ECOSYSTEM SERVICES AND CONSERVATION OF FOUR SALISH SEA MARINE HABITATS

Kelp Forests, Eelgrass Beds, Olympia Oyster Beds, Rocky Subtidal

Abstract

This document is a compilation of literature reviews and interpretive material on the ecological significance and conservation of four marine habitats in the Salish Sea. This work was completed over the course of the 2018 winter quarter at the University of Washington as part of an internship and independent study with the Port Townsend Marine Science Center. This information is meant to be used for interpretive material (i.e. signs, docent training, public education) for the Marine Exhibit at the Port Townsend Marine Science Center.

Amani Moyer-Ali

March 2018

Table of Contents

Literature Reviews

Interpretive Content

Literature Review: Kelp Forests

Introduction

Kelp forests, or kelp beds, are large collections of kelp growing vertically from rocky substrate in the ocean at depths of between 20-210 feet (Freedman 2004). Kelp, itself, is a form of brown algae consisting of a holdfast, which attaches the algae to the rock, a stipe, which provides vertical structure to kelp, and the blades or fronds, which extend outward from the stipe and photosynthesize, providing nutrients to the kelp. Kelp forests are extremely productive ecosystems, providing habitat and/or food for an estimated 1,000 species of smaller algae, fish, invertebrates, marine mammals, and birds in North America alone (Freedman 2004). Researchers have discovered 23 species of kelp living here in the Puget Sound, making it one of the most diverse kelp ecosystems in the world (Mumford 2007). However, despite our kelp's diversity, only two main species have been well-studied: *Macrocystis pyrifera* (Giant Kelp) which is dominant along the outer coast of Washington and along the Strait of Juan de Fuca, and *Nereocystis luetkeana* (Bull Kelp) which is dominant within Puget Sound proper (Mumford 2007). The growth of kelp in the Puget Sound is limited by three main natural factors: availability of rocky substrate, amount of light, and amount of dissolved nitrogen in the water (Mumford 2007, Steneck 2002).

In order to convey the incredible value of kelp forests in the Puget Sound we will examine the contributions of kelp forest ecosystems to the field of scientific research, the diversity and health of marine life, and the economic wellbeing of fisheries and other marine industries.

Kelp Forests as Subjects of Scientific Study

The most extensive studies that have been conducted on kelp forests have been examining either its unique life cycle or its interaction with other species in the food web. In the Puget Sound the most frequent consumer of kelp is the sea urchin, which can gather in herds of thousands and decimate kelp forests. Areas where kelp has been completely mowed by herds of sea urchins are known as "urchin barrens" (Freedman 2007). James Estes, a marine ecologist based out of Washington, spent a great deal of time in the Aleutian Islands in the early 1990s studying the differences between areas where kelp forests were present and areas where they were absent. What Estes discovered was that in areas where sea otters (a main predator of the sea urchin) were present, kelp forests thrived, and in areas where sea otters had been absent there were almost no kelp forests left (Eisenberg 2014). This led Estes to the logical conclusion that the predation of sea urchins by sea otters controlled the population of urchins, which decreased grazing on kelp forests. Conversely, when sea otters were removed from a kelp forest ecosystem, urchin populations boomed and led to overgrazing of kelp. This domino effect in the natural world is a direct example of an ecological concept known as a "trophic cascade" which describes situations in the natural world wherein a predator is removed from an ecosystem and its prey reproduces unsustainably, eventually decimating its own food source and dying out from lack of resources (Eisenberg 2014). The discovery of the sea otter/sea urchin/kelp forest cascade has contributed greatly to the study of marine ecosystems and the importance of the conservation of predators such as the sea otter which, previously, had been hunted nearly to extinction by humans for its dense fur. Later in his research, Estes witnessed a remarkable shift in this interaction between sea otters and kelp when orca whales began preying on sea otters, drastically reducing sea otter numbers and instigating, once again, the decimation of kelp forests in the study area (Eisenberg 2014). This study should provide a cautionary tale to humans about the indirect negative effects that can result from unsustainable hunting practices on keystone predators.

While the trophic cascade study is by far the most extensive, other studies of kelp forests have contributed to our understanding and protection of marine ecosystems as well. Professor Laura Carney's research on the ideal size of bull kelp to transplant in order to establish successful kelp forest ecosystems has formed an understanding of the logistics of restoring kelp forests within the

Puget Sound and reinforces the importance of maintaining and restoring these vital marine ecosystems (Carney 2005). Additionally, extensive research has been done into the biology and life cycle of kelp plants and how their fast growth and reproduction in a relatively short lifespan allows them to be consistent source of habitat for kelp forest-dwelling fish and invertebrates (Schiel 2015). It is also important to note that while the sea otter is the most famous predator of the sea urchin, it is not the only one. Indeed, in the southern region of Puget Sound (where we live) the main predator to the sea urchin is not the sea otter (which has not reestablished residence in the area since their reintroduction to the PNW) but the sunflower star. In the midst of the epidemic of Sea Star Wasting Disease (SSW), divers began to notice vastly increased numbers of green sea urchins on the sea floor. While this is not a scientifically studied correlation, it is another potential example of how trophic cascade affects our region of Puget Sound (Heery 2015).

Habitat for Fish and Invertebrates

Kelp forest ecosystems provide habitat for many different marine organisms by supplying nutrients and shelter from the harsh open water. One characteristic unique to kelp forests is its three-dimensional structure which encourages a diverse array of fish and invertebrate species to take up residence within the forest at varying depths in the water column. This three-dimensional structure is comparable to that of terrestrial forests with lower, mid, and upper stories to the canopy which each provide habitat to different organisms (Eisenberg 2014). In kelp forests, the understory is usually made up of smaller species of kelp and algae, as well as the holdfasts of taller kelp plants, which can act as groundcover and ideal shelter for large species of juvenile fish such as the calico rockfish (Kritzer 2006) or adult benthic species such as the kelp greenling (Wheeler 1990). The mid story and upper stories usually consist of the fronds of kelp plants of varying heights in the water column and may act as shelter for adult and juvenile neritic fish species or small gastropods which can take up residence in the stipes of kelp (Kritzer 2006, Wheeler 1990). Kelp forests can support hundreds of species of marine organisms and some, such as the sea urchin, are dependent on kelp forests for food and shelter throughout their entire lives (Dietrich 2003, Kritzer 2006).

An excellent example of the vastness and power of kelp forests is the fact that they can actually have an influence on local currents. The large surface area of kelp fronds can create enough drag in moving water that it slows the speed of water flow to 1/2 or even 1/3 the speed of the surrounding water, meaning that marine organisms struggling in the open water can seek refuge from wave action in kelp forests (Schiel 2015). Perhaps as a result of its protective structure or simply because it is a good source of food to grazers, which, in turn, attract predators, kelp forests are centers for biodiversity. In Wheeler's paper on kelp forest resources the fish species found within Puget Sound kelp forests were divided into three categories: resident, associated, and transient. Resident species were classified as fish that spend the majority of their lives inside the kelp forest, associated species spend most of their time interacting with the kelp forest and various species within it, but not necessarily living in it, and transient are species that are rarely found within the kelp forest and generally only spend a short amount of time there (Wheeler 1990). This categorization of kelp forest species gives an indication of the sheer number of species that kelp forests support, and the diverse needs and behaviors of those species. For a full list of fish species reported in each of these categories, see Figure 1. In addition to the diversity of fish species and behavior, there is also vertical diversity provided within kelp forests, meaning that the ecosystem found at the bottom of a kelp forest, near the sea floor, could be entirely different that the ecosystem found in the mid and upper stories. Benthic species such as sculpins and flatfish can be found resting on the sea floor feeding on worms or crustaceans, while rockfish and perch swim between the fronds up above feeding on marine zooplankton or other neritic fish species (Wheeler 1990).

Ecosystem Services

While it is abundantly clear that kelp forests are immensely important to marine ecosystems and the diverse array of life within the Puget Sound, it is also important to discuss how kelp forests influence and contribute to the everyday life of humans. A commonly cited "fun fact" about kelp is that it is used in toothpaste, ice cream, and many other commercial products, but few people know what it contributes to these products. Alginic acid, a carbohydrate derived from kelp plants, is a binding agent used in a wide variety of food and beverage products as a preservative or thickener. It can also be used in paints and varnishes and in a range of other household and construction products. It is tasteless and harmless and provides a great deal of convenience to manufacturers (Wheeler 1990). A benefit of utilizing kelp for this chemical is that it is extremely fast-growing and, in ideal conditions, can grow up to 2 feet in length per day (Dietrich 2003). This makes it a very renewable and cheap resource which, when harvested sustainably, can continue to support both marine ecosystems and economic demand. Some regulations have been put in place to ensure kelp harvesting is sustainable, for example regulations in California restrict cutting to the top 4 ft. of the water column, keeping the majority of the lower portion of the forest intact and allowing for successful regrowth; even with these regulations, approximately 176,000 tons of kelp is harvested per year (Freedman 2004).

While the use of kelp as a product is an important aspect of its economic contribution, it is certainly not its greatest contribution. Many of the benefits of kelp forests to human wellbeing are indirect and therefore go unrecognized by the general public. One such indirect contribution is the reduction of wave action near the coast, subsequently reducing the rate and severity of coastal erosion (Dietrich 2003). While there has not been substantial study of the exact degree to which kelp forests reduce coastal erosion, it is the logical conclusion to draw when considering the reduced rate of local currents caused by kelp forests and the relationship of currents to erosion. This is an issue of utmost importance to property owners with homes on beachfronts or bluffs. The risk of both encroaching water levels and landslides play a major role in property value (Kriesel 2000) and the proximity and abundance of kelp forests to waterfront property may play a role in mitigating those concerns.

The most influential, and likely the most overlooked economic benefit of kelp forest ecosystems is the multi-million-dollar fishery industries that they support. Among the most well-known fish species found in Puget Sound kelp forests are Coho, pink, chum, Sockeye, and Chinook salmon, northern anchovies, black and copper rockfish, and herring, just to name a few (Wheeler 1990). Some of these fish species are residents and spend their whole lives living in kelp forests, and some are transient, simply swimming through and briefly utilizing the abundance of resources kelp forests have to offer. Commercial fisheries, in turn, rely on these fish species for income and consumers rely on those fisheries as a local food source. If kelp forests are not conserved throughout these commercial fishing areas it will compromise the success and availability of these already delicate fisheries and could have a substantial economic impact (Carney 2005).

Threats, Conservation, and Conclusion

There are several major threats to kelp forest habitats in the Puget Sound, one of which is the aforementioned trophic cascade influencing sea urchin numbers which, in turn, determines the level of grazing occurring on kelp beds (Freedman 2004, Schiel 2015, Eisenberg 2014, Heery 2015). While some of this fluctuation of kelp forest coverage is natural (such as the decline in sunflower star populations as a result of SSW) (Heery 2015), there are also several anthropogenic factors such as sedimentation from coastal development, oil spills, and herbicides and detergents carried to the water by runoff or dumping (Carney 2005) as well as the over-exploitation of sea otter populations throughout the 19th and 20th centuries which contributed to increased urchin grazing. In addition to these rather localized influences, some researchers have also theorized about the influence that global climate change will have on the location and distribution of kelp forests. Kelp forests generally thrive in cold-water coastal zones which can extend as far south as Baja, California, however with increasing ocean temperatures it is likely that kelp forests may begin to retreat to more northern latitudes, taking with them the valuable commercial and sport fish species they support ((Steneck 2002). Additionally, warming temperatures also decrease the ocean's capacity to store nitrogen, a limiting nutrient for kelp, and decreasing nitrogen availability could lead to kelp "deforestation" (Steneck 2002). Some researchers such as Professor Laura Carney at San Diego State University are working toward inexpensive ways to repopulate kelp forests by transplanting young kelp plants to ideal growth areas to encourage the establishment of kelp forest ecosystems (Carney 2005). Additionally, regulations limiting the amount of kelp that can be harvested in California kelp forests indicates that kelp forests are beginning to get recognized as important economic and ecological contributors and are being valued as a resource worth conserving (Freedman 2004).

While, it is certainly important to recognize and reinforce the economic value that kelp forests provide, it is also vital to stop and consider the intrinsic value that diverse marine ecosystems hold. Kelp forests are extensive, powerful structures within the Puget Sound and have become a symbol of Pacific Northwest marine ecosystems. They represent the beauty and diversity of the Puget Sound and embody its characteristic greenery which can be foreboding to some but tantalizing to others. While kelp forests may not appear as colorful or inviting as famous tropical coral reefs, they represent a bountiful ecosystem supporting incredible creatures who rely on these gigantic forests for food and shelter, and that, in and of itself, holds immense value.

List of Figures

Table 9.1: Classification of kelp bed fish species by habitat association (after Leaman 1980).

Neritic - Resident	Neritic - Associated	Neritic - Transient
Sebastes melanops	*Engraulis mordax?*	*Squalus acanthias*
Cymatogaster aggregata	*Clupea harengus pallasi?*	*Porichthys notatus*
Rhacochilus vacca	*Ammodytes hexapterus?*	*Sebastes miniatus*
Embiotoca lateralis		*Sebastes nebulosus*
Aulorhynchus flavidus		
Brachyistius frenatus		
Benthic - Resident	**Benthic - Associated**	**Benthic - Transient**
Hemilepidotus hemilepidotus	*Enophrys bison*	*Scopraenichthys marmoratus*
Hexagrammos decagrammus	*Ophiodon elongatus*	*Hydrolagus colliei*
Hexagrammos lagocephalus	*Jordania zonope*	*Pleuronichthys coenosus*
Anoplarchus purpurescens	*Coryphopterus nicholsi*	
Chirolophis nugator	*Hexatrammos decagrammus*	
Blepsias chirrhosus		
Nautichthys oculofasciatus		
Artedius harringtoni		
Phytichthys chirus		
Liparis florae		
Liparis mucosus		
Gobiesox maendricus		
Artedius lateralis		
Synchirus gilli		
Xiphister atropurpureus		
Pholis schultzi		
Ascelichthys rhodorus		
Bothragonus swani		
Oligocottus rimensis		
Oligocottus snyderi		
Hemilepidotus spinosus		
Artedius fenestralis		

(Wheeler 1990)

Table 2: Commercial fish species found in Puget Sound kelp forests

Table 8.1: Commercial Fish species caught in Port Hardy area kelp beds.

Species	Common Name	*Macrocystis*	*Nereocystis*
Anaplopoma fimbria	blackcod	x	
Citharichthys sordidus	Pacific sanddab	x	
Clupea harengus pallasi	Herring	x	x
Engraulis mordax mordax	northern anchovy	x	x
Gadus macrocephalus	Pacific, grey cod	x	x
Lepidopsetta bileneata	rock sole		x
Microstomus pacificus	Dover sole	x	
Ophiodon elongatus	lingcod	x	x
Parophrys vetulus	English sole	x	x
Pleuronichthys coenosus	C-O sole	x	x
Pleuronicththys decurrens	curlfin sole	x	
Oncorhyncus gorbuscha	pink salmon	x	x
Oncorhyncus keta	chum salmon	x	x
Oncorhyncus kisutch	coho salmon	x	x
Oncorhyncus nerka	sockeye salmon	x	x
Oncorhyncus tshawtscha	chinook salmon	x	x
Salvelinus malma	Dolly varden	x	x
Sebastes auriculatus	brown rockfish	x	
Sebastes caurinus	copper rockfish	x	x
Sebastes flavidus	yellowtail rockfish	x	
Sebastes maliger	quilback rockfish	x	
Sebastes melanops	black rockfish		x
Sebastes spp.	other small rockfish	x	

(Wheeler 1990)

Works Cited

Carney, Laura & Robert Waaland, J & Klinger, Terrie & Ewing, Kern. (2005). Restoration of the bull kelp Nereocystis luetkeana in nearshore rocky habitats. Marine Ecology-progress Series - MAR ECOL-PROGR SER. 302. 49-61. 10.3354/meps302049.

Dietrich, W. (2003). *Natural grace : the charm, wonder, and lessons of pacific northwest animals and plants*. Retrieved from https://ebookcentral.proquest.com

Eisenberg, Cristina. The Wolf's Tooth : Keystone Predators, Trophic Cascades, and Biodiversity, Island Press, 2014. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/washington/detail.action?docID=3317488.

Freedman, B. (2004). Kelp Forests. In K. L. Lerner & B. W. Lerner (Eds.), *The Gale Encyclopedia of Science* (3rd ed., Vol. 3, pp. 2236-2237). Detroit: Gale. Retrieved from http://link.galegroup.com.offcampus.lib.washington.edu/apps/doc/CX3418501278/GVRL?u=wash_main&sid=GVRL&xid=6fdf4786

Heery, Eliza. Urchin Takeover? Urban Marine Ecology. 2015. Retrieved from: http://urbanmarineecology.org/urchin-take-over/

Kriesel, W., Landry, C., & Keeler, A. (2000). *Costs of Coastal Hazards: Evidence from the Property Market* [Scholarly project]. Retrieved January 15, 2018, from https://ageconsearch.umn.edu/bitstream/21745/1/sp00kr01

Kritzer, J. P., & Sale, P. F. (2006). *Marine metapopulations*. Retrieved from https://ebookcentral.proquest.com

Mumford, Thomas F. (2007). Kelp and Eelgrass in Puget Sound. *Army Corps of Engineers Technical Report*. Retrieved from: http://www.pugetsoundnearshore.org/technical_papers/kelp.pdf

Schiel, D. R., & Foster, M. S. (2015). *The biology and ecology of giant kelp forests*. Retrieved from https://ebookcentral.proquest.com

Steneck, R., Graham, M., Bourque, B., Corbett, D., Erlandson, J., Estes, J., & Tegner, M. (2002). Kelp forest ecosystems: Biodiversity, stability, resilience and future. *Environmental Conservation, 29*(4), 436-459. doi:10.1017/S0376892902000322

Wheeler, William N. (1990) Kelp Forests of British Columbia: A Unique Resource. *Bamfield Marine Station*. Retrieved from: ftp://ww4.dnr.wa.gov/aqr/SVMP/For%20Tom/Kelp%20Forests%20of%20British%20Columbia.pdf

Literature Review: Eelgrass Beds

Introduction

Zostera marina, commonly referred to as "eelgrass", is a perennial, flowering sea grass which thrives in intertidal and shallow subtidal regions of temperate marine zones (Mumford 2007, Thayer 1977). It is a rhizomatous plant, meaning that its roots grow laterally beneath soil and interlock, forming a mat of roots that can reproduce by sending up new shoots without the necessity for seeds (Mumford 2007). *Z. marina* has a very wide distribution in both the Pacific and Atlantic oceans, ranging from Alaska to Mexico on the west coast of the U.S., and from Greenland to North Carolina on the east coast (Thayer 1977). Despite its extensive geographic range, however, Thayer and Philips (1977) report that eelgrass meadows support surprisingly similar community structures, regardless of geographic location. That is, similar varieties of organisms occupy the same niches across most eelgrass communities. Thayer and Phillips describe the general community structure as follows: small organisms live on leaves and feed on algae and other microscopic organisms living on eelgrass blades, larger organisms with the ability to move freely between plants (such as decapods and fish) move within the meadows, and benthic invertebrates occupy the sandy bottom between the bases of eelgrass plants (1977). The habitat requirements for *Z. marina* include high light levels, cold temperatures, and sandy substrate. Due to its high light requirement, *Z. marina* is not usually found at depths below 10m. In deeper areas it has been found to grow up to 2 m, with a blade width of 1-2 inches, however, the average height of the plant is much lower, and average blade width is closer to 2-5 mm (Mumford 2007). While *Z. marina* is the most abundantly occurring seagrass in the greater Puget Sound (Christaen 2017), it is not the only species. Other species include the non-native seagrass *Z. japonica*, a widgeon grass *Ruppia maritima*, and three species of surfgrass (Mumford 2007). *Z. marina* meadows support a diverse array of marine fish and invertebrates, as well as some species of seabirds. However, the interactions with these species is somewhat unusual in that it is very rare for an organism to feed directly on the biomass of *Z. marina* itself, but rather most of the nutrients that *Z. marina* supplies to marine ecosystems is in the form of carbon and other nutrients released as detritus when the leaves of the plant decompose and slough off (Mumford 2007, Thayer 1977). In addition to the abundance of nutrients that *Z. marina* produces, it also provides excellent habitat to many species of marine organisms by creating drag in the water and reducing the impact of wave action, providing shelter and camouflage to certain cryptic species, and stabilizing substrate with its roots (Mumford 2007). *Z. marina* has been studied in locations all over the world, including locally in the Puget Sound, likely because of its unique community structure, high productivity, and ecosystem services. In this paper we will examine the scientific value, ecological value, and ecosystem services provided by *Z. marina* in the greater Puget Sound.

Scientific Value of *Z. marina*

A large amount of research has been done as to the geographic expanse and community structure of eelgrass meadows, but not extensively within Puget Sound. One exception was a very successful measure of *Z. marina* expanse in Padilla Bay estuary in 1989 which determined that, among the four most commonly occurring species of sea grass in the estuary, *Z. marina* was the most abundant, covering about 2,900 hectares (Douglas 1994). In addition to examining the expanse of *Z. marina* in Padilla Bay, the research paper discussed the carbon production of *Z. marina*, indicating that carbon production in Padilla Bay was 351 grams per m^2 (Douglas 1994). This is significant because it is further evidence that *Z. marina* meadows are extremely productive environments that contribute high amounts of nutrients to the surrounding waters. Other studies have found that *Z. marina* can be used as an indicator of health for ecosystems because it provides an abundance of ecosystem services (like carbon fixation) which help to create healthy ecosystems, and also because it is extremely sensitive to environmental stressors, meaning that *Z. marina*'s presence indicates an absence of stressors (Goehring 2015). Studies of the genetic composition of *Z. marina* indicate that populations within the Puget Sound are highly genetically homogenous, likely due to the fact that *Z. marina* can reproduce asexually (using rhizomes) as well as sexually (seed dispersal) (Mumford 2007). When organisms reproduce asexually, the offspring that result are genetically identical to their parent, which can result in genetic homogeneity and overall lower fitness to tolerate environmental stressors (Primack 2016). This is an important piece of information for conservationists because it indicates the importance of reducing environmental stressors to avoid a mass die-off of *Z. marina* due to lack of adaptability.

Ecological Value of *Z. marina*

Z. marina supports a wide variety of fish, invertebrate, and algae species within Puget Sound, as well as several seabird species, and while many species depend on *Z. marina* for nutrients, very few actually consume the biomass of *Z. marina* directly. For the most part, small invertebrates and fish feed on the algae that grows on blades of the *Z. marina* plant, or, in other cases, scavengers feed on the detritus produced from organic matter that sloughs off of *Z. marina* blades when they begin to break down (Thayer 1977). One notable exception, however, is the Brant goose (*Branta bernicla*) which feeds directly on the blades of *Z. marina* during its migration (Douglass 1994, Thayer 1977). One of the many reasons that *Z. marina* meadows provide such valuable habitat to such a wide variety of organisms is that they are incredibly productive ecosystems. As previously mentioned, they can generate immense amounts of organic carbon which serves as nutrients to other species of plants (Douglas 1994) which, in turn, provides nutrients to herbivores and scavengers feeding on the plants. They also take up nutrients from the substrate via their root system and bring them into their leaves, eventually releasing the nutrients back into the water to be fed on by other marine organisms (Thayer 1997). *Z. marina* plants are able to contribute these immense amounts of nutrients because they are fast-growing and able to replenish their lost biomass very quickly, further contributing to their reputation as, according to representatives from the Puget Sound Seagrass Monitoring, "Among the most productive, valuable habitats in the biosphere" (Christaen 2017). The ecological value of Z. *marina*'s productivity cannot be overstated, as its immense productivity in only one of its contributions to sub and intertidal ecosystems.

One of the better-known benefits of Z. *marina* ecosystems is its three-dimensional structure which provides habitat and protection to many fish and invertebrate species that are vulnerable to predation. Notable species that utilize this three-dimensional structure are Pacific herring which enter Z. *marina* meadows in winter and spring to spawn, silver salmon which utilize meadows as migratory corridors during juvenile stages of life, and bivalves and crabs which use meadows as a nursery (Mumford 2007, Thayer 1977). Z. *marina* meadows are ideal nursery areas for juvenile fish and invertebrates because they provide stable substrate, protection from predators, abundant nutrients, and refuge from wave action by creating drag in the water, slowing it down (Thayer 1977). The reduction water movement in Z. *marina* meadows is of particular interest because, in addition to providing shelter to organisms that may not be able to survive high amounts of wave action, the decrease in water movement tends to cause phytoplankton and zooplankton to settle out of the water and take up residence within the meadow (Thayer 1977). This is an important process to take note of because not only does the settlement of phyto and zooplankton provide food to organisms within the Z. *marina* beds, but some of the zooplankton may also consist of larval stages of larger fish and invertebrates which may grow to adulthood and become residents of that Z. *marina* community. Another important service that Z. *marina* provides to marine ecosystems is substrate stabilization caused by the thick mat of rhizomatous root systems which bind the sediments together, minimizing coastal erosion and limiting movement of sandy substrate (Thayer 1977).

All of the previously mentioned ecological benefits of Z. *marina* meadows are extremely important to local marine ecosystems, and many researchers are now finding new applications for these highly productive ecosystems, including a potential method of mitigating ocean acidification (Tejeda 2014).

Ocean acidification is the process by which atmospheric carbon dioxide (CO2) is absorbed into the ocean and decreases the overall pH of the water. While some experiments within Puget Sound have indicated that pH levels in water increased after passing over *Z. marina* beds, indicating that CO_2 was being utilized in photosynthesis and thus, removed from the water, other tests have not shown any significant difference in the rate of change of pH over time in *Z. marina* beds. This is not to say that *Z. marina* is not a viable carbon sink, but rather it is an indication that variation in geography and other physical aspects of a location may influence the degree to which *Z. marina* is able to increase pH levels in the water (Tejeda 2014). It is important that further research be conducted to understand the role that photosynthetic marine plants can play in reducing the impacts of ocean acidification because maximizing its impacts could have global applications for reducing ocean acidification, thereby preserving many of the species (namely shellfish) whose populations are being directly affected (Tejeda 2014).

***Z. marina* Ecosystem Services and Threats**

Of all of the services that *Z. marina* meadows provide, their economic value is likely the most well-documented. Much in the same way that marine organisms do not derive their nutrients directly from the *Z marina* plant, humans do not capitalize directly on the plant itself, but rather the ecosystem services that it provides, such as providing shelter to various commercial fish and shellfish species, and minimizing substrate erosion (Mumford 2007, Thayer 1977). Some noteworthy commercial fisheries supported by *Z. marina* meadows include Pacific herring-a common baitfish and prey species, English sole, striped seaperch, fingerling stages of silver and chum salmon, Geoduck clam, steamer (softshell) clam, Washington butter clam, and Dungeness crab (Douglas 1994, Thayer 1977). In addition to the various fisheries being supported by *Z. marina*, it has also historically been used by Native American peoples as a ceremonial material and as hunting ground (Mumford 2007). With commercial fisheries (and consumers) benefitting so extensively from the abundance of fish species that *Z. marina* supports, as well as coastal developers benefitting from the sediment stabilization, some estimates of the monetary value of *Z. marina* have suggested that it is with $19,004 per hectare per year in the Puget Sound (Mumford 2007). This figure represents a massive contribution to the economy of the great Puget Sound, especially considering that *Z. marina* has been estimated to cover 200 km^2 (20,000 hectares) of Puget Sound shoreline (Tejeda 2014). While it is valuable to have a monetary figure representing the value of this marine habitat, it is also important to recognize that without *Z. marina* many of the important fishery species we assign direct monetary value to would not survive, and that loss would equate to a much higher economic loss than the $19,004 per hectare that *Z. marina* is supposedly worth.

With all of the immensely important ecosystem services, ecological benefits, and scientific value that *Z. marina* meadows hold, it is extremely important that conservation efforts be put in place to ensure that these valuable habitats are not lost to environmental stressors. Unfortunately, *Z. marina* is highly susceptible to environmental (particularly anthropogenic) stressors and can die off quickly when conditions are not suitable (Christaen 2017, Goehring 2015). Some very harmful anthropogenic stressors that are causing reductions in *Z. marina* expanse in Puget Sound include shoreline development, eutrophication, sediment loading, bottom trawling, and vessel mooring and anchoring (Goehring 2015, Kritzer 2006). Shoreline development and sediment loading often go hand-in-hand, with sediments being kicked-up in construction and burying *Z. marina* plants, or diminishing sediment quality, reducing the amount of nutrients that *Z. marina* can obtain from the substrate (Christaen 2017). Eutrophication often occurs as a result of human pollutants and runoff, and inhibits *Z. marina*'s ability to photosynthesize by blocking most of the light from the surface (Christaen 2017). Additionally, nutrient-loading and subsequent eutrophication can increase epiphytic growth on *Z. marina* blades, once again inhibiting growth and photosynthesis (Goehring 2015). Finally, the most direct and avoidable form of stress placed on *Z. marina* by humans is bottom trawling, mooring, and anchoring. Trawlers, moorings, and anchors all disturb the sediment by sinking into or scraping along the sea floor, ripping up clumps of rhizomatous root mats and *Z. marina* blades in the process (Goehring 2015). These highly destructive practices, when implemented in *Z. marina* beds, can be catastrophic to *Z. marina* populations and communities. Other, lesser researched threats to *Z. marina* communities include over-water and in-water structures (such as bridges) which block sunlight to previously vegetation-rich marine ecosystems (Goehring 2015), as well as a virus known as "eelgrass wasting disease" which produces necrotic lesions on the blades of *Z. marina* and can cause massive die-offs (mostly recorded on East-coast, though the disease has been isolated in Puget Sound as well) (Short 1987).

Conservation Efforts and Conclusion

While the abundance of anthropogenic stressors acting on *Z. marina* can be overwhelming, there are also a wide variety of conservation efforts currently in place with the goal of *Z. marina* preservation and restoration. Jefferson County has implemented "Voluntary No Anchor Zones" in an attempt to reduce eelgrass destruction from mooring and anchors, and they now protect 52 acres of *Z. marina* along the waterfront (jeffersonmrc.org). Other methods of preserving *Z. marina* have included restoration projects which involve re-planting *Z. marina* in areas where it has grown in the past, enhancement projects where sparse occurrences of *Z. marina* are supplemented with transplants, and creation projects where *Z. marina* is placed in areas where it has not previously existed (Thom et. al. 2008). There have been other proposed ideas as to how to support the growth and health of *Z. marina* beds that have not yet been implemented, including planning in-water and over-water structures to avoid blocking light to *Z. marina* habitat, modifying existing structures to minimize their impact on *Z. marina*, encouraging expansion of *Z. marina* compatible boating infrastructure (like the "Voluntary No Anchor Zones" mentioned above), and restoring coastlines and tidal wetlands to allow for *Z. marina* reestablishment (Goehring 2015). While all of these potential methods could make a huge difference as far as *Z. marina* health and reestablishment, it is important to ensure that these restoration projects do not create undue burden or expense on residents and marine industries, as public support is incredibly important in implementation and compliance, as evidenced by the 98% compliance rate for Voluntary No Anchor Zones in Jefferson county (jeffersonmrc.org). Community engagement and support is a major influence on which projects get funding and approval, therefore it is extremely valuable to invest time into community education on the value and function of *Z. marina* ecosystems.

Of course, because *Z. marina* is such a valuable and aesthetically pleasing ecosystem it has been relatively well-researched (compared to other, similar ecosystems such as kelp forests) and has become something of a flagship species for marine habitat conservation. It is incredibly valuable to have a well-known marine plant species be a representative for marine conservation in the Puget Sound because it encourages the conservation of not just the *Z. marina* species, but all of the species that it supports. Additionally, further research on *Z. marina* ecosystems may encourage expansion of conservation efforts into other important marine ecosystems in Puget Sound.

Important Figures

Community structure of *Z. marina* beds

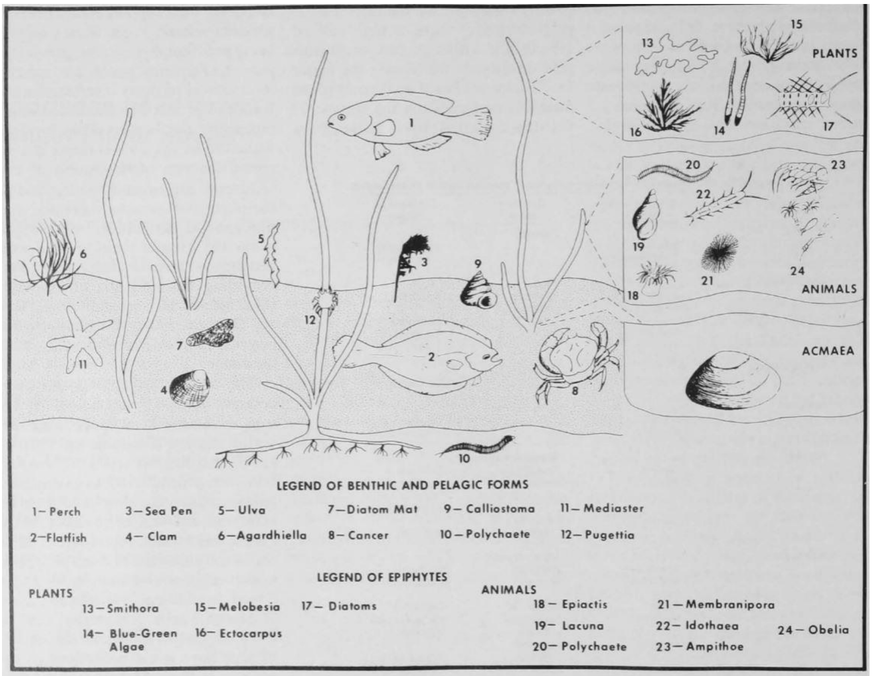

Figure 2.—Diagram of an eelgrass community showing some of the more conspicuous associated organisms in Puget Sound.

(Thayer 1977)

References:

Christaen, B., Ferrier L., Dowty, P., Gaeckle, Jeff., Berry, H. (2017). Puget Sound Seagrass Monitoring. *Nearshore Habitat Program-Aquatic Resources Division*. Retrieved from: http://file.dnr.wa.gov/publications/aqr_nrsh_psseagrass_report_2017.pdf

Douglas A. Bulthuis, Distribution of seagrasses in a North Puget Sound estuary: Padilla Bay. 1994. Washington, USA, Aquatic Botany, Volume 50, Issue 1, 1995, Pages 99-105, ISSN 0304-3770, https://doi.org/10.1016/0304-3770(94)00443-P. (http://www.sciencedirect.com/science/article/pii/030437709400443P)

Goehring, M., Gaeckle, J., Hass, T., & Brandt, S. (2015, February). *Puget Sound Eelgrass (Zostera marina) Recovery Strategy* [Scholarly project]. In *Dnr.wa.org*. Retrieved from http://www.dnr.wa.gov/publications/aqr_nrsh_eelgrass_strategy_final.pdf

Kritzer, J. P., & Sale, P. F. (2006). *Marine metapopulations*. Retrieved from https://ebookcentral.proquest.com

Mumford, Thomas F. (2007). Kelp and Eelgrass in Puget Sound. *Army Corps of Engineers Technical Report*. Retrieved from: http://www.pugetsoundnearshore.org/technical_papers/kelp.pdf

Primack, R. B., & Sher, A. (2016). *Introduction to conservation biology*. Massachusetts, U.S.A: Sinauer Associates, Inc. .

Short, F., Muehlstein, L., & Porter, D. (1987). Eelgrass Wasting Disease: Cause and Recurrence of a Marine Epidemic. *Biological Bulletin, 173*(3), 557-562. Doi:10.2307/1541701

Tejeda, C. (2014). *AN ANALYSIS OF THE EFFECTS OF EELGRASS BEDS ON THE WATER CHEMISTRY OF PORT GAMBLE, PUGET SOUND* (Unpublished master's thesis). Evergreen State College.

Thayer, G. W., & Phillips, R. C. (1977, November). *Importance of Eelgrass Beds in Puget Sound*[Scholarly project]. In *Noaa.org*. Retrieved January 16, 2018, from http://spo.nmfs.noaa.gov/mfr3911/mfr39114.pdf

Thom, R., Gaeckle, J., Borde, A., Anderson, M., Boyle, M., Durance, C., . . . Rumrill, S. (2008, August). Eelgrass (Zostera Marina L) Restoration in the Pacific Northwest: Recommendations to Improve Project Success. Retrieved from https://www.wsdot.wa.gov/research/reports/fullreports/706.1.pdf

Voluntary No Anchor Zones. (n.d.). Retrieved January 26, 2018, from http://www.jeffersonmrc.org/projects/voluntary-no-anchor-zones/

Literature Review: Olympia Oyster Beds

Amani Moyer-Ali

The Olympia Oyster (*Ostrea lurida*) is the only species of oyster native to the Pacific Northwest and British Columbia. This small oyster species occurs along the west coast of North America and thrives in brackish water such as saltwater lagoons, estuaries, and tidal flats (CRD, Peter-Contesse 2005). While this oyster was once a dominant feature of the Puget Sound, habitat destruction and over-harvesting between the late 1800s and the 1920s decimated populations to the point that today, the Olympia oyster only exists in small, isolated pockets along the coast (Brumbaugh 2009).

Prior to 1800 the Olympia Oyster was a consistent food source for Native American tribes and is known to Native people today as a once abundant resource that has been exploited to the point of decimation (Solomon 2010). Researchers estimate that before over-harvesting practices began, Olympia Oysters spanned 10,000-20,000 acres in Puget Sound, making up 13-26% of total Puget Sound intertidal area (Restoration Fund). When over-fishing ensued beginning with the California Gold Rush in 1849, populations did not recover at a sustainable rate and Olympia Oyster cultivation projects were implemented to increase populations (Solomon 2010). When these efforts were not successful long-term, the Japanese (or Pacific) Oyster was introduced in 1905 to increase oyster yield in the Puget Sound (Solomon 2010). By 1927 paper mills became abundant near Puget Sound coastlines and toxic outputs from mills ran off into the Puget Sound waters, harming and killing native oysters, and the near collapse of the native oyster fishery was imminent by the late 1950s (Solomon 2010). Today, numerous short and long-term restoration projects are being conducted in an attempt to boost Olympia oyster populations to at least a portion of their former extent.

Unique Features of the Olympia Oyster

The Olympia Oyster is a relatively small species of oyster, with shell width reaching a max of about 60-90mm (CRD, Gillespie 2011). This species is categorized by its flat, irregular-ovoid shape, and iridescent coloration ranging from white to green to purple (CRD, Buselco 1990). Olympia oysters thrive in saltwater areas with consistent freshwater influence and salinity no lower than 23-24 ppt (Peter-Contesse 2005). They will only reproduce at a critical temperature range between 12.5-16°C (Peter-Contesse 2005, Buselco 1990) and reproduction occurs larviparously, meaning that offspring develop as larvae, rather than inside of eggs (Buselco 1990). Fertilization and early development of larvae occurs in the mantle cavity of the female, and after 10-12 days the larvae are released into the water (Buselco 1990) where they eventually settle out onto hard substrate—ideally the shells of other oysters—and remain sedentary for the remainder of their life cycle (CRD). Olympia oysters are alternating hermaphrodites, meaning that they possess both male and female reproductive organs and alternate back and forth depending on environmental conditions (CRD). One female Olympia oyster may release between 250,000 and 300,000 larvae at a time (Gillespie 2011). Over time, the shells of living and dead oysters begin piling up creating a textured, vertical reef structure which can be utilized by a variety of marine organisms as shelter and feeding ground (Brumbaugh 2009).

Ecosystem Services

The most commonly known ecosystem service provided by Olympia oysters (and most other bivalves) is water filtration. Oysters are filter-feeders, meaning that they siphon water and collect nutrients from detritus and plankton suspended in the water, and then release the now-filtered water back into the environment (CRD, Northwest Straits). This process not only helps to clean the water of potentially harmful chemicals and algae, but also reduces turbidity allowing photosynthetic marine organisms like kelp and eelgrass to have access to more sunlight and, in turn, increase survival (CRD). Additionally, Olympia oysters, when undisturbed by harvesting, settle out of their larval stages onto the shells of other Olympia oysters, eventually creating a biogenic reef structure which provides habitat to many nearshore organisms such as Dungeness and rock crabs, juvenile salmon, perch and a variety of bottom fishes (Northwest Straits), all of which are important fishery species.

This reef structure can also provide shoreline stabilization by anchoring substrate and preventing erosion or sedimentation (Brumbaugh 2009). It is also worth noting that before the near-collapse of the Olympia oyster harvesting industry, Olympia oysters contributed immensely to the economy of Puget Sound fisheries (Northwest Straits).

Threats, Conservation, and Conclusion

The most frequently-discussed threat to Olympia oyster populations is the over-harvesting of oysters beginning in the mid to late 1800s, and while this did deal a significant blow to oyster populations, it was actually the removal of the reef structure (made up of Olympia oyster shells) which prevented the re-establishment of former Olympia oyster populations (Solomon 2010). In 2004, ecologists discovered that Olympia oysters were establishing and growing on the shells of Pacific oysters but could not be found anywhere in the surrounding muddy substrate (Solomon 2010). This led to the conclusion that Olympia oyster larvae require hard substrate to settle out and begin to grow (Solomon 2010). With this new information, ecologists and conservationists began a 10-year long project placing empty Pacific oyster shells in historic Olympia oyster grounds to encourage native oyster growth and preserve the remaining Olympia oyster genetic stock (Solomon 2010). Other anthropogenic stressors also threaten Olympia oyster reestablishment such as the effects of pollution, rising ocean temperatures, and ocean acidification. Experiments by Hettinger et. al. published in 2012 found that exposing larval Olympia oysters to low pH water (7.8 vs. 8.0) showed a 15% decrease in shell growth rate in settling larvae, but interestingly, these effects carried over into later life stages and they found a 41% decrease in shell growth-rate in the juvenile stage (Hettinger et. al. 2012). This is important because it indicates that even if larval oysters do survive to the juvenile stage, the stressors of their larval environment will continue to negatively impact their growth and we may not even realize the extent to which a stressor is impacting a population until it struggles in a later life stage, thereby making it more difficult to identify the initial stressor (Hettinger et. al. 2012).

Although Olympia oyster populations have been drastically diminished as a result of anthropogenic stressors, breakthroughs in understanding the limiting resources (such as hard substrate) and direct threats to larval and juvenile survival are helping researchers to find effective means of conserving this historically important native species. Olympia oysters are no longer fished commercially (CRD) and many organizations are conducting long-term restoration projects, such as the Puget Sound Restoration Fund which conducted the previously mentioned 10-year project aimed at distributing empty Pacific oyster shells into historic oyster bed areas to encourage re-establishment of Olympia oyster reefs (Solomon 2010). The parameters set forth by Bible et al. in the publication *A Guide to Olympia Oyster Restoration* detail that for an Olympia oyster population to be sustainable, it must have:

- Large adult population size
- High density on hard substrate
- High/reliable rate of juvenile recruitment
- Diversity of size
- High survival rate

(Bible et al. 2015)

These are the goals that conservationists are working toward for all future Olympia oyster populations. While some small populations of Olympia oysters today do exhibit many of these characteristics, they are rare and fragmented (Bible et al. 2015). Estimates of today's Olympia oyster populations are about 1% of historic levels (Bible et al. 2015), so while the small-scale populations within protected embayments may exhibit signs of a healthy oyster bed, they are not rebuilding the vast, productive reef structure that was so prevalent 150 years ago. Additionally, there are plenty of Olympia oyster beds in Puget Sound that are struggling to maintain populations due to low juvenile recruitment (Bible et al. 2015). While this information does seem discouraging, it merely indicates that Olympia oyster populations will not recover independently. Restoration attempts using the information currently available on Olympia oysters have yielded increased juvenile recruitment and increasingly successful Olympia oyster populations in historic oyster bed areas, indicating that restoration of this important native species, which provides habitat to numerous fish and invertebrates, in addition to other vital ecosystem services, is absolutely possible with sufficient effort and education.

Works Cited

Bible, Jillian., Briley, Sara., Ceballos, Elena., Chang, Andrew., Cheng, Brian., Deck, Anna., Ferner, Matt., Grosholz, Ted., Helms, Alicia., Latta, Marilyn., Wasson, Kerstin., Yednock, Bree., Zabin, Chela., Zacherl, Danielle. June 2015. *A Guide to Olympia Oyster Restoration and Conservation.*

Capital Regional District. *Olympia Oysters.* Retrieved from: https://www.crd.bc.ca/education/our-environment/wildlife-plants/marine-species/olympia-oysters

Hettinger, A., Sanford, E., Hill, T., Russell, A., Sato, K., Hoey, J., . . . Gaylord, B. (2012). Persistent carry-over effects of planktonic exposure to ocean acidification in the Olympia oyster. Ecology,93(12), 2758-2768. Retrieved from http://www.jstor.org/stable/41739632

Northwest Straits Commission. Olympia Oyster Restoration. Retrieved from: http://www.nwstraits.org/our-work/olympia-oyster-restoration/

Peter-Contesse, T., Peabody, B. (August 2005). Reestablishing Olympia Oyster Populations in Puget Sound, Washington. Retrieved from: https://wsg.washington.edu/wordpress/wp-content/uploads/Reestablishing-Olympia-Oyster.pdf

Puget Sound Restoration Fund. *Olympia Oyster Restoration.* March 2015. Retrieved from: http://www.restorationfund.org/projects/olympiaoyster

Robert D. Brumbaugh and Loren D. Coen. Contemporary Approaches for Small-Scale Oyster Reef Restoration to Address Substrate Versus Recruitment Limitation: A Review and Comments Relevant for the Olympia Oyster, Ostrea lurida Carpenter 1864. *Journal of Shellfish Research* **2009** 28 (1), 147-161

Solomon, Shelly. (2010). "Almost Lost But Not Forgotten-Olympia Oyster". *Leapfrog Films*. Available from: www.restorationfund.org/projects/olympiaoyster

Literature Review: Rocky Subtidal Habitat

Introduction

Rocky subtidal habitat is defined by the Oregon Conservation Strategy as all hard substrate at the ocean floor, including cobble, boulders, bedrock, or hard substrate of human origin such as rock jetties or sunken ships (2016). Other names for rocky subtidal habitat include reefs, rocky reefs, pinnacles, "hard bottom", or subtidal rock-walls (Oregon Conservation Strategy 2016, WDFW 1994). While the substrate and depth of rocky subtidal habitats can be extremely varied, this habitat type tends to be one of the most diverse in terms of species richness when compared to rocky intertidal, sandy intertidal, and sandy subtidal habitats (Grantham et. al. 2003). Rocky subtidal habitat has been known to support countless species of fish, invertebrates, and algae (WDFW 1994) and could provide a buffer for marine species from the effects of rising ocean temperatures (Sebens). Rocky subtidal habitats can be found on almost every coastline in the world, and many reefs are simply extensions of shorelines or islands (Oregon Conservation Strategy 2016). The physical characteristics of a rocky subtidal habitat are heavily influenced by wave action and placement in the water column (Oregon Conservation Strategy 2016). Reefs that are closer to the shoreline (also called "nearshore systems") tend to bear the impact of harsher wave action which leads to more drastic direct erosion, sand scour, or burial of reefs than "offshore systems" (Oregon Conservation Strategy 2016). The boundary between nearshore and offshore systems is identified by the Oregon Conservation Strategy as the 30m depth contour (2016), meaning that all reef habitat located above a depth of 30m is considered "nearshore" while everything below the 30m line is considered offshore; the main difference between the two systems (aside from the differing wave action) being that nearshore has higher light penetration, allowing for kelp and other algae to grow (Oregon Conservation Strategy 2016). The growth of kelp and algae is also supported by the stronger currents and wave action (see kelp literature review for more information on the relationship between high water flow and kelp growth). Some fish species rely on both nearshore and offshore habitat depending on their life stage, for example canary and yelloweye rockfish move from nearshore to offshore as they grow, while kelp greenlings, cabezon, and grass rockfish remain in nearshore habitat for their whole lives (Oregon Conservation Strategy 2016). Some associated fish species which may pass through the habitat without necessarily relying on it include herring, smelt, sharks, ratfish, and salmon (Oregon Conservation Strategy 2016).

Scientific Studies/Habitat

Due to its extraordinary biological diversity, several rocky subtidal habitats have been designated as marine preserves in order to formally protect these ecosystems. Sund rock in Hood Canal is one of these marine preserves which was designated to protect the rare natural bedrock and boulder habitats (WDFW 1994). Since it's designation as a marine preserve in 1994, a wide variety of commercial fishery and non-commercial fish and invertebrate species have been recorded living on Sund rock including:

Fish	Mobile Invertebrates	Sessile Invertebrates
o Copper rockfish (*Sebastes caurinus*) o Brown rockfish (*S. auriculatus*) o Yelloweye rockfish (*S. ruberimus*) o Vermilion rockfish (*S. miniatus*)	o Giant Pacific octopus (*Enteroctopus dofleini*) o Red sea cucumber (*Parastichopus californicus*) o Red sea urchin (*Strongylocentrotus franciscanus*)	o Sea sponges o Sea anemones o Barnacles o Bryozoans o Hydrozoans o Tunicates o Coldwater corals

○ Black rockfish (*S. melanops*) ○ Puget Sound rockfish (*S. emphaeus*) ○ Quillback rockfish (*S. maliger*) ○ Wolfeel (*Anarrichthys ocellatus*) ○ Lingcod (*Ophiodon elongatus*) ○ Pile perch (R*hacochilus vacca*) ○ Striped seaperch (*Embiotoca lateralis*) ○ Shiner perch (*Cymatogaster aggregata*). ○ Blackeye goby (*Coryphopterus nicholsii*)	○ Sunflower sea star (*Pisaster helianthoides*) ○ Red rock crab (*Cancer productus*) ○ Squat lobster (*Munida quadrispina*)	

(Compiled using information from Oregon Conservation Strategy 2016 and WDFW 1994)

Each of these species are important ecological participants, and while studies have not been conducted on each of their roles within rocky subtidal habitats, several have been the focus of studies on the importance of rocky subtidal habitat to the success of the species. One study by Elahi on the productivity and ecology of rocky subtidal habitats indicated that the presence of urchins and chitons determines the structure of rock-wall subtidal communities because they graze on spatially dominant ascidians and free up substrate for other sessile invertebrates (Elahi 2013). This, in turn, increases the overall species richness of the habitat by allowing a wider variety of species to exist within the available space. Studies like Elahi's help to contribute to our understanding of why rocky subtidal habitats are so biologically diverse.

Additionally, some studies have indicated that since the approximately 0.9°C rise in temperature in the Salish Sea in the past 40 years there has not been a significant change in biodiversity (Elahi 2013, Sebens). This indicates that rocky subtidal habitats could act as a refuge for marine organisms from the negative impacts of rising ocean temperatures, however, more research must be done to understand how this process works (Sebens).

Ecosystem Services

Similar to previously mentioned habitats such as kelp forests, eelgrass beds, and Olympia oyster reefs, rocky subtidal habitats provide vital resources to important commercial fishery species such as rockfish, lingcod, and shrimp (WDFW 1994). In an interview for a University of Washington Publication, Dr. Kenneth Sebens discussed the detrimental affect that fishing in rocky subtidal zones can have on fishery stock, citing a trophic cascade involving the copper rockfish as an example. The copper rockfish is the most abundant demersal predatory fish encountered in the Puget Sound, and in areas where copper rockfish stocks have been greatly depleted, there was evidence of greater abundance of prey species like shrimp (Sebens). Conversely, areas designated as marine preserves showed larger abundance of predatory fish and fewer shrimp (Sebens). He indicates that reducing, or better yet, eliminating fishing in rocky subtidal areas could result in a significant rebound of rockfish populations (Sebens).

Additional ecosystem services of rocky subtidal include its potential to minimize impacts of climate change for marine organisms, and the fact that it can act as a buffer for wave action and strong local currents by creating drag in the water (Elahi 2003, Oregon Conservation Strategy 2016). While these ecosystem services do not necessarily provide direct economic value to humans, it is in our best interest to encourage protection of marine ecosystems which support important fishery species like rockfish and lingcod in order to ensure the sustainability of these fisheries.

Another minor economic contribution of of rocky subtidal habitat is its popularity among divers as a sightseeing venture, especially within marine preserves which support immense biological diversity (Oregon Conservation Strategy 2016). Likewise, recreational fishers enjoy fishing in rocky subtidal areas because of the likely presence of edible fish species, and researchers prefer rocky subtidal habitat to study specific species interactions because the ecosystems tend to be relatively undisturbed and representative of natural habitats (Oregon Conservation Strategy 2016).

Threats and Conservation Status

The most prevalent threats to the structure of rocky subtidal habitat are destructive fishing practices such as bottom trawling, which destroys the reef structure utilized by fish and invertebrates for shelter (NOAA). While trawling is an immense threat to the underlying structure of the reef, there is also intense pressure on the biological components of rocky subtidal habitat such as deep-water corals and other calcifying invertebrates which are struggling to reproduce and grow due to ocean acidification (NOAA). The bigger threat at this point in time, though, is over-fishing. As mentioned in Dr. Sebens' interview, the removal of important predator fish species like lingcod and rockfish can have detrimental effects on trophic interactions within the habitat and can lead to loss of biodiversity (Sebens).

Although there are significant threats to this important marine ecosystem, it is important to note the efforts being made by conservationists to protect these ecosystems. First, the designation of rocky subtidal habitats as marine preserves has been shown to preserve some of the biodiversity of these systems which may be lost elsewhere due to over-fishing (Sebens). It is also possible to designate voluntary no-take zones for marine habitats, although compliance with these zones tends to be much lower than with marine preserves (Sebens). Additionally, the Pacific Fishery Management Council has identified rocky reef habitat as a "Habitat Area of Particular Concern" or, HAPC, which identifies it as an area of high priority for additional conservation, and while this distinction does not guarantee higher protections, it does increase its prioritization for conservation efforts (NOAA).

Works Cited:

Elahi, Robin. Diversity and structure of subtidal rock walls in the Salish Sea: the roles of grazing, oceanography, and long-term change. (2013). https://digital.lib.washington.edu/researchworks/handle/1773/22442

Grantham, B., Eckert, G., & Shanks, A. (2003). Dispersal Potential of Marine Invertebrates in Diverse Habitats. *Ecological Applications, 13*(1), S108-S116. Retrieved from http://www.jstor.org.offcampus.lib.washington.edu/stable/3100001

NOAA. Rocky Reef. Retrieved from: http://www.westcoast.fisheries.noaa.gov/habitat/fish_habitat/rocky_reef_habitat_types.html

Oregon Conservation Strategy. Rocky Subtidal. (2016). Retrieved from: http://www.oregonconservationstrategy.org/oregon-nearshore-strategy/habitats/rocky-subtidal/

Sebens KP. Safeguarding Marine Species. faculty.washington.edu. [accessed 2018 Feb 22]. http://faculty.washington.edu/sebens/pages/innovation.pdf

WDFW. Marine Protected Areas within Puget Sound—Sund Rock Conservation Area. 1994. https://wdfw.wa.gov/fishing/mpa/sund_rock.html.

Habitalk! Kelp Forests

Goals:

- Demonstrate the rich, active ecosystems present in kelp forests
- Convey the importance of kelp forest ecosystems to Salish Sea
- Discuss anthropogenic threats to kelp forests
- Discuss conservation efforts

Audience:

- Visitors to PTMSC, all ages

Materials:

- Fresh piece of bull kelp
- Krill

Demonstration:

Pass around a piece of live Bull kelp and have visitors feel the fronds and guess how an animal might use it. Ask visitors what parts of the kelp might provide protection/food to different organisms (holdfasts can be shelter for small inverts, rockfish and snailfish like to hide in the fronds, urchins eat the fronds/stipe, etc.)

Talking Points:

Intro to Kelp Forests:

- Kelp forests are large collections of kelp (a brown algae) growing vertically from rocky substrate in the ocean.
- Kelp consists of three main components: 1) the holdfast, which anchors the base of the kelp to a rock, 2) the stipe, which is a long, often gas-filled tube which helps the top of the kelp float, and 3) the blades or fronds, which act like leaves, photosynthesizing to create nutrients for the kelp.
    - Why might the kelp want to float up near the surface? (Answer: to stay in the photic zone and get the most sunlight to photosynthesize)
- Kelp forests create three-dimensional structure, much like trees on land, which provides habitat to marine organisms of all shapes and sizes.
    - Like forests, there are canopy-forming kelps, which act like trees, and shorter, groundcover kelp which create mid and lower-stories to the kelp forest, like shrubs and groundcover on land.
- The kelp that we often find on Puget Sound beaches is called Bull kelp, or *Nereocystis luetkeana*, but there is another species commonly found just outside of Puget Sound called Giant kelp or *Macrocystis pyrifera* which is abundant all along the west coast of North America (point out *Nereocystis* and *Macrocystis* in tank).

Why do we care about kelp?

- Kelp supports many species of fish that we rely on for food such as salmon and rockfish. These fish use the fronds of the kelp to stay hidden from potential predators like larger fish or marine mammals.
- *Before the next step, put some krill in the tank to get fish and inverts moving around so we can see them.*
- Kelp forests also support diverse and healthy ecosystems like the one modeled in this tank. Some of the organisms in this tank swim among the fronds (shiner perch), some cling to the stipe and fronds and wait for food to come along (kelp crabs), some crawl along the bottom between the holdfasts looking for food to scavenge (Dungeness crabs, cucumbers), and some even eat the kelp itself! (urchins).
    - All of these organisms rely on the kelp in some way whether it be food, protection, or nursery grounds for their young.
- As humans, we also rely on kelp for some of our everyday needs, just like the organisms in this tank! Can you name a product you use that you think might contain kelp?
    - Answer: Who here uses toothpaste? Does anyone here eat ice cream? What about pudding? All of those things contain a derivative of kelp called algin, which thickens things like toothpaste and ice cream and gives them their thick, gooey consistency.

Kelp Forest Threats:

- Now that we know how important kelp forests are, it's important to talk about some things that may be threatening kelp. Kelp gets eaten by a variety of different organisms, but the most common is the sea urchin.
    - Urchins can be found all over kelp forests in Puget Sound, and they have the ability, in large numbers, to totally wipe out entire kelp forests, creating areas with no kelp known as "urchin barrens". What stops them from doing this? Predators. Animals like sunflower stars and sea otters eat urchins and control populations, ensuring that they do not grow to large enough numbers to eat all the kelp.
    - Unfortunately, sea otters do not occur in this area in high enough numbers to control urchin populations due to over-hunting by humans in the 1800s.
    - It's believed that sunflower sea stars took the place of otters as the main predator of urchins in the Puget Sound, but with the epidemic of sea star wasting disease in the last several years, urchin populations spiked again. It is unclear, as of yet, how SSW will impact urchin populations in the Salish Sea.

How are we helping?

- Researchers are looking into the best methods of transplanting kelp to create new kelp forests and restore historic kelp forest areas.
- Sustainable kelp forest farms are being created to ensure that kelp harvest does not negatively impact kelp forest ecosystems.
- Sustainable harvest methods have been implemented at kelp harvest sites in California to ensure that the kelp is able to re-grow and remain suitable habitat.

What can you take away?

- We rely on kelp forests just like the fish do!
- Taking away one species from a food web can have a domino effect on all the rest of the species in the web (trophic cascade).
- Kelp forests=cool kelp forest critters.

Habitalk! Eelgrass Beds

Goals:

- Describe the ways in which eelgrass contributes to various marine ecosystems
- To communicate the importance of eelgrass to commercial fishery species
- Help visitors understand the reasons eelgrass habitat is diminishing
- Inform visitors about conservation efforts that they can take part in

Audience:

- Visitors to PTMSC, all ages

Materials:

- Krill

Talking Points:

Intro to Eelgrass:

- Eelgrass is a flowering sea grass that thrives in intertidal and subtidal regions.
- It is a rhizomatous plant, meaning that its roots grow laterally under the substrate and form a mat of roots. Their roots can also send up shoots to form new eelgrass plants, forming large networks of eelgrass meadows.
- The same species of eelgrass that we have here in the PNW also exists on the East Coast of North America!
- Eelgrass is just one of several species of seagrass in the Salish Sea, another common species is called surfgrass. The two are distinguishable by the substrate on which they grow: eelgrass requires soft, sandy substrate while surfgrass grows on hard substrate like rocks.

Why do we care about eelgrass?

- Eelgrass provides habitat to many, many different species of marine organisms. Many of the species that rely on eelgrass live there when they are very young (juvenile) because it is a good nursery habitat where small organisms can seek shelter from predators. Some of the important fishery species that you might recognize (and maybe eat!) like Dungeness crabs and salmon often live in eelgrass beds as juveniles.
- Another cool feature of eelgrass beds is that they contribute large amounts of nutrients to other marine ecosystems, as well as their own. There are very few species that actually eat the leaves of eelgrass, but when the leaves begin to break down and decay, tiny, nutrient-rich particles slough off and drift through the water where they can be consumed by filter-feeders like clams or eaten by small-mouthed fish like tubesnouts. This contribution of nutrients to the marine environment is part of what makes eelgrass so valuable to the Salish Sea.

Threats to Eelgrass

- Over the years the abundance of eelgrass meadows has declined.
    - What are some things that you can think of that might be threatening eelgrass survival?
        - Answer: shoreline development destroys habitat, anchoring can dredge up and destroy eelgrass plants and roots, overwater structures like bridges can reduce sunlight reaching eelgrass, construction causes sediments to get kicked up which can then settle out onto eelgrass plants and reduce ability to photosynthesize.

How are we helping?

- Transplanting eelgrass into historic eelgrass habitat can help replenish abundance.
- Protecting current eelgrass meadows by avoiding anchoring on or near them or disturbing sediment near them.
    - YOU can help by participating in Jefferson County's Voluntary No-Anchor Zones which exist to protect eelgrass beds.

What can you take away?

- Eelgrass is important to many marine species.
- We rely on eelgrass to protect important fishery species while they're young so that we can fish sustainably.
- Eelgrass meadows can be found in temperate waters all over the world, not just in the Pacific Northwest.

Demonstration:

Tell visitors that there are some fish species that blend in with the eelgrass environment and see how many of the "cryptic" species they can find. Examples: penpoint gunnels, pipefish, flatfish (on bottom). Then add some krill to the tank to get animals moving and see if visitors are able to find more that way.

Habitalk! Olympia Oyster Beds

Goals:

- Visitors learn the importance of Olympia Oyster beds to the Salish Sea.
- Visitors understand the value of native species restoration.
- Visitors learn about the many benefits of filter-feeding organisms on water clarity
- Visitors have some idea of how to distinguish Olympia Oysters from Pacific Oysters (size and shape).

Audience

- Visitors to the Port Townsend Marine Science Center (all ages)

Materials

- Tablet (if ready for use) with video of oysters cleaning up water already loaded.
- Example of Pacific oyster shell and Olympia oyster shell for comparison.

Talking Points

Intro to Olympia Oysters

- Olympia oysters are the only species of oyster native to the Pacific Northwest.
    - A native species is a species that naturally occurs in an area, without having been introduced to the area by human actions.
- Olympia oysters are a very small species of oyster whose color can range from white to green to purple.
- Oysters reproduce larviparously, meaning that their offspring are released as larvae which swim in the water as zooplankton until they find hard substrate like rocks or other oyster shells to settle onto.

Why do we care about Olympia Oysters?

- When larvae settle on other oyster shells, they can build up a reef structure after many generations which can provide habitat to other animals like fish and invertebrates.
- This oyster reef structure used to cover about 10,000 to 20,000 acres of Puget Sound intertidal area.
- The reef structure not only provides habitat to marine organisms but can also stabilize substrate to reduce erosion.
- *Demonstration: Begin to play video of oysters cleaning up water while talking.*
    - Oysters are filter-feeders, meaning that they siphon water and filter out the various particles to eat, while releasing clean, clear water. This is a time-lapse of oysters cleaning a tank full of water with lots of particles in it.
- Oysters contribute greatly to the marine ecosystem within the Salish Sea.

Threats

- Now that we understand the importance of Olympia oysters, we should talk about the things that are threatening them too. How many of you here have eaten an oyster before?

- Well in all likelihood, the species of oyster that you ate was not an Olympia oyster, but a non-native species called the Pacific oyster, which was brought here from Japan in 1905 to supplement the declining populations of Olympia oysters.
  - *Demonstration: show differences in Pacific oyster and Olympia oyster size/shape. Pacific oysters are more frilled and much larger, Olympias are flatter on one side, much smaller, iridescent green or purple.*
  - Why do you think that Olympia oyster populations might have been declining? (Answer: Due to over-harvesting)
- Oyster harvesters found that Olympia oyster populations continued to decline, and it wasn't until the early 2000s that researchers looking into Olympia oyster populations figured out why:
  - Remember how we said that oyster larvae need hard substrate to settle out onto? Well, when harvesting oysters for sale, the shells were taken along with the oysters, leaving only sandy or muddy substrate behind.
  - When oyster larvae settled onto the seafloor, they would just sink into the sand and die.
- Additionally, when people brought over the Pacific oyster in the early 1900s, they brought with them an oyster predator called the oyster drill snail. This snail secretes acid onto the shell of an oyster and then scrapes away the shell to consume the oyster.
  - Since Pacific Oysters lived alongside oyster drill snails for so long, they adapted to have thicker shells to be able to defend themselves against the snails.
  - Olympia oysters, however, never had to face a predator like the oyster drill snail before, therefore the Olympia oysters have no defense against the snail and get consumed at high rates when the snails are present in high numbers (talk about the potential dangers of non-native invasive species outcompeting native species).
- Although all of this information is very concerning, there are efforts in place by conservationists to re-establish oyster beds on historic oyster grounds. One method that they are using is to gather large amounts of Pacific oyster shell from oyster farmers and spread it along the substrate in historic oyster beds.
  - This gives Olympia oyster larvae the ability to settle out onto the hard substrate of the oyster shells and begin building back up the vast reef structure that used to be so abundant in the Salish Sea.
- Can you name any other invasive species you know of, on land or in the sea?
  - Himalayan blackberry, Scotch broom, European beach grass, etc.
- What are some ways we can help to reduce the presence/effects of non-native invasive species?
  - Volunteer at invasive removal work parties.
  - Check your shoes and clothes for seeds or other means that an invasive species might use to reproduce when you travel to other environments.

What can we take away?

- Oysters are vital contributors to cleaning up water in marine environments, providing habitat to many species of marine fish and invertebrates, and even stabilize substrate to protect against erosion.
- It is just as important to make sure that we maintain habitat for important marine organisms as it is to ensure that we don't over-harvest them. Habitat destruction is a huge problem!
- Restoring native species is an important way to improve the health of the Salish Sea.