Aquatic Areas	Polygons delineating the regions containing oyster culture activities.	Washington Department of Natural Resources
SubVeg	Native Eelgrass	A set of polygons delineating native eelgrass beds.	Washington Department of Natural Resources
Bathymetry/Topography	Elevation Hill-shade	Raster DEM	USGS/NOAA

Figure 12. Case-Study Testing File Geodatabase Data Definitions and Sources.

Projected Coordinate System:	NAD_1983_UTM_Zone_10N		
Projection:	Transverse_Mercator		
False_Easting:	500000.00000000		
False_Northing:	0.00000000		
Central_Meridian:	-123.00000000	Geographic Coordinate System:	GCS_North_American_1983
Scale_Factor:	0.99960000	Datum:	D_North_American_1983
Latitude_Of_Origin:	0.00000000	Prime Meridian:	Greenwich
Linear Unit:	Meter	Angular Unit:	Degree

Figure 13. Case-study Projected and Geographic Coordinate Systems.

The next step is to clip both oyster plat layers to the eelgrass layer to ensure only oyster plats overlapping eelgrass are evaluated. Each of the output clip layers is then converted to a raster with the value focal cells set to TotalCreditVal and TotalDebitVal respectively. The Raster Calculator is then used to sum the two output rasters with an 'add' operation set up as an expression in the Raster Calculator tool (Figure 15). An output raster is then generated displaying the net credits remaining in the geo-referenced cells once the cell add operations are completed.

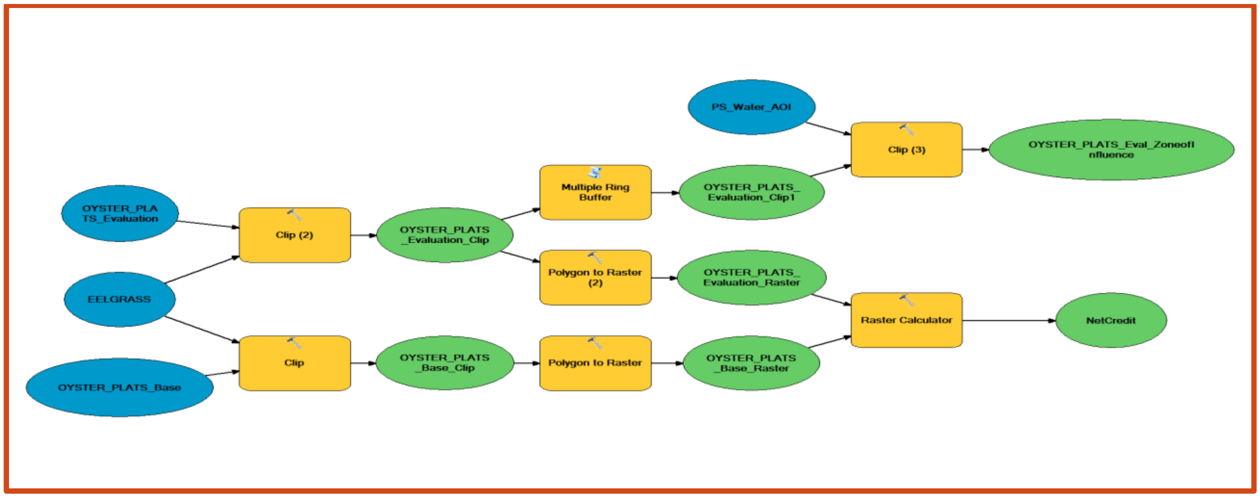

Figure 14. Case-Study Model Geoprocessing in ArcGIS Model Builder.

Table 1. Oyster Plat Base (Credit) Layer.

OID	Production	FoodChain	Cover	TotalCredit	Acres	TotalCreditVal
1	400	300	250	950	0.95	902.5
2	500	450	375	1325	44.99	59611.75
3	100	100	75	275	21.46	5901.5

Table 2. Oyster Plat Evaluation (Debit) Layer

OID	StrucDisp	StrucImp	LethDir	LethIndir	SubLethDir	SubLethIndir	TotalDebit	Acres	TotalDebitVal
1	-25	-150	-250	-50	-75	-25	-575	0.95	-546.25
2	-100	-325	-125	-150	-50	-25	-775	44.99	-34867.25
3	0	0	0	0	-25	-25	-50	21.46	-1073

Base Raster	+ Evaluation Raster	= Output Raster
902.5	-546.25	356.25
59611.75	-34867.25	24744.5
5901.5	-1073	4828.5

Figure 15. Oyster Plat Base (Credit) Layer + Oyster Plat Evaluation (Debit) Layer

The net credits raster was added to an ArcMap project and then classified across a stretched high to low net value range. Selected zoomed in views at individual oyster plat extents are then used as example model outputs and exported as pseudo-maps for display and discussion purposes (Figures 16,

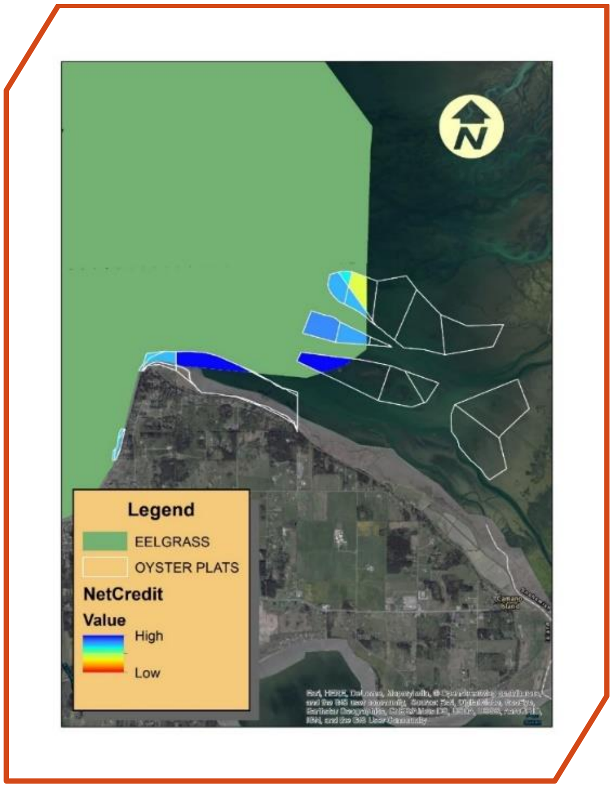

Figure 16. Preliminary Trial Classification Test Site A1

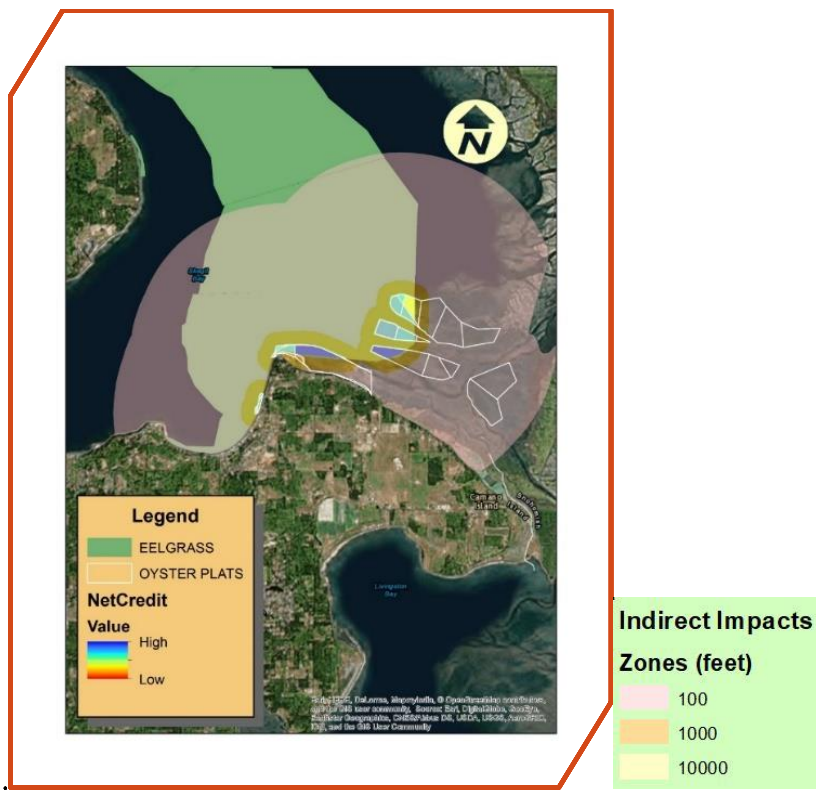

Figure 17. Preliminary Trial Classification Test Site A1 (Zones of Influence).

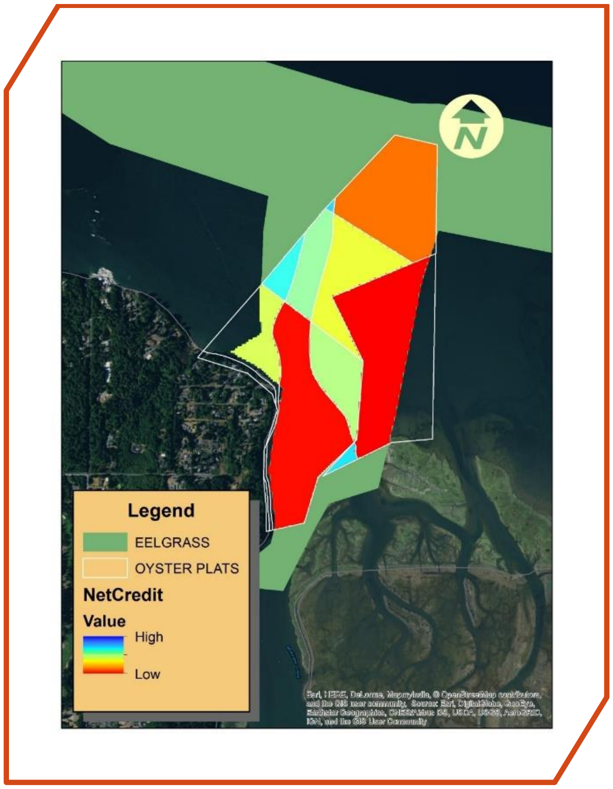

Figure 18. Preliminary Trial Classification Test Site B1.

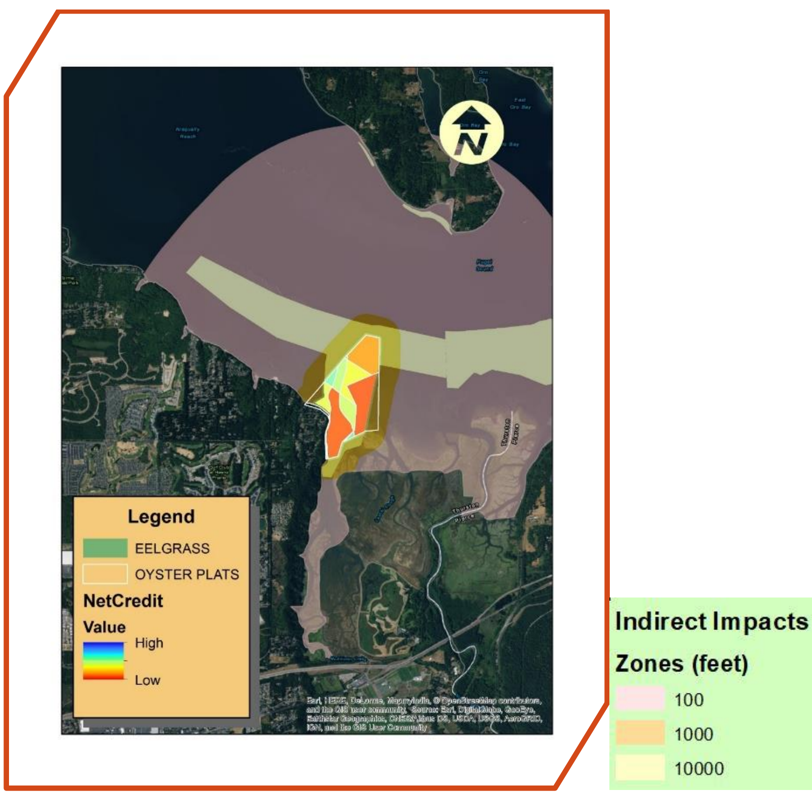

Figure 19. Preliminary Trial Classification Test Site B1 (Zones of Influence).

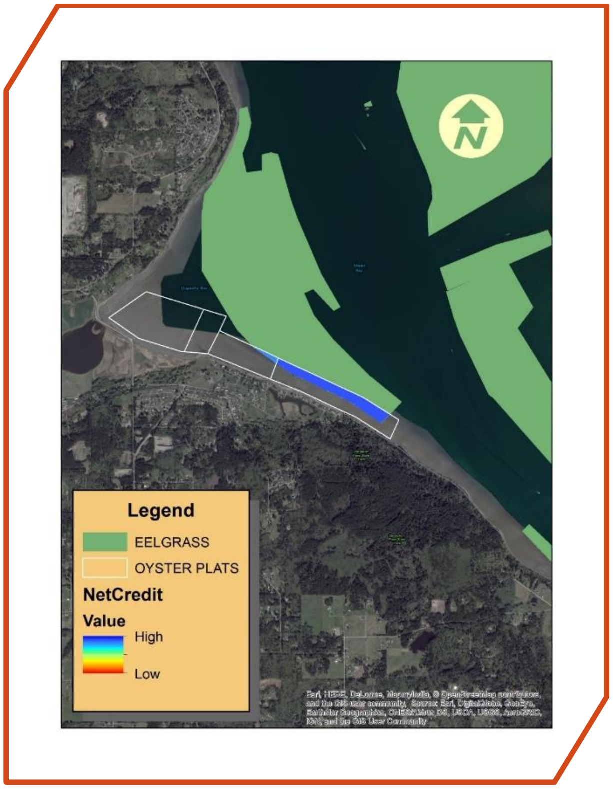

Figure 20. Preliminary Trial Classification Test Site C1.

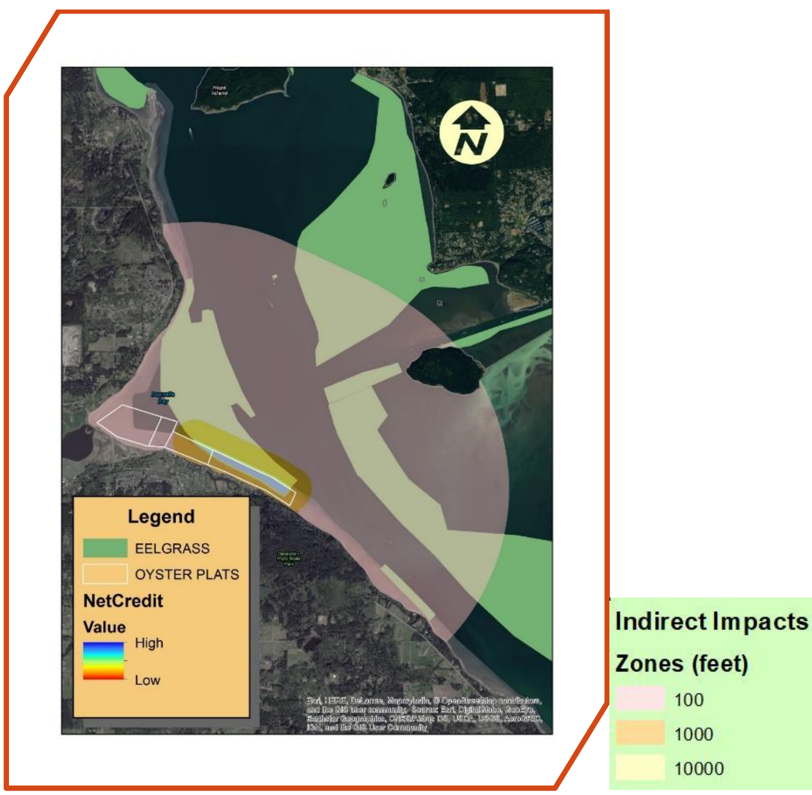

Figure 21. Preliminary Trial Classification Test Site C1 (Zones of Influence).

18, and 20). They represent three trial classification test sites (A1-C1) and are used solely to test operations and logic. Because of the lack of site level data, arbitrary data inputs were used. Therefore, no real-world inferences can be made from the output.

To illustrate potential oyster plat zones of influence on areas in the tidal and subtidal surface waters outside the oyster tract footprints, a multiple ring buffer tool was run on the oyster plat evaluation layer (three indirect influence distance zones were set at 100-ft, 1000-ft, and 10000-ft) and clipped to the Puget Sound Water Area of Interest polygon. The resulting output polygon was added to the same ArcMap Project and symbolized. Selected zoomed in extents were exported as pseudo-maps. Zone of influence distance zones at trial classification test sites A1-C1 in Figures 17, 19, and 21 are hypothetical and not based on field documentation. Therefore, no attempt is made to assign them a credit or debit value.

Preliminary Summary. Through literature review and personal experience, reasonable lists of eelgrass habitat process functions and oyster culture related stressors were compiled. A model structure was designed using carrying capacity as a guiding principle for its conceptual framework and operational logic. However, the lack of on-site data for each of the oyster plats containing eelgrass habitat made model calibration and meaningful data interpretation of real-world circumstances unobtainable.

Existing Limitations

Both the overarching SD / SM CFA and the oyster / eelgrass case-study CFA (including the GIS-Ecology) are incomplete for two primary reasons:

- The Socio-Political Domain requires a number of high level organizational changes be in place before SD/SM is feasible. For example, human homeostasis vs human greed thresholds must be democratically defined. Benchmarks for ecological recovery and balance are needed for a broad suite of natural capital. Then policies, regulations, and laws are needed to guide and enforce the appropriate changes in human behavior per its concurrence with the laws; and

- The natural capital currencies (debit/credit) cannot be gauged and measured without a systematic collection of field data using peer reviewed research design and field data collection methods.

The first would require several major societal and political paradigms to shift and the latter dedicated funding and staff to carry out the necessary work. The latter is more likely to be obtainable in the near-term than the former but will likely require a substantial and concerted effort toward unveiling ‘tacit’ knowledge (Goguen 1997) from the stakeholders. It is possible the former will never be completely achieved but true SD/SM cannot be obtained without it.

If SD/SM is not currently feasible, what exactly are all the SD/SM endeavors reported almost on a daily basis? Many, possibly most, are likely old school development with short-term economic gain for a few and long-term environmental losses for the masses but tempered by one or more token environmental innovations, like more fuel efficient trucks or a new shopping mall development off-setting the filling of wetlands and take of Federally listed species by purchasing mitigation and conservation bank credits. These endeavors are perhaps '*sustainable like*' or '*more sustainable than the status-quo*', but not completely SD/SM. They are, however, necessarily transitional to larger paradigm shifts.

<u>Filling the Gaps</u>

It is beyond the scope of this paper to address the gaps in the overarching SD/SM umbrella from which all aspirational SD/SM projects ultimately inherit and instantiate from. Suffice it to say these gaps are internationally global in scope and filter worldwide through each respective set of natural capital, socio-political, and economic domains.[6] Moreover, recent trends in 'nationalism' by major world powers have likely severely set-back, if not altogether annihilated, any hope of substantial progress toward overarching SD/SM umbrella reformation. However, progress can be made at the project level.[7]   For this paper, that means the Puget Sound oyster/eelgrass case-study. And, for that case study, the largest gap is an absence of a collection of standardized field data necessary to inform natural capital currency measurements (credits and debits) and natural capital performance standards necessary to determine if project level SD/SM thresholds are met.

It is also outside of the scope of this paper to survey oyster / eelgrass stakeholders for information needed to design and create a database schema. Nor can we go out between now and the deadline for this paper to collect the field data necessary for populating the database once it is created. But there are surrogate avenues we can explore to help us develop a few preliminary key geodatabase schema designs for an initial roll-out presentation to potential stakeholders. Actor Network Theory concepts and terms are used to help organize and describe this effort (Monteiro 2000).

Following Latour 2005a, Actor-Network-Theory (ANT) weaves a tapestry whereby both animate and inanimate actors are equally important and, indeed, it is not the identity of the actors that brings the network into focus but the relationships between them. These relationships are reportedly dynamic and everchanging, sometimes telescoping to vast scales or collapsing to near singularities, never remaining static. ANT does not appear to offer much on the subject of causality, nor does it attempt to discern patterns by which predictions of events are possible. Instead it avoids a focus on any part of the network and encourages broadening analyses to the entire network(s), networks can be nested. Apparently multiple truths are simultaneously possible in the ANT tapestry depending on one's focus on any given part of a given network.

Considering regulatory agencies as actors in an ANT network and that they have relationships with the focal actors, nonnative oysters and native eelgrass, all subsequent translations of their potential interactions are based on transcriptions comprising the problem ontology. Because management actions at the oyster plat level have a range of potential impacts *(Simenstad and Fresh 1995)* on eelgrass and eelgrass dependent species, and because eelgrass responses to stressors may be dependent on spatially variable genotypes (Thom and Judd 2011), it is imperative that the scale of our data actors begin at the oyster plat actor level.

[6] The core overarching SD/SM umbrella target elements requiring reformation are discussed in the Introduction and Problem section of this paper.
[7] Larger area, smaller scale, SD/SM umbrella paradigm shifts may in-fact ultimately partially come into fruition by way of building a scaffold for them based on sets of highly compartmentalized modular '*SD/SM-like*' projects collectively completed over time.

Table 3. Overarching Regulatory Constraints on Oyster Culture in the Puget Sound.

Agency / Tribe	Authority	Constraints
U.S. Army Corps of Engineers	Sec. 404 Clean Water Act - 33 USC 1344; Sec. 10 Rivers and Harbors Act – 33 USC 403; National Environmental Policy Act – USC 4321et seq.	Does not authorize activities affecting more than 1/2-acre of eelgrass in plats that have not been used for oyster aquaculture during the past 100 years (insecticides and other pesticides not regulated by Corps so not considered in affects analysis). If the operator will be conducting commercial shellfish aquaculture activities in multiple contiguous project areas, he or she can either submit one PCN for those contiguous project areas or submit a separate PCN for each project area.
U.S. National Marine Fisheries Service	Endangered Species Act – 16 USCA 1531 et seq.; Fish and Wildlife Coordination Act – 16 USC 661 et seq. Magnuson-Stevens Fishery Conservation Act	Does not authorize the "take" of a threatened or endangered species. DE must require PCN if project greater than 100-acres[8] or substantial change in type or location(s) of BMPs. If take is determined, DE must reinitiate consultation with NMFS case-by-case.
U.S. Fish and Wildlife Service	Endangered Species Act – 16 USCA 1531 et seq.; Fish and Wildlife Coordination Act – 16 USC 661 et seq.; MBTA – 16 USC 703 et seq.	Determined there is no "take" of a threatened or endangered species. No constraints are required.
Washington Department of Ecology	Sec. 401 Clean Water Act - 33 USC 1251 et seq.;	Does not authorize new operations, or expansions of existing operations with direct impacts to eelgrass beds nor activities affecting more than 1/2-acre of eelgrass in plats that have not been used for oyster Aquaculture during the past 100 years (insect-icides and other pesticides not regulated by Corps so not considered in affects analysis).
Puget Sound Tribes	Sec. 401 Clean Water Act - 33 USC 1251 et seq.;	NWP 48 Section 401 CWA WQ Certification is denied without prejudice by Confederated Tribes of the Lummi Nation, Makah Tribe, Port Gamble S'Klallam, Puyallup Tribe of Indians, Swinomish, and Tulalip Tribes over activities on their respective tribal lands.

[8] Out of 1191 inventoried oyster plats in the Puget Sound, four are greater than 100-acres.

Before we proceed to the philosophical ontology, it is necessary to first to dive deeper into the actors in the problem ontology that manifest institutional constraints. While the National Academy of Sciences National Research Council (2001) concluded the absence of compliance inspections by the US Army Corps of Engineers (USACE) allows substantial numbers of permittees to ignore the conditions of their permits, it is still incumbent on us to identify the focal institutions of interest, their authorities, and those constraints that are imposed on the translations of the potential transcriptions involving oyster / eelgrass interactions (Table 3 and Appendix 7) in the Puget Sound focal area.

Summary of Regulatory Constraints. Except for the Puget Sound tribal tide lands[9], existing Puget Sound nationwide permit (NWP) 48 oyster culture activities are *de-facto* grandfathered and essentially granted a pass for any historical adverse effects to eelgrass and eelgrass interdependent species. In addition, the USACE denies its responsibilities under the CWA, NEPA, and ESA to address the

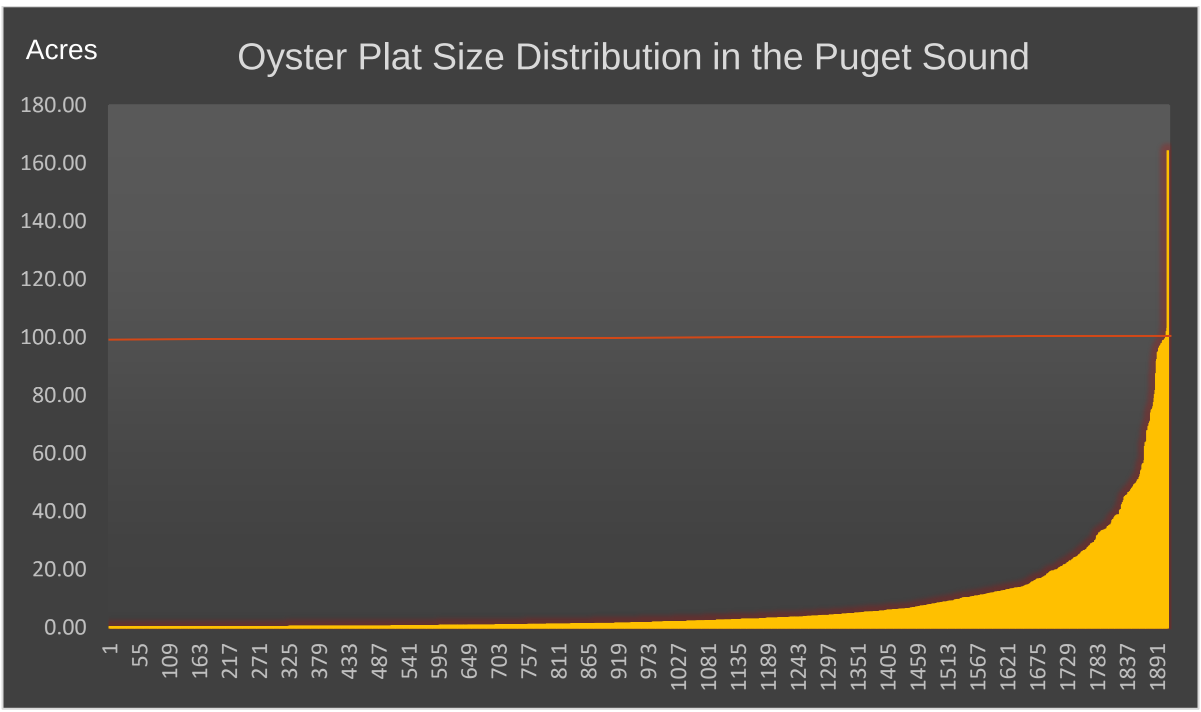

Figure 22. Oyster Plat Size Distribution in the Puget Sound in Relation to NMFS Threshold for PCN.

potential indirect, cumulative, and interrelated adverse effects of oyster industry related non-target neurotoxins in their permit conditions.

Unless there is a new site-specific discovery of one or more practices resulting in the "take" of a Federally listed species (see Table 3 and Appendix 7), new plats only require pre-construction notification (PCN) to the District Engineer (DE) if the applicant indicates to the DE the activities in

[9] Federal permits from the USACE, and Section 401 CWA Water Quality Certifications from each respective tribe on their tribal lands, are required for all existing and new oyster culture activities regulated by the CWA. If the USACE determines a may effect for a Federally listed species associated with any of these individual permits, Section 7 ESA consultations will also have to be initiated by the Corps unless the permit actions are covered by a programmatic Section 7 consultation (Sanguinetti 2018).

the new plat will affect more than ½-acre of native eelgrass or if the new plats exceed 100-acres (see Figure 22). A PCN is also required if there are significant management changes in existing plats.[10]

Even if a PCN is required and provided to the Corps, it does not necessarily mean the conditions reported in the PCN will be field verified by a Corps staff person. Basically, verifications of permit violations are generally contingent on '*good-Samaritan*' reporting on tide flats rarely visited by anyone outside the aquaculture industry and, even then, are more or less limited to addressing adverse effects to a relatively narrow suite of Federally listed species. In other words, NWP 48 writes off significant historical losses of eelgrass due to oyster culture activity, it rejects any responsibility for regulating applications of nontarget lethal neurotoxins, and for newly proposed actions, more or less selectively exercises regulatory agency trust obligations to effectively state "*species are generally considered unimportant unless they are determined to be on the brink of extinction or commercially beneficial.*"

An alternative interpretation of NWP 48 regulatory constraints may be that the responsible regulatory agencies have developed creative methods within the limits of their regulatory authorities to ensure existing and new oyster-culture plats in the Puget Sound do not exceed a threshold of minimal impacts, individually or cumulatively, nor are they likely to do so in the foreseeable future. For example, Seattle District Corps reportedly uses general NWP conditions related to the Magnuson-Stevens Fishery Conservation Act and the Federal Endangered Species Act to require PCNs from all shellfish operations in the Puget Sound and the programmatic Section 7 ESA consultation for shellfish activities in Washington State to require 16-foot minimal setbacks from all existing native eelgrass beds on new (authorized after March 18, 2007) plats (Sanguinetti 2018) (USACE 2016).

So, if existing oyster-culture operations in the Puget Sound meet the Federal test of minimal individual and cumulative impacts and any new plats will be held to that same test by general Nationwide Permit conditions and programmatic Section 7 ESA consultations, problem solved, right? While trends in eelgrass distribution and abundance in Puget Sound prior to 2000 are difficult to establish due to a lack of long-term and broad-scale information preceding the initiation of the Submerged Vegetation Monitoring Program (SVMP), Thom and Hallum (1990) completed an examination of historical hydrographic charts, aerial photographs, Washington Department of Fish and Wildlife (WDFW) survey information, and other limited observations of eelgrass distribution in Puget Sound. Their conclusions indicated apparent declines in eelgrass abundance since the late 1800s in Bellingham Bay and the Snohomish River Delta, and an apparent increase in eelgrass abundance over approximately the same period in Padilla Bay (a National Estuarine Research Reserve). Given what we know about the adverse effects oyster-culture can have on eelgrass structure, it is reasonable to consider that a substantial portion of that historical loss can be attributed to past and on-going oyster-culture operations. Also, assuming PCN reporting is required for old and new plats and the reports are accurate and complete, even if new oyster-culture operations do avoid existing eelgrass beds at their onset, their proximity to eelgrass can manifest in significant indirect impacts to adjacent eelgrass beds and eelgrass interdependent species. In addition, they may effectively prevent the natural colonization and establishment of new eelgrass beds.

[10] Preconstruction notification does not necessarily mean any adjustments will be imposed on existing management practices.

The data required by the PCNs entails a description of the proposed activity and any proposed mitigation measures should be *sufficiently detailed to allow the district engineer to determine that the adverse environmental effects of the activity will be no more than minimal and to determine the need for compensatory mitigation or other mitigation measures*. The following information is required: (1) a map showing the boundaries of the project area(s), with latitude and longitude coordinates for each corner of each project area; (2) the name(s) of the species that will be cultivated during the period this NWP is in effect; (3) whether canopy predator nets will be used; (4) whether suspended cultivation techniques will be used; and (5) general water depths in the project area(s) (a detailed survey is not required). However, there are several matters of concern:

- There are no criteria by which to measure eelgrass performance;
- There are no criteria by which to measure oyster-culture stresses on eelgrass performance;
- There are no thresholds that can be used to objectively determine if eelgrass performance has been substantially compromised; and
- There are no data collected at the oyster-plat level that can be tested in the context of a criteria / threshold based decision framework.

Interestingly, minimal effects decisions that should be informed by plat level data and the afore mentioned criteria / threshold based decision framework are apparently now made based on general literature reviews and collective best professional judgement (BPJ) about the state of the Puget Sound region. On this basis, regulatory permit coordinators and resource agency biologists conference with one another at the time of NWP 48 reauthorizations (once every 5-years) or during reviews of infrequent case-by-case oyster-aquaculture individual permit applications. With this type of regulatory oversight, depending on staff differences in expertise, highly variable oyster-culture related impacts (see Figure 23 and Appendix 5), burgeoning workloads, and the lack of standardization, at best agency decisions are likely to appear difficult to defend based on the information available, or at worst arbitrary and capricious.

One could argue that revelations about the regulatory actors brings us full circle back to one of the required components of our problem ontology (Latour 2005b): "*in order for something to be considered a matter of concern, it must be liked*." Since the regulatory actors are essentially silent about oyster plat level eelgrass performance and oyster-culture stressor criteria and thresholds, does it mean they are, therefore, "*not liked*" and consequently ineligible candidate actors in the problem ontology? History is rife with accounts of minority reports that were discounted initially only to be discovered after-the-fact of tragedies that could have been summarily prevented had they been allowed to be addressed in earlier considerations (see McDonald and Hansen 2009). In the tradition of Critical GIS (Wilson 2015) and for the purposes of this case-study, oyster plat level eelgrass performance, oyster-culture stressor criteria, and thresholds are all considered part of the problem ontology.

Exploring Alternative Problem Ontology Information Sources. The question now becomes, where do we look for information that will be useful in establishing eelgrass performance and oyster-culture stressor criteria and thresholds at the oyster plat scale? Fortunately, there is a substantial body of literature displaying relevant data on the subject. To better organize our literature/data review, the following categories were inherited from the initial case-study CFA:

Figure 23. Oyster-culture Farm.

Native Eelgrass Habitat Value

- Habitat Production
- Habitat Cover
- Habitat Forage

Native Eelgrass Stressors

- Direct Oyster-Culture Stressors
- Indirect Oyster-Culture Stressors

The next step was to populate each category with relevant key species (aka ANT Actors) as part of a preliminary screening and per the problem ontology regarding native-eelgrass values and oyster-culture stressors (Generalized from Dethier 1990):

- Habitat Production Beneficiary
    - Pacific herring - *Clupea pallasii*

- Habitat Cover Beneficiary
    - Dungeness crab - *Metacarcinus magister*

        - Tube-snout - *Aulorhynchus flavidus*
        - Bay pipefish - *Syngnathus leptorhyncus*
        - Shiner perch - *Cymatogaster aggregate*
        - Saddleback Gunnel - *Pholis ornata*
        - Silverspotted sculpin - *Blepsias cirrhosis*
        - Sharpnose sculpin - *Clinocottus acuticeps*
        - English sole - *Pleuronectes vetulus*
        - Chinook salmon - *Oncorhynchus tshawytscha*
        - Coho salmon - *Oncorhynchus kisutch*
        - Bull trout - *Salvelinus confluentus*

    - Habitat Forage Beneficiary
        - American wigeon - *Mareca Americana (Primary consumer native eelgrass)*
        - Black brant - *Branta bernicula (Primary consumer native eelgrass)*
        - Marbled murrelet - *Brachyramphus marmoratus (Secondary consumer Pacific herring)*

    - Important Forage Prey Species
        - Ghost shrimp - *Neotrypaea spp.*
        - Mud shrimp - *Upogebia pugettensis*

- Native Eelgrass Stressors

    - Direct Oyster-Culture Stressors
        - *Bottom Culture*
        - *Rack Culture*
        - *Stake Culture*
        - *Rack and Stake Culture*
        - *Long-line Culture*
        - *Nursery Shell Bags*

    - Indirect Oyster-Culture Stressors
        - *Boat Traffic*
        - *Foot Traffic*
        - *Raking Oysters*
        - *Neurotoxin Applications*
        - *Predator Nets*

The scaffold now contains a thematic list of the primary entities or actors and the plat scale level problem ontology is now transitioning to a philosophical ontology. To complete the transition, the entities must have relationships. Both the key entities and their relationships are required to help understand the pathways toward better informed decisions in the matters involving the focal problems. Returning to our CFA, since our problems and related entities manifest in space and time, and since a GIS can be interpreted very broadly as any information system which tracks and analyzes phenomena both spatially and temporally, and is capable of tracking both entity attributes and their relationships, it is considered here as logical technical apparatus for use in this stage of the case-study.

Preliminary Key Geodatabase Schema Designs. The overarching goal is to build a schema framework that can further progress on a geodatabase design for containing data that will inform natural currency (credits/debits) calculations at the oyster plat scale level. The geodatabase will also be used for archiving, assessing, and reporting oyster plat conditions, both individually and regionally. While the categories inherited from the case-study CFA provide a superstructure on which to begin building a schema design, a theory for natural currency at the plat level scale is also needed. The logic being the data needed to inform the methods used to apply the theory strongly dictate the fields required to contain that data. Based on the nature of the research problem ontology, it was determined the theory should:

- be spatially and temporally explicit;
- reflect the relationships between native eelgrass and native eelgrass interdependent species; and
- reflect the effects oyster-culture related stressors have on native eelgrass and eelgrass interdependent species values.

Using the foundation of numerous natural capital based classification and / or assessment methods (Marshall 1985a) (Marshall 1985b) (Marshall et al 1987) (Marshall 1993a) (Marshall 1993b) (Marshall 2007) (Marshall 2010a) (Marshall 2010b) (Marshall 2012) (Marshall 2017a) (Marshall 2017b), the credit portion of this model theory is based on the relationships between a focal habitat, native eelgrass, and eelgrass interdependent species and their relationships with one another. Simply stated, natural capital (credit) is an aggregate representation of the ecological relationships between a suite of focal species (aka ANT actors). Each species receives a calculated credit score based on: 1. their relative abundance or habitat suitability index (Figures 24 and 25), 2. their importance or focal weight (Figure 26), and 3. the amount of undisturbed focal habitat (native eelgrass) available to them. Figure 27 represents potential sample elevation, percent cover (an abundance metric), and oyster-culture disturbance classes.[11] The credit scores for each species are summed to derive a total credit score for the portion of the management unit (reference site or oyster plat) containing native eelgrass.

$$\text{Species x: } [\text{Credit}_1] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$$
$$\text{Species y: } [\text{Credit}_2] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$$
$$\text{Species z: } [\text{Credit}_3] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$$

$$\text{Total Credit} = \text{Credit}_1 + \text{Credit}_2 + \text{Credit}_3$$

When viewing the referenced abundance tables[12], you will find that most of the metrics records for abundance[13] are in a null state. That is because the abundance data have not yet been collected and therefore relative abundance classifications and thresholds cannot be determined. In fact, much of the point in developing this type of an assessment method is to lay out the framework for multiple site level scale regionally distributed data collections that, once completed, can be calibrated and used to populate the relevant data needed to inform the assessment method's ordinal decisions (e.g., H, MH, M, ML, L) and ultimately, credit ranking thresholds.

[11] Each table displays examples of fields with geodatabase range or coded value domains.
[12] All the tables in this section that are related to the field assessments are in schema formats conducive for use in geodatabase feature class attribute tables.
[13] The appropriate abundance metric will vary depending on the species being represented in the record.

To better understand what a practical application of this model assessment strategy might look like, see three hypothetical trials[14]:

- Reference Site Application (Appendix 1);
- Relatively Undisturbed Oyster Plat Application (Appendix 2); and
- Significantly Disturbed Oyster Plat Application (Appendix 3).

	Abundance Ranks								
UID	Density	Ordinal	Numeric	% Cover	Ordinal	Numeric	Population	Ordinal	Numeric
1	null	H	10	null	H	10	null	H	10
2	null	MH	8	null	MH	8	null	MH	8
3	null	M	5	null	M	5	null	M	5
4	null	ML	3	null	ML	3	null	ML	3
5	null	L	1	null	L	1	null	L	1

Figure 24. Abundance Ranks (Partially Based on King County 2014).

Habitat Suitability Index (HSI) Ranks[15]			
UID	HSI Criteria	Ordinal	Numeric
1	1.0	H	10
2	.80 – .99	MH	8
3	.50 – .79	M	5
4	.30 – .49	ML	3
5	.10 – .29	L	1

Figure 25. Habitat Suitability Index Ranks (Partially Based on King County 2014).

Focal Weight Ranks			
UID	Focal Weight Criteria	Ordinal	Numeric
1	Keystone Habitat or Federally Listed Species	H	10
2	Important Forage for Federally Listed Species	MH	8
3	Highly Dependent on Keystone Habitat	M	5
4	Partially Dependent on Keystone Habitat	ML	3
5	Common Species Cohort	L	1

Figure 26. Focal Weight Ranks (Partially Based on King County 2014).

[14] All data and maps are hypothetical for illustration purposes only.

[15] HSI is presented as a potential alternative to abundance based weighting given the potential difficulty in collecting abundance field data.

Elevation Range Table		Percent Cover Table		Disturbance Type Table		
UID	Elevation (Feet below MLLW)	UID	Percent Cover	UID	Direct Disturbance Type	Indirect Disturbance Type
1	0 - 5	1	0 - 5	1	Bottom Culture	Boat Traffic
2	5 - 10	2	5 - 25	2	Rack Culture	Foot Traffic
3	10 - 15	3	25 - 50	3	Stake Culture	Neurotoxin Applications
4	15 - 20	4	50 - 75	4	Rack and Stake Culture	Predator Nets
5	20 -25	5	75 - 100	5	Long-line Culture	
6	> 25			6	Nursery Shell Bags	

Figure 27. Potential Eelgrass / Oyster-Culture Elevation, Percent Cover, and Disturbance Classes.

Conclusion. The intent of developing this simplified model assessment system is merely to illustrate the utility of decision models based on robust field data collection (aka smart data) and to persuade readers that specifically regarding the Puget Sound oyster-culture industry and native eelgrass interactions, that as a general concept, data driven assessment decision models are worthy of further consideration.[16] Moreover, an emphasis in GIS and GIS related technology suggests the utility of these models are likely significantly augmented through the deployment of enterprise GIS web applications.

Making better and more defensible decisions based on reliable data is a cornerstone of sustainable development. Regulatory agencies stand to gain an increased confidence in their minimal individual and cumulative impacts findings and the regulated public has potential for a higher certainty their operational side-bars are bright lines and not foggy mazes subject to multiple interpretations. Also, by treating native eelgrass as natural capital, another important cornerstone of sustainable development, new regulatory tools become further enabled to help insure continued operational capacity of the oyster industry while providing additional means to help protect and recover vital Puget Sound natural resources.

[16] An effort to build such an assessment model would require a substantial commitment by stakeholders to collaborate on its criteria and methods design. Stakeholders would likely include but not necessarily be limited to representatives for regulatory agencies, resource agencies, tribes, and oyster growers.

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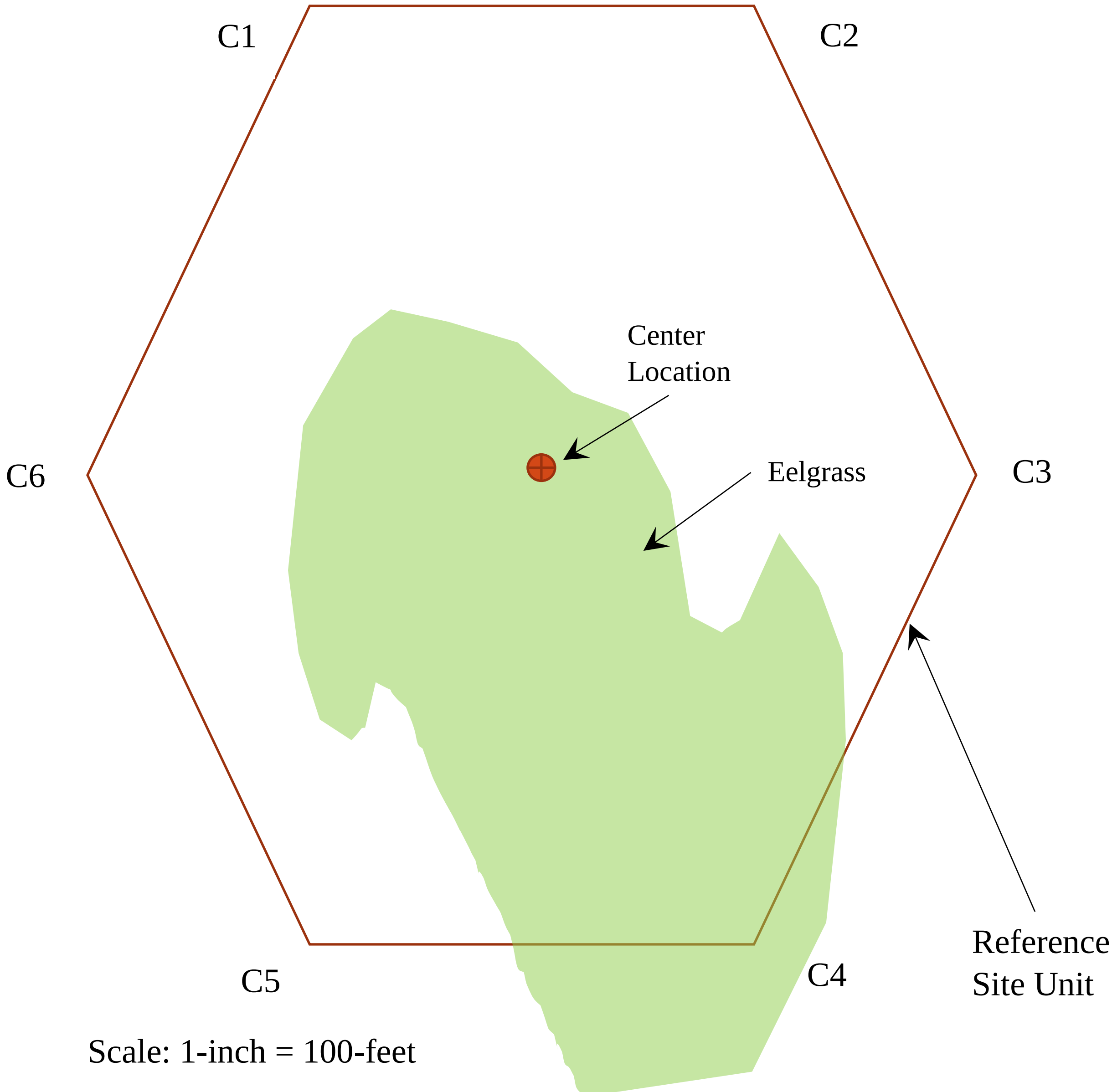
Appendix 1. Model Assessment Reference Site Application.



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Reference Site Unit Corner Locations												
UID	C1 - Lat	C1 - Lon	C2 - Lat	C2 - Lon	C3 - Lat	C3 - Lon	C4 - Lat	C4 - Lon	C5 - Lat	C5 - Lon	C6 - Lat	C6 - Lon
1	48.291476	-122.4067	49.291430	-122.4016	48.288234	-122.3991	48.284985	-122.4016	48.285071	-122.4069	48.288226	-122.4090
2												
3												
4												
5												
6												

Figure 1. Reference Site Unit Corner Locations.

Appendix 1 (Cont). Model Assessment Reference Site Application.

Reference Site Credit Score Card – Based on Species Associations (Generalized from Dethier 1990)									
UID	Genus	Species	Present	Density	HSI	Population	Focal Weight	Acres	Credits
1	*Zostera*	*marina*	x	10			10	100	10000
2	*Metacarcinus*	*magister*	x		10		5	100	5000
3	*Neotrypaea*	*spp*	x		10		5	100	5000
4	*Upogebia*	*pugettensis*	x		10		5	100	5000
5	*Clupea*	*pallasii*	x		10		8	100	8000
6	*Aulorhynchus*	*flavidus*	x		10		5	100	5000
7	*Syngnathus*	*leptorhyncus*	x		10		5	100	5000
8	*Cymatogaster*	*aggregata*	x		10		5	100	5000
9	*Pholis*	*ornata*	x		10		5	100	5000
10	*Blepsias*	*Cirrhosis*	x		10		5	100	5000
11	*Clinocottus*	*acuticeps*	x		10		5	100	5000
12	*Oncorhynchus*	*tshawytscha*	x		10		10	100	10000
13	*Oncorhynchus*	*kisutch*	x		10		10	100	10000
14	*Salvelinus*	*confluentus*	x		10		10	100	10000
15	*Pleuronectes*	*vetulus*	x		10		5	100	5000
16	*Mareca*	*americana*	x		10		3	100	3000
17	*Branta*	*bernicula*	x		10		5	100	5000
18	*Brachyramphus*	*marmoratus*	x		10		10	100	10000
	Total								116000

Figure 2. Credit Score Schema (Informed by Hypothetical Field Data).

Species x: [Credit_1] = [Abundance] x [Focal Weight] x [Acres]
Species y: [Credit_2] = [Abundance] x [Focal Weight] x [Acres]

Total Credit = $\text{Credit}_1 + \text{Credit}_2$ . . .

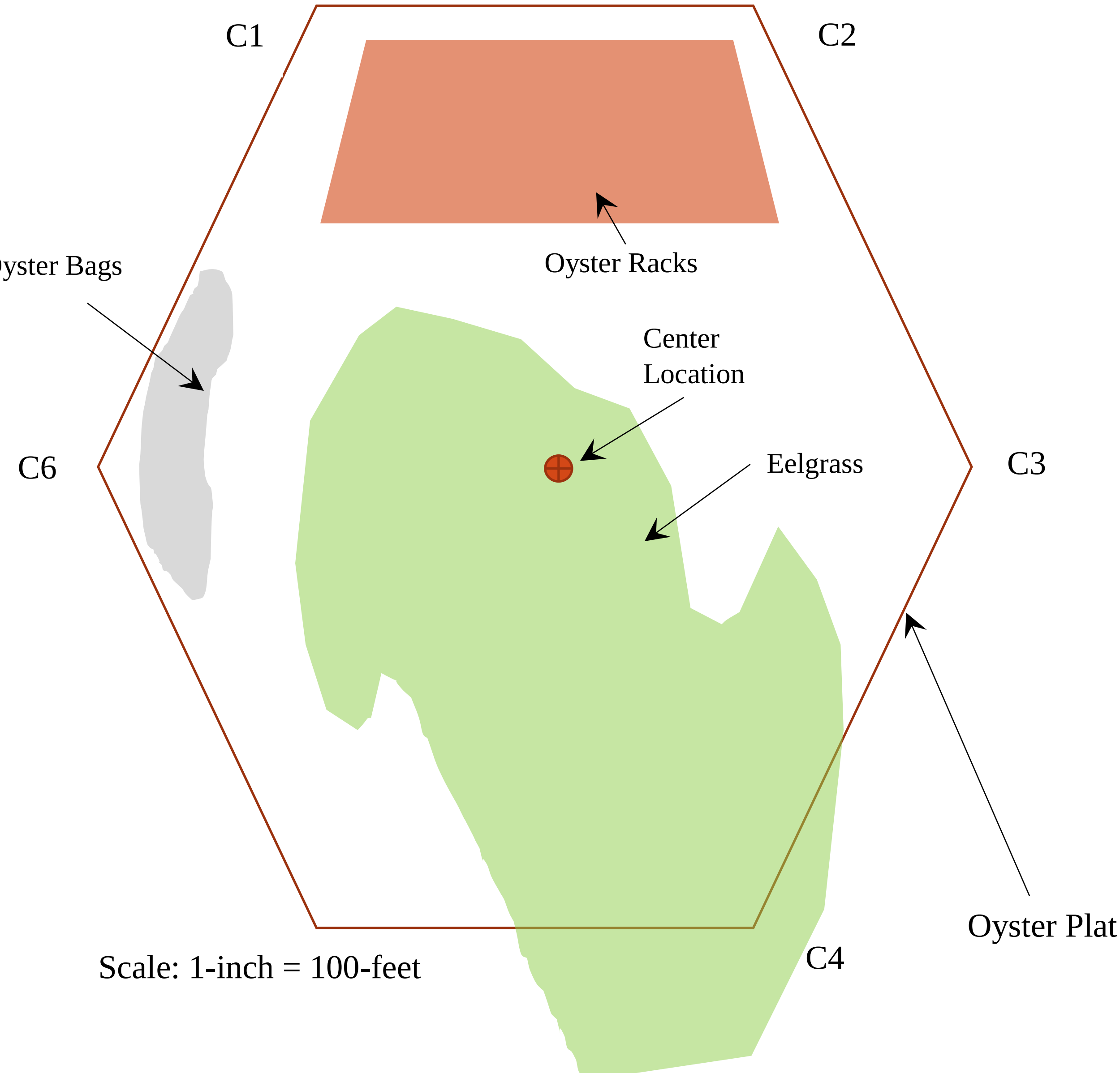
Credit Ranks			
UID	Credit Criteria	Ordinal	Numeric
1	Highly Functional System	H	116000
2	Moderately High Functional System	MH	null
3	Functional System	M	null
4	Moderately Low Functional System	ML	null
5	Low Functional System	L	null

Figure 3. Hypothetical Credit Score for Reference Site Unit.

Puget Sound Reference Site							
UID	Date	Disturbance Type	Elevation (ft < MLLW)	Acres	Total Credit	Latitude	Longitude
1	5/23/2018	None	0 -10	100	116000	48.288240	-122.404113
2							
3							
4							
5							
6							

Figure 4. Hypothetical Summary Credit Score for Multiple Reference Site Units (Only One of Many Potential Records is Displayed in this Table).

Appendix 2. Model Assessment Relatively Undisturbed Oyster Plat Application.



Oyster Plat Corner Locations												
UID	C1 - Lat	C1 - Lon	C2 - Lat	C2 - Lon	C3 - Lat	C3 - Lon	C4 - Lat	C4 - Lon	C5 - Lat	C5 - Lon	C6 - Lat	C6 - Lon
1	48.291476	-122.4067	49.291430	-122.4016	48.288234	-122.3991	48.284985	-122.4016	48.285071	-122.4069	48.288226	-122.4090
2												
3												
4												
5												
6												

Figure 1. Eelgrass / Oyster Plat Site Diagram Hypothetical Corner Locations.

Appendix 2 (Cont). Model Assessment Relatively Undisturbed Oyster Plat Application.

Example 1 Oyster Plat Credit Score Card – Based on Species Associations (Generalized from Dethier 1990)									
UID	Genus	Species	Present	Density	HSI	Population	Focal Weight	Acres	Credits
1	*Zostera*	*marina*	x	10			10	100	10000
2	*Metacarcinus*	*magister*	x		10		5	100	5000
3	*Neotrypaea*	*spp*	x		10		5	100	5000
4	*Upogebia*	*pugettensis*	x		10		5	100	5000
5	*Clupea*	*pallasii*	x		10		8	100	8000
6	*Aulorhynchus*	*flavidus*	x		10		5	100	5000
7	*Syngnathus*	*leptorhyncus*	x		10		5	100	5000
8	*Cymatogaster*	*aggregata*	x		10		5	100	5000
9	*Pholis*	*ornata*	x		10		5	100	5000
10	*Blepsias*	*Cirrhosis*	x		10		5	100	5000
11	*Clinocottus*	*acuticeps*	x		10		5	100	5000
12	*Oncorhynchus*	*tshawytscha*	x		10		10	100	10000
13	*Oncorhynchus*	*kisutch*	x		10		10	100	10000
14	*Salvelinus*	*confluentus*	x		10		10	100	10000
15	*Pleuronectes*	*vetulus*	x		10		5	100	5000
16	*Mareca*	*americana*	x		10		3	100	3000
17	*Branta*	*bernicula*	x		10		5	100	5000
18	*Brachyramphus*	*marmoratus*	x		10		10	100	10000
	Total								116000

Figure 2. Credit Score Schema (Informed by Hypothetical Field Data).

Species x: $[\text{Credit}_1] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$
Species y: $[\text{Credit}_2] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$

$$\text{Total Credit} = \text{Credit}_1 + \text{Credit}_2 \ \ldots$$

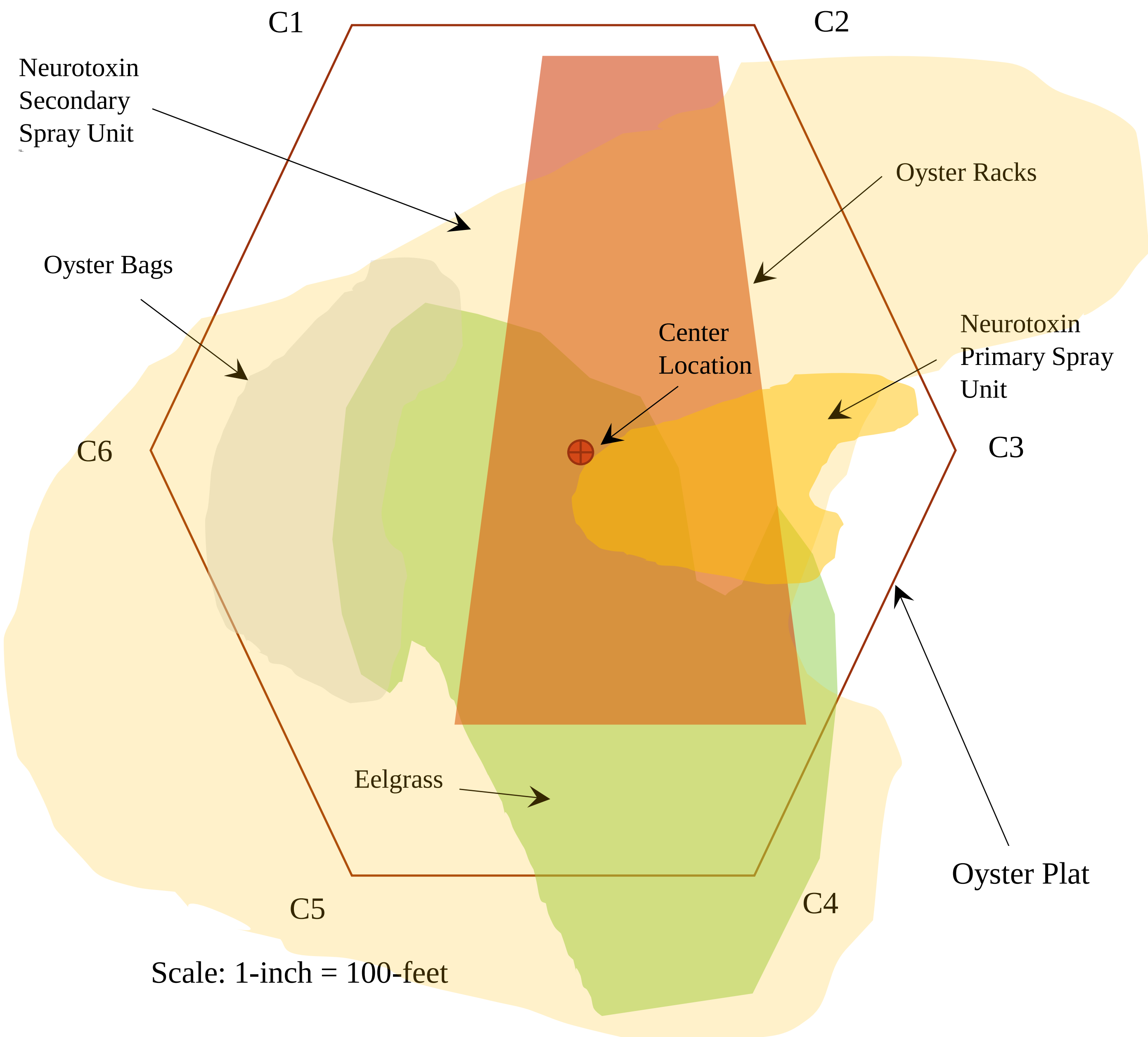
Credit Ranks			
UID	Credit Criteria	Ordinal	Numeric
1	Highly Functional System	H	116000
2	Moderately High Functional System	MH	null
3	Functional System	M	null
4	Moderately Low Functional System	ML	null
5	Low Functional System	L	null

Figure 3. Hypothetical Credit Score for Oyster Plat Unit.

Puget Sound Oyster Plat Example 1							
UID	Date	Disturbance Type	Elevation (ft < MLLW)	Acres	Total Credit	Latitude	Longitude
1	5/23/2018	None	0 -10	100	116000	48.288240	-122.404113
2							
3							
4							
5							
6							

Figure 4. Hypothetical Summary Credit Score for Multiple Oyster Plat Units (Only One of Many Potential Records is Displayed in this Table).

Appendix 3. Model Assessment Disturbed Oyster Plat Application.



Oyster Plat Corner Locations												
UID	C1 - Lat	C1 - Lon	C2 - Lat	C2 - Lon	C3 - Lat	C3 - Lon	C4 - Lat	C4 - Lon	C5 - Lat	C5 - Lon	C6 - Lat	C6 - Lon
1	48.291476	-122.4067	49.291430	-122.4016	48.288234	-122.3991	48.284985	-122.4016	48.285071	-122.4069	48.288226	-122.4090
2												
3												
4												
5												
6												

Figure 1. Eelgrass / Oyster Plat Site Diagram Hypothetical Corner Locations.

Appendix 3 (Cont). Model Assessment Disturbed Oyster Plat Application.

Example 2 Oyster Plat Credit Score Card – Based on Species Associations (Generalized from Dethier 1990)									
UID	Genus	Species	Present	Density	HSI	Population	Focal Weight	Acres	Credits
1	*Zostera*	*marina*	x	3			10	25	750
2	*Metacarcinus*	*magister*	x		3		5	25	375
3	*Neotrypaea*	*spp*	x		1		5	2	10
4	*Upogebia*	*pugettensis*	x		1		5	2	10
5	*Clupea*	*pallasii*	x		3		8	25	600
6	*Aulorhynchus*	*flavidus*	x		3		5	25	375
7	*Syngnathus*	*leptorhyncus*	x		3		5	25	375
8	*Cymatogaster*	*aggregata*	x		3		5	25	375
9	*Pholis*	*ornata*	x		3		5	25	375
10	*Blepsias*	*Cirrhosis*	x		3		5	25	375
11	*Clinocottus*	*acuticeps*	x		3		5	25	375
12	*Oncorhynchus*	*tshawytscha*	x		3		10	25	750
13	*Oncorhynchus*	*kisutch*	x		3		10	25	750
14	*Salvelinus*	*confluentus*	x		3		10	25	750
15	*Pleuronectes*	*vetulus*	x		3		5	25	375
16	*Mareca*	*americana*	x		3		3	25	225
17	*Branta*	*bernicula*	x		3		5	0	0
18	*Brachyramphus*	*marmoratus*	x		3		10	25	750
	Total								7595

Figure 2. Credit Score Schema (Informed by Hypothetical Field Data).

Species x: $[\text{Credit}_1] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$

Species y: $[\text{Credit}_2] = [\text{Abundance}] \times [\text{Focal Weight}] \times [\text{Acres}]$

$$\text{Total Credit} = \text{Credit}_1 + \text{Credit}_2 \ldots$$

Credit Ranks			
UID	Credit Criteria	Ordinal	Numeric
1	Highly Functional System	H	116000
2	Moderately High Functional System	MH	null
3	Functional System	M	null
4	Moderately Low Functional System	ML	7595
5	Low Functional System	L	null

Figure 3. Hypothetical Credit Score for Oyster Plat Unit.

Puget Sound Oyster Plat Example 2							
UID	Date	Disturbance Type	Elevation (ft < MLLW)	Acres	Total Credit	Latitude	Longitude
1	5/23/2018	Oyster Bags	0 - 5	20	10	48.288359	-122.407111
2	5/23/2018	Oyster Racks	5 - 10	45	25	48.288534	-122.403292
3	5/23/2018	Neurotoxin Direct	5 - 10	15	5	48.289079	-122.402677
4	5/23/2018	Neurotoxin Indirect	0 - 30	> 100	7555	48.288100	-122.404861
5							
6							

Figure 4. Hypothetical Summary Credit Score for Multiple Oyster Plat Disturbance Units.

Appendix 4. Native Eelgrass Representations.

Figure 1. Native Eelgrass and Pacific Herring Spawning.

Figure 2. Native Eelgrass and Dungeness Crab.

Appendix 4 (Cont). Native Eelgrass Representations.

Figure 3. Native Eelgrass and Starfish.

Figure 4. Native Eelgrass Sampling.

Appendix 5. Oyster-Culture Operations

Figure 1. Oyster-culture Farm.

Figure 2. Oyster-culture Farm.

Appendix 5 (Cont). Oyster-Culture Operations

Figure 3. Oyster-culture Farm.

Figure 4. Oyster-culture Farm.

Appendix 6. Model Python Code

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# OysterEelgrass_Model_PythonScript.py
# Created on: 2018-04-28 17:56:55.00000
#   (generated by ArcGIS/ModelBuilder)
# Description:
# Research Problem:
#
# Significant portions of intertidal habitat in the Puget Sound are dedicated to oyster aquaculture operations under the premise that they are inherently biologically and ecologically compatible with undisturbed estuary structure and function.  However, history informs us that aquaculture is a type of agriculture that can have serious direct and indirect adverse impacts on native species and the natural habitats they depend on.
#
# Research Question:
#
# What are the focal stressors on native eelgrass (Zostera marina) and associated native eelgrass dependent species that stem from oyster aquaculture operations in the Puget Sound and what is the ordinal magnitude and geographic distribution of these stressors?
#
# Research Task:
#
# This model attempts to isolate one key habitat type, native eelgrass, itemize focal stressors, and use a Geographic Information System (GIS) based model to spatially evaluate the geographic distribution and relative magnitude of these stressors in the Puget Sound area of Washington State.

# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy


# Local variables:
OYSTER_PLATS_Evaluation = "D:\\University of Washington GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\PSOE_EIP.gdb\\AQUACULTURE\\OYSTER_PLATS_Evaluation"
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OYSTER_PLATS_Evaluation_Clip = "D:\\University of Washington GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_Evaluation_Clip"
OYSTER_PLATS_Evaluation_Clip1 = "D:\\University of Washington GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_Evaluation_Clip1"
```

```
PS_Water_AOI = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\PSOE_EIP.gdb\\FOCALAREA\\PS_Water_
AOI"
OYSTER_PLATS_Eval_ZoneofInfluence = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_E
valuation_Clip2"
OYSTER_PLATS_Base = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\PSOE_EIP.gdb\\AQUACULTURE\\OYSTE
R_PLATS_Base"
OYSTER_PLATS_Base_Clip = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_
Base_Clip"
OYSTER_PLATS_Base_Raster = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_
Base_Clip_Polyg"
OYSTER_PLATS_Evaluation_Raster = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\OYSTER_PLATS_E
valuation_Clip3"
NetCredit = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb\\NetCredit"

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\SCRATCH_PSOE.gdb"
arcpy.env.workspace = "D:\\University of Washington
GIS\\UOWFall2017\\InVest\\RESEARCH\\myWork22\\PSOE_EIP.gdb"

# Process: Clip (2)
arcpy.Clip_analysis(OYSTER_PLATS_Evaluation, EELGRASS,
OYSTER_PLATS_Evaluation_Clip, "")

# Process: Multiple Ring Buffer
arcpy.MultipleRingBuffer_analysis(OYSTER_PLATS_Evaluation_Clip,
OYSTER_PLATS_Evaluation_Clip1, "100;1000;10000", "Feet", "distance", "ALL", "FULL")

# Process: Clip (3)
arcpy.Clip_analysis(OYSTER_PLATS_Evaluation_Clip1, PS_Water_AOI,
OYSTER_PLATS_Eval_ZoneofInfluence, "")

# Process: Clip
arcpy.Clip_analysis(OYSTER_PLATS_Base, EELGRASS, OYSTER_PLATS_Base_Clip, "")

# Process: Polygon to Raster
arcpy.PolygonToRaster_conversion(OYSTER_PLATS_Base_Clip, "TCVAL",
OYSTER_PLATS_Base_Raster, "CELL_CENTER", "TCVAL", "10")
```

```
# Process: Polygon to Raster (2)
arcpy.PolygonToRaster_conversion(OYSTER_PLATS_Evaluation_Clip, "TDValue",
OYSTER_PLATS_Evaluation_Raster, "CELL_CENTER", "TDValue", "10")

# Process: Raster Calculator
arcpy.gp.RasterCalculator_sa("\"%OYSTER_PLATS_Base_Raster%\" +
\"%OYSTER_PLATS_Evaluation_Raster%\"", NetCredit)
```

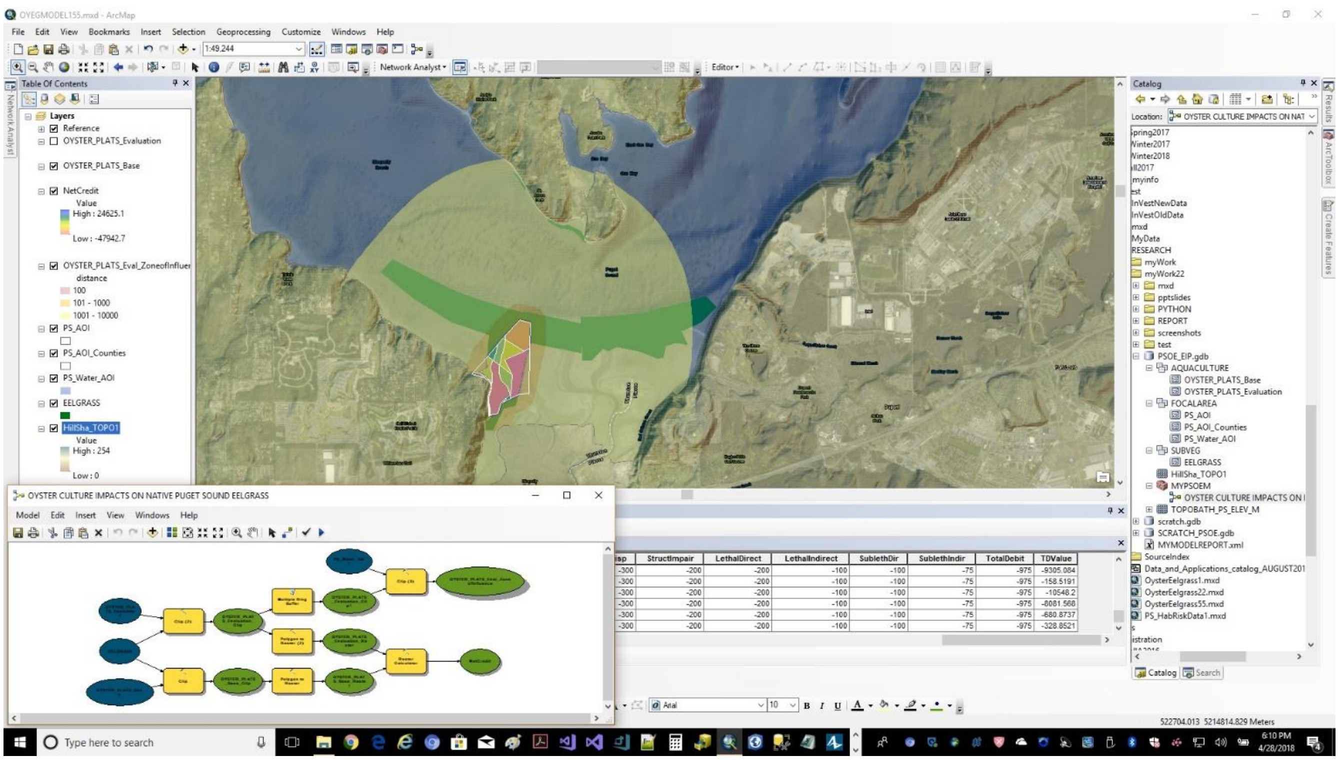

Figure 1. Example of Model Run.

Appendix 7. Oyster / Eelgrass Interaction Related Primary Institutions, Authorities, and Constraints

Table 1. Primary Institutions, Authorities, and Constraints.

Corps of Engineers (*Federal Register* on January 6, 2017 (82 FR 1860))
Authorities: Section 10 of the Rivers and Harbors Act (RHA); Section 404 of the Clean Water Act (CWA); National Environmental Policy Act (NEPA). Focal Permit: Nationwide Permit 48
Constraints: This NWP 48 authorizes the installation of buoys, floats, racks, trays, nets, lines, tubes, containers, and other structures into navigable waters of the United States and authorizes discharges of dredged or fill material into waters of the United States necessary for shellfish seeding, rearing, cultivating, transplanting, and harvesting activities. **Note:** The Corps determined they ***do not have the authority to regulate the use of insecticides and other pesticides***, so they cannot modify their PCN requirements to gather that information. They offer the use of insecticides and other pesticides may be regulated under other federal or state laws. **It does not authorize activities** that directly affect more than 1/2-acre of submerged aquatic vegetation beds *in project areas that **have not** been used for commercial shellfish Aquaculture activities during the past 100 years.* The permittee must submit a pre-construction notification to the district engineer if: (1) the activity will include a species that has never been cultivated in the waterbody; or (2) the activity occurs in *a project area that **has not** been used for commercial shellfish aquaculture activities during the past 100 years.* If required, the pre-construction notification must also include: A description of the proposed activity; the activity's purpose; direct and indirect adverse environmental effects the activity would cause, including the anticipated amount of loss of wetlands, other special aquatic sites, and other waters expected to result from the NWP activity, in acres, linear feet, or other appropriate unit of measure; a description of any proposed mitigation measures intended to reduce the adverse environmental effects caused by the proposed activity. The description of the proposed activity and any proposed mitigation measures should be sufficiently detailed to allow the district engineer to determine that the adverse environmental effects of the activity will be no more than minimal and to determine the need for compensatory mitigation or other mitigation measures. In addition, the following information is required: (1) a map showing the boundaries of the project area(s), with latitude and longitude coordinates for each corner of each project area; (2) the name(s) of the species that will be cultivated during the period this NWP is in effect; (3) whether canopy predator nets will be used; (4) whether suspended cultivation techniques will be used; and (5) general water depths in the project area(s) (a detailed survey is not required). No activity is authorized under any NWP 48 which is likely to directly or indirectly jeopardize the continued existence of a threatened or endangered species or a species proposed for such designation, as identified under the Federal Endangered Species Act (ESA), or which will directly or indirectly destroy or adversely modify the critical habitat of such species. No activity is authorized under any NWP 48 which "may affect" a listed species or critical habitat, unless ESA section 7 consultation addressing the effects of the proposed activity has been completed. Direct effects are the immediate effects on listed species and critical habitat caused by the NWP 48 activity. Indirect effects are those effects on listed species and critical habitat that are caused by the NWP 48 activity and are later in time, but still are reasonably certain to occur.
U.S. Fish and Wildlife Service (USFWS 2009)
Authorities: Section 7 of the Federal Endangered Species Act (ESA); Fish and Wildlife Coordination Act, Migratory Bird Treaty Act (MBTA); Section 404(q) Clean Water Act. Focal Consultation: Biological Opinion on NWP 48 – Portland Operating Division – USACE 2009

ESA Focal Species: Marbled murrelet (*Brachyramphus marmoratus*) – Threatened, Bull trout, Puget Sound, *Salvelinus confluetus*, - Threatened.[17]

Upon entering marine waters, bull trout can make extensive, rapid migrations, usually within nearshore marine areas. Aquatic vegetation and substrate common to all or most of the nearshore marine areas frequently used by bull trout includes eelgrass, green algae, sand, mud, and mixed fine substrates. Not surprisingly, these habitat features are also correlated with forage fish occurrence.

Shallow water habitats with prey may be the key focus of bull trout, and other variables may be less important. However, movement data were inadequate to determine if bull trout actively select specific vegetative habitats. Green algae and eelgrass were the most common vegetation types where bull trout were found in Skagit Bay.

Murrelets do not depend directly on eelgrass, as their association occurs primarily through their prey. In general, small schooling fish and large pelagic crustaceans are the main prey items of marbled murrelets. Pacific sand lance, northern anchovy, immature herring, capelin, Pacific sardine, juvenile rockfishes (*Sebastas* spp.) and surf smelt are the most common fish species eaten. Squid (*Loligo* spp.), euphausiids, mysid shrimp, and large pelagic amphipods are the main invertebrate prey. A number of these species are associated with the nearshore food web and many of them utilize eelgrass during larval and juvenile stages.

Herring are particularly important to murrelets as an energy rich prey item. Murrelets are able to shift their diet throughout the year and over years in response to prey availability. However, long-term adjustment to less energetically-rich prey resources (such as invertebrates) appears to be partly responsible for poor marbled murrelet reproduction in California. Prey types are not equal in the energy they provide. For example, parents delivering fish other than age-1 herring may have to increase deliveries by to up 4.2 times to deliver the same energy value. This may result in marbled murrelets preferring to forage in marine areas in close proximity to their nesting habitat. However, if adequate or appropriate foraging resources (i.e., “enough” prey, and/or prey with the optimum nutritional value for themselves or their young) are unavailable in close proximity to their nesting areas, marbled murrelets may be forced to forage at greater distances or to abandon their nests.

Aquaculture farms are often located within eelgrass beds. Various types of aquaculture activities affect distribution, density, and biomass of eelgrass. Off-bottom culture results in shading, bio-deposition and buildup of feces and pseudo feces, silt buildup, and anoxic conditions in the sediment. Off-bottom and rack culture results in erosion or sedimentation that appears to be the primary cause of eelgrass depletion in areas where this type of aquaculture is practiced. Additionally, the intertidal areas of Samish Bay have been rototilled in the past during the spring to disrupt the life cycle of the Atlantic oyster drill (*Urosalpinx cinerea*). This invasive oyster drill was first reported in Samish Bay in 1937 and was likely introduced through shipments of Atlantic oyster for aquaculture. If the oyster drill continues to be a problem, and rototilling is successful in disrupting its lifecycle, the continuation of this activity is likely.

Bed preparation is one of a sequence of activities that comprises cultivation of shellfish. It is done at the initial stage of oyster (rack and bag; stake and bottom) culture. It is also conducted for clam culture. Of the species of shellfish grown in the action areas, the activities conducted for oyster culture have the greatest potential for overlap with eelgrass beds. Although these specific activities have not been directly investigated, it reasonable to assume that bed preparation activities such as tilling, disking, raking, harrowing, and dragging in eelgrass beds would directly impact them. These activities are part of the overall process of shellfish aquaculture, and it is apparent that intensive commercial cultivation of oysters typically results in ongoing and variable levels of disturbance to eelgrass beds and their related communities. Both rack and stake culture cause a reduction in eelgrass density, primarily through. Stake culture also provides substrate, resulting in an increase in algae such as *Ulva* (sea lettuce) and *Enteromorpha*. These species are suspected of having an adverse effect on eelgrass.

Aquaculture activities are conducted on a year-round basis. Therefore, impacts to eelgrass beds could occur at any time. The seasonal effects of operation (e.g., during the growing vs. dormant season) have not been studied. Data are not available to determine whether impacts would be more severe during the growing or the dormant season. We are

[17] This Biological Opinion also involved consultations on California brown pelicans and western snowy plover, but brown pelicans have since been delisted and western snowy plover were considered to be outside of the action area.

assuming, however, that if disturbance were to occur at a time when the amount of aboveground vegetation was greater (growing season), there would be more impact to the bed. This assumption is predicated on the fact that the leaf and shoot density would be greater; effects to the underground component of the plants (rhizomes) would be expected to be equivalent regardless of season.

It is expected that, even during the dormant season, bed preparation activities would reduce the biomass generated during the following growing season. This assumption is based on the reproductive biology of eelgrass. Eelgrass reproduces both asexually (via rhizomes) and sexually (via seed generation). The rhizomes store carbohydrates generated by the plant during photosynthesis. These carbohydrates are used in the winter to sustain the plant during the dormant (non-growing) season. If, because of bed preparation, the rhizomes are severed, the translocation of carbohydrates to the plant would be interrupted (Thom, pers. comm. 2009). Indeed, biomass may be reduced the following growing season by working beds and removing shoots.

While the case can be made that a reduction in biomass will occur the following growing season if the beds are prepared during the dormant season, we assumed that the overall effect would be lower than if these activities were conducted during the growing season because the amount of above-ground vegetation would be less. Additionally, during the growing season aquatic organisms use the eelgrass for the structural habitat functions it provides. Therefore, bed preparation activities conducted at this point in the plants lifecycle would have a greater detrimental effect on the organisms that utilize this habitat.

After disturbance, a reduction in eelgrass density can persist for some time. Oyster stake and rack culture has been shown to significantly reduce eelgrass density, in some cases up to 75 percent if stakes and/or racks are positioned too closely to limit light penetration. This reduction in percent cover and shoot density was still evident after one year; eelgrass was also eliminated from the treatment sites after 17 months. In a longer term study, eelgrass biomass was reduced from 30 percent to 96 percent based on a culture period from one to four years.

Eelgrass plays a pivotal role in the ecology of the nearshore community. Approximately one third of the eelgrass beds in Puget Sound have been lost since they were first inventoried. This loss could represent a significant ecosystem impact, as eelgrass provides the following ecosystem functions:

- Supports the base of the food web harboring important prey species for forage fish and juvenile salmonids.
- Offers protection as a nursery habitat for herring and other developing aquatic organisms.
- Controls erosion and attenuates wave action to allow for settling out of fine material that builds up the organic content of the sediment.

Available evidence indicates it is reasonable to assume a temporary loss of eelgrass as a result of shellfish aquaculture. Aquaculture activities are expected to cause a reduction in eelgrass through direct displacement from bed preparation (mechanical dredging, tilling, raking and harrowing[4]), and shellfish harvesting (mechanical dredging, water injection). Eelgrass may recover, although it may take an extended period of time and densities are expected to be lower. Eelgrass will encroach on shellfish beds over time, but it is reasonable to assume it will provide limited and ephemeral habitat given the subsequent harvesting that will take place. The quality (density and biomass) of the eelgrass that may be present in shellfish beds is likely to be lower than the density of the native bed displaced when the shellfish bed was first created. Therefore, while some of the functions may be restored, it is unlikely that the recovering eelgrass will completely offset the lost function of the displaced eelgrass due to its reduced quality and ephemeral nature.

Direct overlap between shellfish aquaculture farms and documented herring spawning areas exists. Through the process of bed clearing and preparation and harvest, eelgrass is removed or reduced. This eelgrass would otherwise have been available to herring for spawning substrate. Most herring stocks in Puget Sound have declined in the past five years. For some stocks (North Sound and the Straits), this is a continuation of a longer-term decline, while for other stocks (in the central and south Sound) this decline follows a variable trend of stock increases and declines. The force behind this decline is not well under-stood and may be due to a combination of changing ocean conditions, degraded water quality, nearshore habitat loss, and other factors."

The reduction of herring could lead to a measurable reduction in prey species for bull trout, particularly in Samish Bay. It is reasonable to assume that there would be an annual reduction of the herring population in Samish Bay based on a 42 percent overlap between shellfish aquaculture farms and documented herring spawning habitat. It is anticipated that dredge harvest activity will cause localized reductions in water quality from increased turbidity through the suspension of sediments. We expect short term adverse effects to bull trout associated with the harvest activities primarily because bull trout will avoid the plume or otherwise experience adverse behavioral effects. Based on the apparent overlap between shellfish activities, eelgrass beds, and documented herring spawning habitat, we expect measureable effects to bull trout prey species and ultimately adverse effects to bull trout, primarily in Samish Bay. While Carbaryl, a pesticide used to control burrowing shrimp, is acutely toxic to invertebrates, and sublethally toxic to fish.
Constraints: The Service does not anticipate the proposed action will incidentally take any marbled murrelets or bull trout, therefore, no reasonable and prudent measures are required. The Service is to be notified within three working days upon locating a dead, injured or sick endangered or threatened species specimen. Initial notification must be made to the nearest U.S. Fish and Wildlife Service Law Enforcement Office. Notification must include the date, time, precise location of the injured animal or carcass, and any other pertinent information. Voluntary conservation measure recommendations: • Where this is the case, and threatened or endangered species are present, growers must include mitigation efforts in their farm management plans. This might include setting aside areas where submerged aquatic vegetation (SAV) is growing and taking care to avoid disturbing these beds during periods when these common areas are being utilized as habitat for important prey species such as herring spawn. • Protection of eelgrass beds is of particular concern. Growers must be familiar with the laws that govern operation in eelgrass beds in their particular region and assure their farm practices comply with applicable regulations and permit requirements.
National Marine Fisheries Service (NMFS 2012)
Authorities: Section 7 of the Federal Endangered Species Act (ESA) and Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA); Fish and Wildlife Coordination Act (FWCA); Section 404(q) Clean Water Act (CWA). Focal Consultation Biological Opinion on NWP 48 – Seattle District USACE **ESA Focal Species:** Beluga whale, Cook Inlet (with critical habitat) *Delphinapterus leucas* - Endangered; Salmon, Chinook (Puget Sound) with critical habitat – Threatened; Salmon, Chum (Hood Canal summer run) with critical habitat – Threatened; Killer whale, Southern Resident (with critical habitat) *Orcinus orca* – Endangered; Eulachon, Pacific (Southern population) *Thaleichthys pacificus* – Threatened; Rockfish, Canary (Georgia Basin) *Sebastes pinniger* – Threatened; Rockfish, Yelloweye (Georgia Basin) *Sebastes ruberrimus* -Threatened; Sturgeon, Green (southern population) with critical habitat *Acipenser medirostris* – Threatened.
Constraints: Authorization of an activity by a Nationwide Permit 48 does not authorize the “take” of a threatened or endangered species as defined under the ESA. In the absence of separate authorization (e.g., an ESA Section 10 Permit, a Biological Opinion with “incidental take” provisions, etc.) from the FWS or the NMFS, both lethal and non-lethal “takes” of protected species are in violation of the ESA. The permittee must submit a pre-construction notification to the district engineer if: (1) The project area is greater than 100 acres; or (2) there is any reconfiguration of the aquaculture activity, such as relocating existing operations into portions of the project area not previously used for aquaculture activities; or (3) there is a change in culture methods (e.g., from bottom culture to off-bottom culture); or (4) dredge harvesting, tilling, or harrowing is conducted in areas inhabited by submerged aquatic vegetation; or, (5) there is an expansion to the project area. The pre-construction

notification must also include the following information: (a) The size of the project area, plus any proposed expansion (in acres); (b) the corner latitude and longitude coordinates of the project area and the expansion area; (c) a brief description of the culture and harvest method(s), including plans for rotating production within a project area; (d) the name(s) of the cultivated species; (e) whether canopy predator nets are being used; and, (f) a description of the composition of the substrate material and vegetation.

Reasonable and Prudent Alternatives:

1. The first element of the reasonable and prudent alternative requires the USACE to systematically collect the basic information that would be necessary to know or reliably estimate how many activities may affect endangered or threatened species under NMFS' jurisdiction or critical habitat that has been designated for those species, where and when the activities occurred, the impact of the activity, and whether a permittee complied with any general conditions of the Nationwide Permit 48 that would apply to their activity (which can be used to verify compliance rates with those conditions and their effectiveness).
2. The second element of the reasonable and prudent alternative requires USACE Districts to formally consult with their counterparts in NMFS on procedures Districts impose to comply with the first element of this reasonable and prudent alternative and additional conditions those Districts might impose on Nationwide Permit 48 and on measures to avoid or minimize the incremental, additive, and interactive impacts of activities that would be authorized by Nationwide Permit 48 in Seattle Districts on endangered and threatened species under NMFS" jurisdiction and critical habitat that has been designated for such species.
3. The third element of this alternative requires the USACE to analyze the information they receive as a result of the first element to assemble a picture of the individual and cumulative impacts of those individual actions on waters of the United States in those watersheds that overlap with the distribution of endangered or threatened species under NMFS' jurisdiction (and critical habitat that has been designated for those species).
4. The fourth, fifth, and sixth elements of this alternative set specific performance triggers for the Nationwide Permit program and requires the USACE to use its authorities to prevent waters of the United States from being degraded by activities that would be authorized by the Nationwide Permit 48.
5. The seventh element of this alternative directs the USACE to develop policy and guidance on assessing the cumulative impacts of Nationwide Permits for USACE project managers and directs the USACE to determine whether or to what degree project managers adhere to that policy and guidance.
6. The eighth element requires the USACE to provide annual reports of the cumulative impact of the actions it authorizes using the Nationwide Permit 48 that overlap with the distribution of endangered or threatened species under NMFS' jurisdiction and critical habitat that has been designated for those species.
7. The final element of this alternative requires the USACE to develop and publish policy and guidance so that prospective permit applicants provide better information when they submit pre-discharge notifications to the USACE (to comply with Element 1). This reasonable and prudent alternative must be implemented in its entirety to insure that the activities the proposed Nationwide Permit 48 authorizes are not likely to jeopardize endangered or threatened species under the jurisdiction of the National Marine Fisheries Service or destroy or adversely modify critical habitat that has been designated for these species.

Requires all prospective permittees who plan to conduct activities under the authority of NWP 48 in waters of the United States located within the boundaries of critical habitat that has been designated for endangered or threatened species under the jurisdiction of the National Marine Fisheries Service in estuaries, and coastal areas that contain critical habitat designations for Cook Inlet beluga whale, southern resident killer whale Puget Sound Chinook salmon, Hood Canal summer run chum salmon, or green sturgeon (southern population) to notify the Seattle USACE District . This notification must, at a minimum, specify:

- The party or parties who plan to undertake the activity;
- The location of the activity (using section, township, range locators; latitude and longitude, or Universal Transverse Mercator locators), including the watershed in which the activity would occur;
- When the activity would occur (start date and end date);
- An estimate of the area or linear distance (with Nationwide Permits 13 and 14) affected by the proposed activity; and

- A narrative explanation of how the prospective applicant satisfied the requirements of the USACE's conditions on endangered species, threatened species, and designated critical habitat.

NWP 48 Permit does not authorize the "take" of a threatened or endangered species unless that "take" has already been exempted from the prohibitions of section 9 of the Endangered Species Act of 1973, as amended, through a separate permit pursuant to section 10(a)(1)(A) of the Act (a permit for research or to enhance the survival or propagation of an endangered or threatened species), section 10(a)(1)(B) (a permit exempting incidental "take" of endangered species or threatened species), or through a biological opinion on a specific action that requires a NWP, Regional General Permit, or standard permit from the U.S. Army Corps of Engineers. In each of these instances, NMFS would normally conduct a separate section 7 consultation and issue a separate biological opinion before any endangered or threatened species might be "taken"; the amount or extent of "take" would be identified in those subsequent consultations on site-specific, area-specific, or permit-specific activities.

The following conservation recommendations would provide information for future consultations involving the issuance of marine mammal permits that may affect endangered whales as well as reduce harassment related to research activities:

1. the Chief of Engineers should establish a policy that directs District Engineers and project managers to consider the direct, indirect, and cumulative impacts of the activities the USACE authorizes on the "species of special concern" during the review of any PCNs; and

2. the Chief of Engineers should establish a policy that directs District Engineers and project managers to consider the direct, indirect, and cumulative impacts of the activities the USACE authorizes on goals set in recovery plans for endangered and threatened species within their geographic areas of responsibility. In order to keep NMFS' Endangered Species Division informed of actions minimizing or avoiding adverse effects or benefitting listed species or their habitats, the U.S. Army Corps of Engineers should notify the Endangered Species Division of any conservation recommendations they implement in their final action.

Washington Department of Ecology (USACE 2012)

Authorities: Section 401 Clean Water Act (CWA) Certification

Focal Certification: Section 401 Clean Water Act Certification

Constraints: This NWP authorizes the installation of buoys, floats, racks, trays, nets, lines, tubes, containers, and other structures into navigable waters of the United States. This NWP also authorizes discharges of dredged or fill material into waters of the United States necessary for shellfish seeding, rearing, cultivating, transplanting, and harvesting activities. Rafts and other floating structures must be securely anchored and clearly marked. This NWP does not authorize:
(a) The cultivation of a nonindigenous species unless that species has been previously cultivated in the waterbody;
(b) The cultivation of an aquatic nuisance species as defined in the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990; or,
(c) Attendant features such as docks, piers, boat ramps, stockpiles, or staging areas, or the deposition of shell material back into waters of the United States as waste.
This NWP also authorizes commercial shellfish aquaculture activities in new project areas, provided the project proponent has obtained a valid authorization, such as a lease or permit issued by an appropriate state or local government agency, and those activities do not directly affect more than 1/2-acre of submerged aquatic vegetation beds.
Notification: The permittee must submit a pre-construction notification to the district engineer if: (1) dredge harvesting, tilling, or harrowing is conducted in areas inhabited by submerged aquatic vegetation; (2) the activity will include a species not previously cultivated in the waterbody; (3) the activity involves a change from bottom culture to floating or suspended culture; or (4) the activity occurs in a new project area. (See general condition 31.)
In addition to the information required by paragraph (b) of general condition 31, the pre-construction notification must also include the following information: (1) a map showing the boundaries of the project area, with latitude and longitude coordinates for each corner of the project area; (2) the name(s) of the cultivated species; and (3) whether canopy predator nets are being used.
Note 1: The permittee should notify the applicable U.S. Coast Guard office regarding the project.

Note 2: To prevent introduction of aquatic nuisance species, no material that has been taken from a different waterbody may be reused in the current project area, unless it has been treated in accordance with the applicable regional aquatic nuisance species management plan.
Note 3: The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 defines "aquatic nuisance species" as "a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural, or recreational activities dependent on such waters."

Summary of National and Regional Pre-Construction Notification Requirements –
Pre-construction notification (e.g., a permit application or JARPA) must be submitted to the Corps for work that results in any of the following:
a) any ESA-listed species, designated critical habitat or essential fish habitat might be affected or is in the vicinity of the project (National General Condition 18 and Regional General Condition 7)
b) impacts to aquatic resources requiring special protection (Regional General Condition 1)
c) new or maintenance bank stabilization activities (Regional General Condition 4)
d) an affect or potential to affect listed historic properties (National General Condition 20)
e) impacts a designated critical resource waters (National General Condition 22)
f) dredge harvesting, tilling, or harrowing is conducted in areas inhabited by submerged aquatic vegetation
g) work that includes a species not previously cultivated in the waterbody
h) work that involves a change from bottom culture to floating or suspended culture
i) work in new project areas. (for f – i NWP 48 Notification Condition)

State 401 Certification – Certified subject to conditions. Permittee must meet Ecology 401 General Conditions. Individual 401 review is required for projects or activities authorized under this NWP if:
1. The project is a new or expanded geoduck operation, on private tidelands, that has not obtained a permit pursuant to an updated Shoreline Master Program (SMP). "Updated" means the SMP has been locally adopted, consistent with Ecology guidelines, after February 11, 2011. Contact Ecology for a list of these jurisdictions.
2. The project is a new or expanded geoduck operation, on state-owned aquatic lands, that has not applied for an aquatic lands lease from WA Department of Natural Resources.

Puget Sound Tribes (USACE 2012)

Authority: Section 401 Clean Water Act (CWA) Certification

Constraints: Federal permits from the USACE, and Section 401 CWA Water Quality Certifications from each respective tribe on their tribal lands, are required for all existing and new oyster culture activities regulated by the CWA. If the USACE determines a may effect for a Federally listed species associated with any of these individual permits, Section 7 ESA consultations will also have to be initiated by the Corps unless the permit actions are covered by a programmatic Section 7 consultation (Sanguinetti 2018).