

Ecology of **Japanese eelgrass, *Zostera japonica*** and Impacts within the Pacific Northwest

Levi Hay

University of Washington

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Figure 1. Blades of Dwarf (Japanese) eelgrass, *Z. japonica* and Pacific eelgrass, *Z. marina*. (Modified from source: California Department of Fish and Game)

Introduction and Overview

Zostera japonica, commonly called Japanese or dwarf eelgrass, belongs to the Kingdom Plantae, Division Angiospermae, Clade Mesangiospermae, Group Monocotyledonae, Order Alismatales, Family Zosteraceae. Classification of the plant is constantly changing, as the International Code of Nomenclature of algae, fungi, and plants is frequently modified (Miller et al. 2011).

Z. japonica is part of a much larger organization of flowering plants known as angiospermae; this division emerged from existent aquatic plants some 475 million years ago (Edwards 2000). Angiospermae adapted specifically to the terrestrial environment through millennia of natural selection. However, this group deviated even further to reclaim the aquatic environment, specifically including the order Alismatales. Alismatales contains all marine species, which are even further distinguished as seagrasses in the family Zosteraceae (Les 1988). This family of organisms is unique in that it spends its entire life in the marine environment, and solely undergoes submarine pollination for sexual reproduction. The significance of this adaptation is great; seagrasses managed to wholly recolonize and embrace the marine environment after spending millennia adapting specifically to terrestrial conditions (Les et al. 1997).

Native to the Eastern Pacific (Shin and Choi 1998), *Z. japonica* was introduced to Pacific Northwest marine water bodies as early as 1930

(Harrison and Bigley 1982; Haynes 2000a), with observed communities by 1957 (Harrison and Bigley 1982; Posey 1988). In the estuarine and intertidal zones that it's found, it can commonly be found in relatively close proximity to *Zostera marina* (Fisher et al. 2011, Ruesink et al. 2010), its native congener. Though found in the same area, the two species have distinct ecological niches with respect to the intertidal zone (Fisher et al. 2011; Ruesink et al. 2010; Shafer et al. 2007).

Though functionally similar and closely related, the two species exhibit drastic morphological differences (Figure 1). *Z. japonica* has significantly narrower blades (1mm; Haynes 2000a) and shorter overall length (30cm; Haynes 2000a) than *Z. marina* (10mm and 100cm, respectively; Haynes 2000b), though these traits vary widely in both *Zostera* spp. as a function of climate, season, and tidal zone in which the organism is found (Kentula 1983; Phillips 1972, 1974; Setchell 1929).

Life-history and Ecology

Life Cycle

As with all flowering plants, new life begins with a seed; *Z. japonica* life generally begins in this manner, however it is possible for new growths to arise from the rhizome (2.2 Reproductive Strategies). These seeds are negatively buoyant and will settle in sediment ripples within the intertidal zone. Once settling occurs, germination follows; relative to *Z.*



Figure 2. The rhizome and roots (1), flower (2), and blades (3) of a typical *Z. japonica* plant. (Modified from source: Chinese Academy of Science Data Center)

marina, *Z. japonica* spends significantly less time in the non-reproductive seedling stage, before finally becoming capable of sexual or asexual reproduction (Ruesink et al. 2010).

Reproductive Strategies

Z. japonica exhibits both sexual and asexual reproductive capabilities. As with all angiospermae, *Z. japonica* produce flowers (Figure 2). The pollen of this particular species is dispersed by changing tides (Ruesink et al. 2010); it is stored in neutrally buoyant pollen

sacs and strung along mucosal strands . These pollen sacs come into contact with pistils of the female flower. Once pollinated, flowering inflorescences grow into crescent-shaped ovoids that have been determined to be extremely successful at germinating (Ruesink et al. 2010). *Z. japonica* exhibit extreme re-vegetation capabilities following mechanical disturbance, made possible by their remarkable sub-sediment rhizome and root system (Figure 2; Park et al. 2011). Asexual reproduction through sediment is possible by a number of invasive plant species, including the Himalayan blackberry *Rubus armeniacus* and morning glory *Convolvulus arvensis* (WSNWCB 2011). The rhizome of *Z. japonica* is not a true root, but is actually a complex stem system modified to grow horizontally through the through the sediment.

Feeding Habits

Z. japonica is a photosynthetic much plant like any other; it requires light to survive and grow. In addition to requiring light, biological function of plants is supplemented by essential nutrients. These nutrients are commonly found in the nearshore aquatic environment; they enter the system through runoff, erosion, and wind-forced sediment movement. Records do not show nutrients to have limited growth of *Zostera* spp.; however, over-fertilization from runoff of manmade products can negatively impact *Z. japonica* health by increasing the productivity of other primary producers such as phytoplankton, which

in turn reduces water clarity and light availability for *Z. japonica* (Burkholder 1992; Burkholder et al. 2007).

Environmental Optima and Tolerances

Z. japonica is traditionally found in the upper intertidal zone, but in absence of *Z. marina* can colonize into the lower intertidal zone (Fisher et al. 2011). However the vertical range limit of *Z. marina* from 1 to 2 meters above MLLW (Figure 3; Ruesink et al. 2010) permits the more breakage resistant and structurally flexible (Les and Cleland 1997; Shafer et al. 2007) *Z. japonica* to exist anywhere from -2 to 2 meters from MLW (Figure 3; Ruesink et al. 2010), an area with much greater wave energy (Fong 1998) and exposure to the atmosphere. The ability for *Z. japonica* to thrive in this morphologically taxing and “weedy” niche could signify that the species

is more fit as an invader than its congener (Duarte 1991, Ruesink et al. 2010).

Biotic Associations

“In most cases in the Pacific Northwest region, there is little opportunity for direct competition between the two *Zostera* species because they occupy different niches in the intertidal zone.” – Excerpted from Shafer et al. 2007.

Typically, *Z. japonica* and *Z. marina* have non-overlapping distributions (70% of collocation occurrences; Mach et al. 2010) with respect to the vertical sea level; if the two species are located within the same intertidal system (30% of occurrences; Mach et al. 2010), *Z. japonica* and *Z. marina* exhibit competitive exclusion upon each other (Ruesink et al. 2010). If the two species do coalesce, their mean vertical distributions (by biomass) differs within the

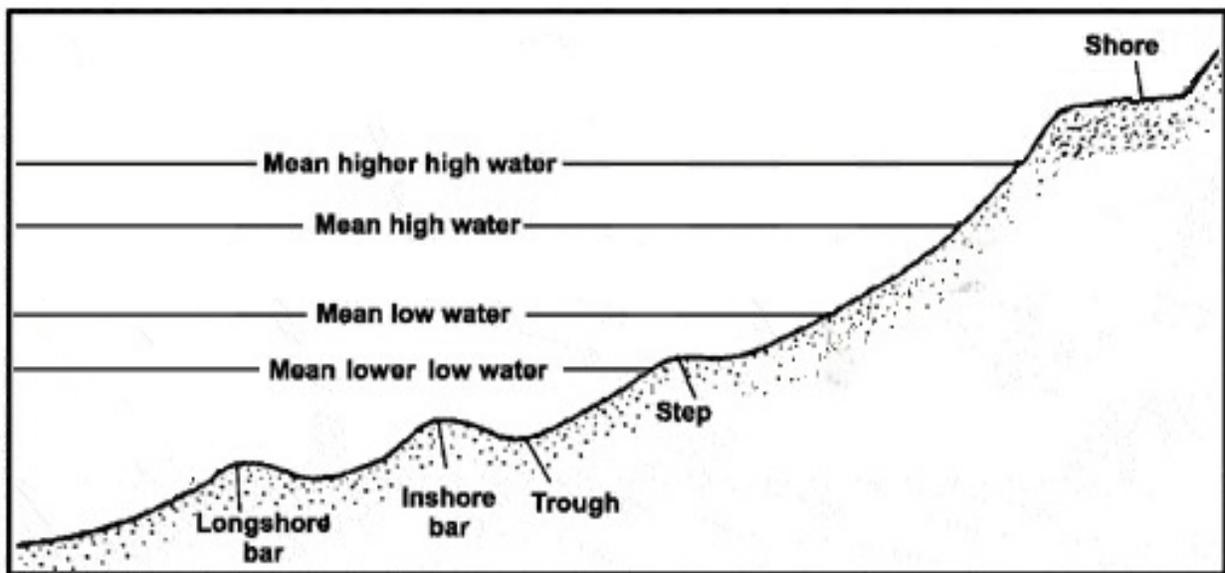


Figure 3. Vertical orientation of mean higher high water (MHHW), mean high water (MHW), mean low water (MLW), and mean lower low water (MLLW). (Modified from source: NOS Tidal Datum’s Pub)

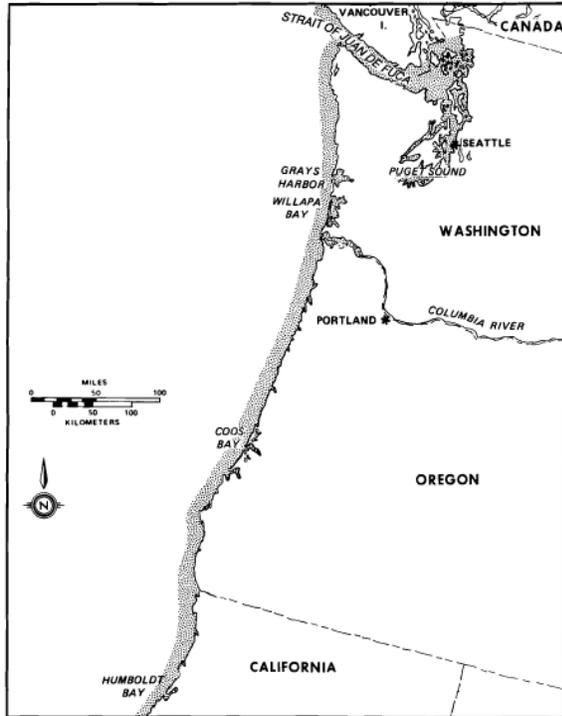


Figure 4. Geographic distribution of *N. californiensis* in the Pacific Northwest's intertidal and mud flats. (Modified from source: Hornig et al. 1989)

intertidal zone (Britton-Simmons et al. 2010; Bulthuis 1995; Ruesink et al. 2010). Competitive exclusion is illustrated in a number of findings. Merrill (1995) found that in the presence of *Z. japonica*, *Z. marina* leaf and rhizome growth was inhibited. It has also been shown that when isolated from competitive pressures placed on it by *Z. japonica*, *Z. marina* is capable of growing much more rapidly (Hourdequin 1994).

The colonization of historically unvegetated mudflats by *Z. japonica*, and the ensuing physical habitat change (Baldwin and Lovvorn 1994), has also contributed to decreased shorebird foraging habitat; the composition of

benthic organisms within *Z. japonica* beds is drastically different than in unvegetated areas (Durance 2002). Burrowing shrimp, such as the ghost shrimp *Neotrypaea californiensis*, are just one example of benthic organisms that are negatively impacted by the establishment of *Z. japonica* (Dumbauld and Wyllie-Echeverria 2003); the typical manner in which *N. californiensis* burrow into the sediment for shelter is inhibited by horizontal *Z. japonica* rhizomal growth. In a seemingly combative response to less habitat availability, *N. californiensis* have been shown to prevent spread of *Z. japonica* by disturbing the benthic root system of seedlings (Harrison 1987); the geographic interaction between the two species can be easily visualized (Figure 4). Reduction in *N. californiensis* habitat impacts shorebirds, but may also impact white and green sturgeon (*Acipenser transmontanus*; *Acipenser medirostris*) which are common to estuarine and marine environments, respectively. *N. californiensis* is a common food source for *Acipenser* spp. (Fisher et al. 2011), and reduction in feeding grounds can severely limit the geographic distribution of *Acipenser* spp. This indirect effect could also be seen in a number of other fish species. Simenstad (1994) hypothesized that surf smelt *Hypomesus pretiosus*, Pacific herring *Clupea pallasii*, Pacific sand lance *Ammodytes hexapteru*, and chum salmon *Oncorhynchus keta*, which are all dependent on copepod biomass, would suffer when the copepod biomass and congregations

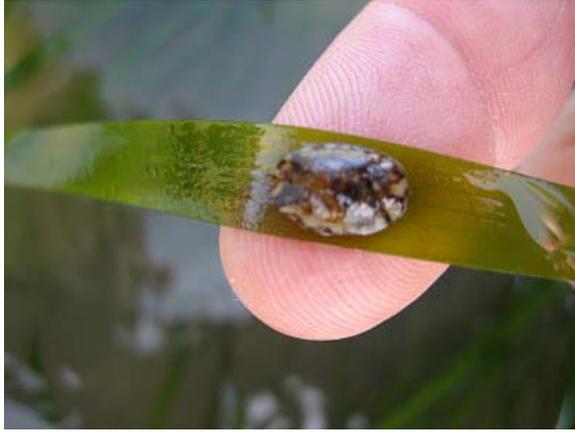


Figure 5. Limpet taking refuge on a *Z. japonica* blade. (Source: Friday Harbor Labs Marine Health Observatory)

were reduced by *Z. japonica* (Simenstad et al. 1988).

Despite having a seemingly negative impact on the native *Z. marina* and potential negative impacts on a number of fish species, *Z. japonica* provides valuable habitat for other commercially and ecologically important vertebrates and macroinvertebrates at many different life stages (Dierssen and Zimmerman 2006; Mach et al. 2010; Simenstad et al. 1988; Thom 1987). The same community of epibenthic organisms that are found in *Z. marina* beds can also be found in *Z. japonica* (Thom et al. 1995); this additional habitat is inarguably beneficial for these epibenthic organisms.

History of Invasion

Global

Z. japonica is native to the Eastern Pacific Ocean – specifically Korea and Japan, which are traditional hotbeds of seagrass

diversity (Les et al. 1997). It has no invasion history outside of the Western United States.

Pacific Northwest

Z. japonica is thought to have been unintentionally introduced during transport of Pacific oysters (*Crassostrea gigas*) from Japan in the early 1930's, in the same way that Japanese oyster drill (*Ocenebrellus inornatus*) and Manila clam (*Venerupis philippinarum*) were introduced (Bardach et al. 1972; Chew 1989; Haynes 2000a).

Spread from the original oyster bed locations in which *Z. japonica* established itself occurs both through seasonal reproduction and creeping rhizomal growth (Almasi and Eldridge 2008); seasonally during warmer temperatures, beds may die off after seeding and float great distances on the surface as mats, all the while dropping seeds that may find the sediment suitable for germination (Dierssen and Zimmerman 2006; Phillips 1972, 1974, 1984; Phillips and Backman 1983).

Geographic Distribution

Global

The East Pacific range of *Z. japonica* extends between the Pacific Northwest and Northern California. In the West Pacific, *Z. japonica* extends from Vietnam northwards past Japan and to the Russian island of Sakhalin (Figure 6; IUCN Redlist Map Service; Fisher et al. 2011; Ruesink et al. 2010).

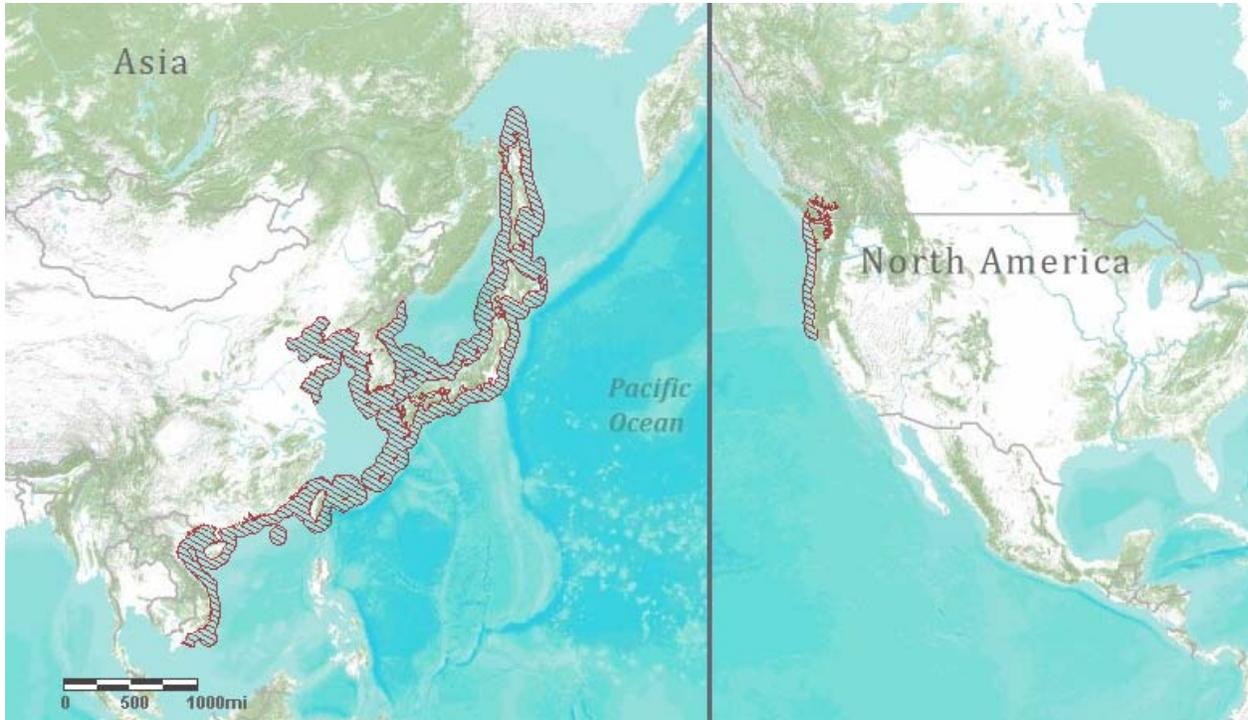


Figure 6. Global distribution of *Z. japonica* (with uninhabited portion of the Pacific Ocean removed). (Modified from source: IUCN Redlist Map Service)



Figure 7. Geographic distribution of *Z. japonica* within the Pacific Northwest and Northern California (Source: IUCN Redlist Map Service)

Pacific Northwest

Z. japonica can nearly be found along the entirety of the Western United States, as far south as Humboldt Bay, California, and as far north as the Strait of Georgia, Canada (Figure 7; IUCN Redlist Map Service; Fisher et al. 2011; Ruesink et al. 2010).

Invasion Process

Pathways, Vectors and Routes of Introduction

The two distinct reproductive processes of *Z. japonica* have enabled it to both persist and expand its range over time. Though Ruesink et al. (2010) found that vegetative expansion was generally limited to rhizomal growth, Fong (1998) contends that new communities can be

established if seeding occurs by a detached flower. The inherent potential for detachment of flowering shoots is significant in the wave-ridden intertidal zone (Phillips 1964; Phillips and Backman 1983). By widely-accepted definition of the word, the vector of potential invasion is thus the individual organisms that have begun floating as debris (Mack 2004); these mats of biological material can then travel with currents, tides, and aquatic vessels as a hitchhiker (Fisher et al. 2011; Fong 1998), which is the pathway leading to possible colonizing of new areas (Mack 2004). There is also a potential for avian transport, as the seeds of *Z. japonica* may be unintentionally ingested and passed through the digestive tract of waterfowl (Fong 1998).

Historically, aquatic macrophytes have played a large role in trans-oceanic transport of aquatic organisms, specifically invertebrates. As early as 1930 (Harrison and Bigley 1982), *Z. japonica* was used to keep *C. gigas* spat cool, and effectively prevented desiccation. Over the last

half century or so, the use of aquatic macrophytes for shipping has been greatly reduced, due largely in part to the invasive species prevention mechanisms put in place by the Pacific Coast Shellfish Growers Association (Fisher et al. 2011).

Factors Influencing Establishment and Spread

With respect to an invader establishment, there is a phenomenon known as the Allee effect that temporally prevents a newly introduced organism from spreading outside their introduced range after the first introduction (Courchamp et al. 1999); more explicitly, the Allee effect is often the result of a limited propagule size, which increases negative population effects stemming from randomly occurring disturbance events.

Though common in the Northern and Central Puget Sound, only ephemeral instances of *Z. japonica* are present in the Southern Puget Sound; following a period without a disturbance, these colonial instances have the potential to



Figure 8. Geographic distribution of *Z. marina* (with uninhabited portion of Asia and Eastern Europe removed), showing potential habitat locations for *Z. japonica* if introduced. (Modified from source: IUCN Redlist Map Service)

establish themselves more permanently as large clonal beds with greater reproductive capabilities (Almasi and Eldridge 2008), overcoming the Allee effect.

Z. japonica has a wide range of potential intertidal habitats (Figure 8). Anywhere within the tolerances of the organism are habitable, however competitive exclusion by has been shown to be the primary factor in limiting spread to areas inhabited by *Z. marina* (Ruesink et al. 2010). *Z. japonica* is unlikely to colonize a *Z. marina* bed by means of seed dispersal and germination, even following a significant disturbance to the *Z. marina* bed (Almasi, Eldridge 2008); rather, residual sub-sediment biomass competitively prevents *Z. japonica* from becoming established. As previously discussed, *N. californiensis* has been shown to inhibit spread of *Z. japonica* (Harrison 1987); Berkenbusch et al. (2007) also found that *Z. japonica* did not recruit into *N. californiensis* territory in a study in Netarts Bay, Oregon.

Ecological and Socioeconomic Impacts

The ecological impacts identified from *Z. japonica* establishment largely relate to the physical habitat changes that result from introduction. Eelgrasses by their very nature have significant habitat and ecology altering characteristics. In addition to distributing kinetic energy transported by wave action (Lacy 2004), their complex rhizome and root system modifies sediment composition. Posey (2005) found that average grain size of sediment decreases where

Z. japonica is present, in addition to increased organic material; faunal abundance also increased within *Z. japonica* beds (relative to surrounding unvegetated areas). The introduction of *Z. japonica*, and likely any other functionally similar eelgrass, to a previously unvegetated area can result in radical community composition changes and indirectly alter ecosystem-wide interactions (Posey 2005). In an experiment performed by Tsai et al. (2010), *Z. japonica* was shown to negatively impact growth of tissue mass in *R. philippinarum*. Ruesink et al. (2006) also found that *Z. japonica* negatively impacted the growth and number of native oyster species *Ostreola conchaphila*. This study in Willapa Bay, Washington sheds light on broad potential negative implications of *Z. japonica* for the shellfish industry, which relies on growing healthy products to please their consumer base. Curiously, although *Z. japonica* affects *R. philippinarum* and *O. conchaphila* production in a negative manner, native softshell clams *Mya arenaria* seemed to benefit with the introduction (Ruesink et al 2006).

In addition to the negative impacts on commercial shellfish production, *Z. japonica* increases sediment fallout by lowering water speeds (Dierssen and Zimmerman 2006); this in turn results in sediment build up which can prevent waterfront homeowners from using their docks and forcing expensive dredging to remove the sediment (Reicher 2010). Interestingly, as sediment accumulates, rhizomes and stems may

Table 1. Valuable ecosystem services provided by the natural world. Note: Ecosystem services followed by (*) signifies an ecosystem service provided by *Z. japonica*. (Modified from source: Costanza et al. 2007)

Number	Ecosystem service	Ecosystem functions	Examples
1	Gas regulation *	Regulation of atmospheric chemical composition.	CO ₂ /O ₂ balance, O ₃ for UVB protection, and SO _x levels.
2	Climate regulation *	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
3	Disturbance regulation *	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
4	Water regulation *	Regulation of hydrological flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
5	Water supply *	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
6	Erosion control and sediment retention *	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes, storage of silt in lakes and wetlands.
7	Soil formation *	Soil formation processes.	Weathering of rock and the accumulation of organic material.
8	Nutrient cycling *	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
9	Waste treatment *	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification.
10	Pollination *	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
11	Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
12	Refugia *	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
13	Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing.
14	Raw materials *	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.
15	Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
16	Recreation *	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, and other outdoor recreational activities.
17	Cultural *	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

be covered so much as to kill the eelgrass, forcing large scale die offs that then detach and float to the surface (Dierssen and Zimmerman 2006; Phillips 1972, 1974, 1984; Phillips and Backman 1983). Despite these expensive and deleterious effects of *Z. japonica* on the environment and economy, it has also been shown to have numerous positive impacts on the environment and economy.

Particulate and dissolved organic matter is one of the most important food sources for aquatic microorganisms such as zooplankton, and primary consumers that filter feed (Fisher et al. 2010). By depositing particulate and dissolved organic matter into the environment through biomass decomposition, *Z. japonica* contributes to the success of the aquatic community. Hahn (2003) found that *Z. japonica* contributed more mass per day than *Z. marina* (1.65% total mass/day; 1.35% total mass/day). The significance of this finding cannot be verified, however; the C:N (carbon: nitrogen) ratio that determines growth efficiency and nutritional value of a plant (Enríquez et al. 1993) is lower in *Z. japonica* than *Z. marina* (Ruesink et al. 2006). There are many possible implications of *Z. japonica* presence in the Pacific Northwest, however if one considers the economic value of the benefits that it can and does provide, a better understanding of *Z. japonica* will be had (Table 1; Costanza et al. 2007). Perhaps the most significant are the abilities of *Z. japonica* to minimize sediment and pollution within the water column (Dierssen and Zimmerman 2006;

Hornig et al. 1989), regulate water flow in estuarine systems (Dierssen and Zimmerman 2006; Lacy 2004), retain and form soil (Lacy 2004; Posey 2005), provide refugia for native species (Mach et al. 2010; Simenstad et al. 1988; Thom 1987; Thom et al. 1995), and also act as primary producers to support the estuarine and marine ecosystems as a whole (Burkholder 1992; Burkholder et al. 2007; Ruesink 2006; Ruesink et al. 2010).

***Zostera japonica* in the Pacific Northwest**

Management Efforts: Past and Present

Z. japonica is difficult to control, and has been determined to be a Class C noxious weed, however it “may have some beneficial value on unmanaged tidelands” and thus is this classification only applies on commercially managed shellfish beds, where it is detrimental to production (WSNWCB 2011). In addition to this regulation limiting large scale removal, all eelgrasses, native or otherwise, are protected by the Clean Water Act (Wonham 2003), partially under the premise that they promote sediment fallout but also filter toxins from the water column (Dierssen and Zimmerman 2006; Hornig et al. 1989).

Historically, large scale efforts have not been made to control *Zostera* spp. in the Pacific Northwest. More recently, however, eelgrasses have had to be controlled to protect commercial

and recreational interests (Reicher 2010; WSNWCB 2011).

A number of large-scale studies with herbicides such as imazapyr and glyphosate have had varying results. In every instance, the chemicals destroyed only the aboveground biomass of *Z. japonica* while the rhizomal structures remained intact (Bulthuis and Shaw 1993; Entrix 2003). In most cases, this caused damage significant enough to impair growth. The herbicides had to be applied in a very specific manner, however; efficacy of application could only be ensured if the herbicide was used on dry beds, since water acted as a protective buffer (Entrix 2003). These chemical controls provide amazing visual efficacy (Figure 9), however impacted beds generally recover within a period of 9-12 months (Bulthuis and Shaw 1993; Entrix 2003; Fisher et al. 2011).

Physical control methods and disturbances have



Figure 9. Herbicides have shown success (right) in temporarily controlling *Z. japonica*. (Source: UNSV)

shown similar results. Rapid re-vegetation is eminent when suitable habitat is available (Tsai et al 2010; Rushton 2005); however, Rushton (2005) interestingly found that upon complete removal of *Z. japonica* in Humboldt Bay, native *Z. marina* quickly established itself in the open area. Though shading is a possibility for destroying *Zostera* spp. (Reicher 2010), colony-scale eradication aided by artificial sheeting has been largely unsuccessful due to shading system failure (Rushton 2005).

No biological method for controlling *Z. japonica* is known.

Current Research

Z. japonica is currently under observation by a number of individuals and organizations, each with varied interest in the species and methods with which to do research.

The Western Ecology Division of the United States Environmental Protection Agency has a number of projects currently in place to better understand the environmental impacts of *Z. japonica*, with respect to bioturbation caused by various burrowing shrimp, water column chemistry effects, and stabilization of sediments. Not only are the researchers in this division spending time in the field observing the ecosystem directly, they are also utilizing advanced remote sensing technology to record multi-dimensional spectral data on energy reflectance. This technology enables humans to “see” outside the visible spectrum, by displaying

invisible energy in red, green and blue. This has many potential applications, including the approximation of habitat changes within an estuarine ecosystem and stress response modeling (WED 2011).

Some researchers prefer a more direct and hands on approach, dealing directly with biological and ecological studies. Ruesink et al.(2010) recently suggested through their findings that it is scientifically important to focus less on taxonomic comparisons of congeners, and more on ecological comparisons, which may vary drastically. Other local studies include desiccation tolerance (Shafer et al. 2007) and broader, system wide approaches to impact (Mach et al. 2010).

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Experts in the Pacific Northwest

Jennifer Ruesink University of
Washington – Biology
ruesink@u.washington.edu
206-543-7095

University of Washington faculty focusing on
Zosteraceae ecology and socioeconomic
impacts, specifically with regards to *Z. japonica*
as a non-native species that shows varying levels
of interaction with its native congener *Z. marina*.

David Specht EPA – Western
Ecology Division
specht.david@epa.gov 541-867-4037
Aquatic research biologist focusing on remote
sensing, aerial photography, and hybrid image
classification of Zosteraceae and their habitats in
Pacific Northwest estuarine systems.

Additional Sources of Information

Washington State Noxious Weed Control Board:
[http://www.nwcb.wa.gov/siteFiles/Zostera_japo
nica.pdf](http://www.nwcb.wa.gov/siteFiles/Zostera_japonica.pdf)

Costanza et al. (1997) Table 2. Summary of
average global value of annual ecosystem
services