From:	Richard Wilson
To:	Rockett, Derek (ECY); Lubliner, Nathan (ECY)
Subject:	Combined comments on impacts to benthic habitat
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Attachments:	EIS comments DOE.pdf

To: Derek Rockett and Nathan Lubliner, Dept. of Ecology

From: Richard Wilson

Attached are my comments on/for the two DOE impact statements. I focus mainly on the negative impacts of Japanese eelgrass and the two species of burrowing shrimp. Hopefully, it will present some useful information or at least some discussion points. This subject has been a long time interest of mine and in writing on the different species, felt there was enough negative impact in common to combine into one comment paper.

I think DOE did a good job on the public information and comment period last Saturday.

Dick

Comments on the scope and draft Environmental Impact Statements (EIS) for pesticide applications for control of Japanese Eelgrass and two species of Burrowing shrimp.

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My comments will relate primarily to the fourth category of the major areas being addressed in the control of Japanese eelgrass and the use of a new control for burrowing shrimp. The focus will be on the negative impacts of the expanding populations of both the eelgrass and burrowing shrimp on the established physical and biological aspects of the benthic habitat. A listing of the four major areas being addressed in the EIS would include these:

Categories 1 and 2: Potential environmental or human health impacts of using low concentrations infrequently on small disjunctive privately owned or leased intertidal shellfish growing areas of both imidacloprid and imazamox:

*Comment: These fast dissipating chemicals appear to have no proven persistence or negative health or physiological impacts on any vertebrate forms including humans. Their use allows leaving the important benthic sedimentary flats unaltered, which then become reoccupied within a few returning tides of species beneficial to the bay and estuary. Control means only treatment on a relatively small percent of the tideland areas infested with extremely high abundances of the rapidly expanding species.

* Question: Should it not be noted (and emphasized) in the final documents the fact most shellfish growers hold deeded title to (i.e. own) the intertidal areas they raise shellfish on and thus pay taxes just as would an upland farm owner? A few intertidal areas are leased through DNR, which is in turn is a source of state revenue as long as they remain useable. Then to make it clear that the area that would be treated is only a small percent of the total which has been taken over by Japanese eelgrass and the two species of burrowing shrimp.

Category 3. Efficacy of treatment:

* Comment: As to efficacy these benign chemical treatments have been tested for many years for the intended purpose. In fact, for both Japanese eelgrass and burrowing shrimp imazamox and imidacloprid have shown the shortest and lightest touch on the environment when contrasted with the other numerous chemical and mechanical methods tried. Several of these should be detailed in the EIS.

Category 4: The negative impacts of both Zostera japonica and the two species of burrowing shrimp.

*Comment: It is felt that the full extent of the negative impacts to the habitat by the invasive/opportunistic Japanese eelgrass and burrowing shrimp is incomplete or not adequately stated in the scoping and draft environmental impact statements. My comments will focus on the benthic sedimentary environment and the spread of the invasive species, which are the subject of the permitting actions.

In both cases being considered, the population increases of highly fecund and rapidly spreading species on the intertidal areas initiates changes to the sedimentary character and alters or eliminates major environmental components of the estuary productivity. I will emphasize that this is not just for shellfish but to a large degree includes many dozens of other important species, which depend on the physical and biological components of the mudflat. Many important species, most only visible through the microscope, are responsible for a major part of the basic productivity in the near shore marine environment. The burrowing shrimp represent a life form, which through various reasons such as the removal of predatory control have expanded to dominate and modify around 10,000 acres in Willapa Bay. The other, the Japanese eelgrass is expanding rapidly and now covers over 9,000 acres and basically takes the vital higher mudflat out of production as the meadows expand and thicken. Whether burrowing shrimp or Japanese eelgrass the results are similar in that the negative modification imposed on the benthic physical and biological elements of the environment is very deleterious to most of the inhabitants that depend upon the uniqueness of this habitat for existence. This replacement includes a large range of types and sizes of living forms starting with the bacteria and smallest single celled algae to larger vertebrates dependent on the overall productivity of the marine near shore environment.

I will note that my comments may be at odds with some resource agency reports or comment by groups who have misguided or incomplete knowledge and understanding about the benthic environment. This leads to a failure to consider all the interacting components of the habitat or to choose one aspect over others leading to the outcome without scientific basis. In addition, occasionally there seems to be a distain directed at uses or users of the marine environment, which might be in conflict with their views or beliefs. I attempt to only present the environmental conditions and changes, which have been observed over four decades along with the scientific studies to verify the credibility. I shall emphasize how both Japanese eelgrass and burrowing shrimp decrease or eliminate the basal stages of the food web and prevent that productivity from passing through the flora and fauna of many key species of the marine near shore.

Comments on the Benthic Habitat and Biota and its Destructive Modification by *Zostera japonica*:

Japanese eelgrass (*Zostera japonica*) should be considered a direct threat to the productivity of the marine intertidal areas. It excludes by blocking sunlight and currents while modifying the chemical and physical properties of the benthic in effect reducing biodiversity and abundance of the biota. The EIS should emphasize this critical factor. The comments, which follow, will detail by utilizing three specific interconnected physical and biological aspects of the benthic to illustrate the mudflat habitat before and what will be modified or eliminated when *Z. japonica* invades the intertidal. These interconnected interdependent aspects include the sedimentary, the primary plant producers and a key consumer (a crustacean grazer). These, it is hoped, will exemplify the very important layers of interrelated phenomenon of a benthic mudflat habitat before *Z. japonica* and what is lost when this sea grass takes over. *Z. japonica* changes key parameters of the benthic with a change from open productive mudflat to a covered protected non-contributing decomposing area rich in organic detritus. Although vital nutrients can be derived from multiple sources the weathering of igneous rock and sediments have the important lithology, structure, chemistry, minerals, nutrients, etc. such as silicic acid or when combined with Ca, Mg, and other cations the salt known as a metasilicate. These are key components to the estuarial production for diatoms. The open (uncovered) undisturbed sedimentary mudflat is the physical habitat, which initiates, contributes and hosts the important productive layers of the food web.

The Sedimentary Contribution: This portion of the critical relationship involves the interplay of the geologic aspects of weathering, erosion and ultimate deposition of sediments, which influence the primary production of diatoms and the micro zooplankton. Several long-term studies on the benthic geology, including several summers by the US geological survey, have been performed on Willapa Bay (Clifton and Phillips, 1980). Focus here will be on a few factors of major importance to the productivity of the bay, which are the sediment composition, pH, and nutrient value with emphasis on the important silicic acid produced in the process of weathering of igneous and sedimentary minerals.

The Willapa estuary has extensive exposed intertidal flats comprised of deposited weathered or weathering igneous mineral, rock or sediments. Clifton and Phillips describe them as largely consisting of both well-sorted and poorly sorted fine sand and silt, and clay. The variable composition of the sediments is generally finer at the points the numerous small streams and creeks of the Willapa Hills enter the bay. These oxygenated mudflats form the extensive surface with the necessary components for plant production. They entrap nutrients and are exposed to solar radiation while being reworked by wind and tides to create a vast area ideal for a critical and important group of plants known as diatoms. Up to 50% of all the marine primary productivity can be attributed to these single-celled diatoms.

In the various discussions and impact statements on estuarial habitat types, little has been mentioned of the mudflat and why it plays an important part in basic productivity. Mudflats are the formational and storage area of nutrients of which silicic acid is one most important to diatoms. Diatoms utilize silicic acid (a usable form of silicate) to construct their cell walls (shell or test) and their abundance and diversity are limited by the availability of silica. A couple of examples of weathering of common igneous minerals to show formation of this key nutrient:

Plagioclase feldspar, a key mineral in igneous rocks, along with quartz are the most common silicate minerals in the earth's crust. Unlike quartz the feldspars are unstable and susceptible to breakdown by weathering. Feldspars are especially abundant in igneous rocks and chemically unweathered clastic sediments derived from them. In the presence of water with atmosphere CO2 a plagioclase feldspar breaks down to form silicic acid, critical for diatoms and an aluminum silicate mineral we know as clay. The other products from weathering usually enter the water column or are entrapped or combined into new compounds. The clay minerals formed are extremely small thin flakes

with a piezoelectric charge, which promotes sticking together when wet, much like sheets of wet paper. This is important in marine water as it supposedly entraps nutrients, as well as, forming larger particles (colloids) to increase settling velocity and adding to the benthic layer. These help encapsulate nutrients and thus, another reason for the value of those benthic sediments. Example (simplified) of hydrolysis (water) weathering:

$$\underset{\text{(Na-plagioclase)}}{2NaAlSi_3O_8} + \underset{\text{(carbonic acid)}}{2H_2CO_3} + \underset{\text{(water)}}{9H_2O} =$$

$$\underset{\text{(dissolved components)}}{2Na^+ + 2HCO_3^- + 4H_4SiO_4} + \underset{\text{(clay mineral)}}{Al_2Si_2O_5(OH)_4}$$

Silicic Acid

And weathering of an igneous silicate mineral by oxidation (oxygen in the air or water) forming silicic acid:

$$\underset{\text{(olivine)}}{2Fe_2SiO_4} + \underset{\text{(water)}}{4H_2O} + \underset{\text{(oxygen)}}{O_2} = \underset{\text{(hematite)}}{2Fe_2O_3} + \underset{\text{(silicic acid)}}{2H_4SiO_4}$$

To illustrate a typical generalized igneous silicate rock (e.g. basalt) weathering reaction:

$$\begin{aligned}&Ca_{0.3}Mg_{0.1}Fe_{0.4}Al_{0.3}SiO_{3.25} + 2.5CO_2\\&\quad + 3.25H_2O \rightarrow 0.3Ca^{2+} + 0.1Mg^{2+} + 0.4Fe^{2+}\\&\quad + 0.3Al^{3+} + H_4SiO_4 + 2.5HCO_3^-.\end{aligned}$$

The geological and specifically the weathering and sedimentary process has not been considered in detail in past EIS level disclosures. It is especially important in understanding the deleterious impacts of *Z. japonica.* Furthermore, in Willapa Bay the fresh and seawater interface may prove a very important area and is associated with the higher intertidal. It is assumed that the drainage system of the watershed carries the various products of erosion to bay. Certainly the rock fragments (clastics) reach the estuary in this manner. However, the soluble products, which include many of the usable nutrients for plants (e.g. algae) enter the ground water system from the unsaturated zone where most weathering is taking place works through the lithologic environment until reaching the zone of saturation. This was rainwater, which does not escape as surface runoff. Thus, rainwater with atmospheric CO2 (see the basalt weathering example) aids in the breakdown of minerals and formation of new stable chemical combinations. Entrapped water will remain in the sedimentary system with the soluble chemicals will move along under the force of gravity playing against the constraints of lithologic porosity and permeability in this saturated zone until reaching a surface level such as a stream or the ultimate base level, sea level.

The eastern high intertidal of Willapa Bay along the inland margin, which abuts the uplifted Willapa Hills, receives the ground water that did not enter the surface drainage system. It probably is this lateral ground water input which makes the near shore intertidal sedimentary area valuable for their nutrient content. Often masses of brown slimy appearing deposits at the margin of highest tide and land are diatoms availing themselves of nutrients from ground water (Figure 1). The contention is that these near shore-wetted areas are where the diatoms can utilize those critical components for growth and division, e.g. sunlight and nutrients. The interesting effect of the marine base level in ground water is that it moves vertically in response to the tide thus creating an ever-changing base level. Water in the saturated zone would move out into the marine sediments during the ebbing tide then upon the flood tide be forced out to the surface. Of course, the lithology of the near shore above and below the base level determines the amount of flow with permeability and porosity two important geological constraints. This ground water not only carries important nutrients from the place of weathering but also would tend to force up nutrients stored in those marine deposits. Anecdotal to that, we raised diatoms for years in an algal culture system using only the fresh ground water from a deep (450 ft) well. We mixed in the sea salts and nutrients but we never had to add silicic acid (metacsilicate) so critical to the diatoms to build their shell. Water from the zone of saturation was rich in the silicate needed. Our continuous culture cylinders of extremely high diatom concentrations would last for weeks.

Diatoms: the Primary Producers: The majority of diatom species are extremely small single celled plants, which form silica shells. The images that follow are microscope views of diatoms and associated biota from water samples over oyster beds. Diatoms can float, attach or cling with their axopoda (thin pseudopods) to a holding spot, drift along, or settle upon the intertidal sediments during low tides, while dividing. They can remain on the mudflat after the tide ebbs and continue to grow and divide. Here they utilize the open mud flats for the most direct means of

obtaining sunlight and nutrients. Under the right conditions and tide we will see large rafts of these diatoms floating like an oil slick as they are lifted from the mudflats. Figure 1 below of a mass of diatoms (±90 meters), which floated off the intertidal at high tide on a sunny calm day on January 27th, 2014 @ 8:35 pst.

Figure 1. Benthic diatom mass floating off at high tide.

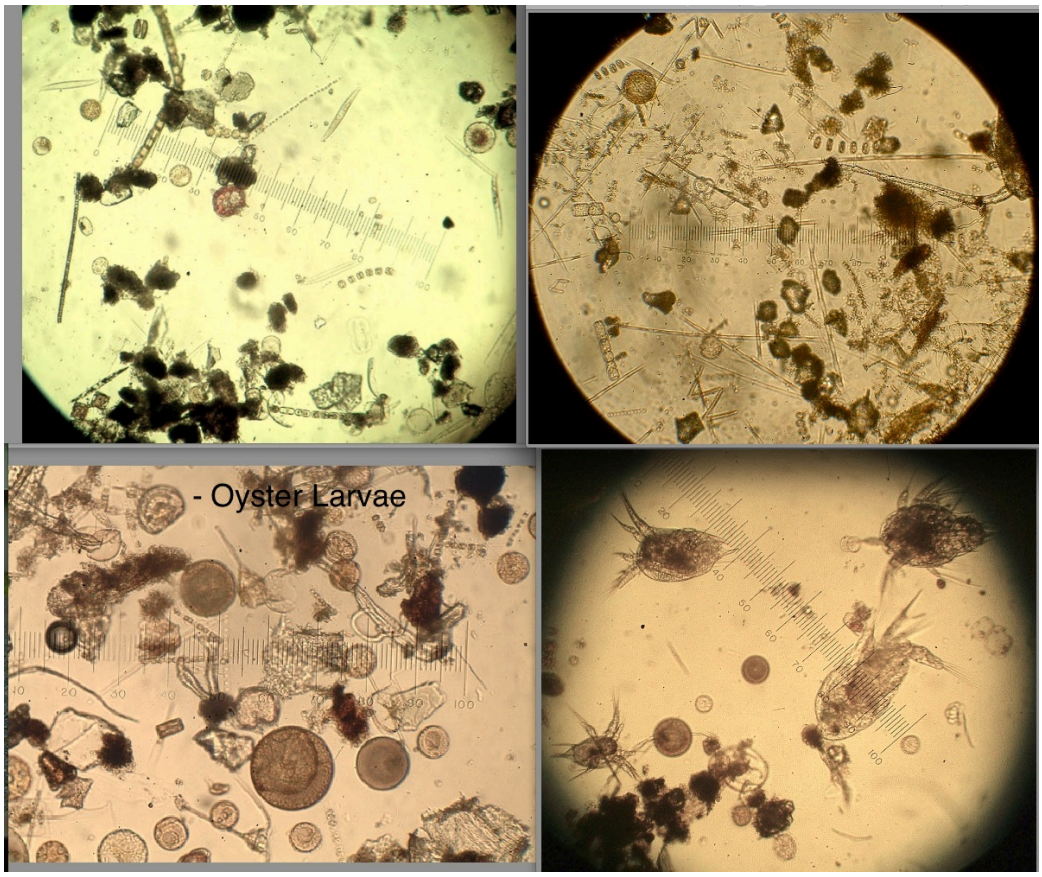

Figure 2: Images through the microscope. Visible scale is one millimeter divided into 10-micron units (1000 microns per millimeter). Phytoplankton as mainly single celled diatoms in many different shapes (concentric, needle, chained, etc.). Some zooplankton (barnacle larvae?) in lower right image. A smaller range of phytoplankton appears as small dots and organic matter is the darker fuzzy blobs. These samples are from the water column but represent the diatoms, which have left the sediment surface.

When our company was culturing diatoms to feed shellfish larvae we took frequent seawater samples to check which species of phytoplankton were present and observed the diatom diversity during changing tides and seasons.

We also isolated single celled diatom specimens to start new cultures. Occasionally a photomicrograph at 100 X was taken for reference (Figure 2). The visible scale length is one millimeter divided into ten-micrometer units.

The single celled diatoms are using the intertidal areas to asexually divide with the increased numbers re-entering the water column as tidal currents and wind action dislodge and disperse them (Figure 1). Diatoms flourish on the warm sun exposed intertidal sediments throughout the year but especially during the summer tides. Studies show diatoms can attach on to benthic sedimentary particles and objects and some researchers have even categorized them as weak, moderate or strong attaché's. The Japanese eelgrass, as the meadow becomes denser over time would eliminate this critical habitat for diatoms by taking away the sedimentary contact and sunlight. Also, this eelgrass area as others report, allows creation of a soft composting sulfide habitat unfit for diatoms, which becomes a low oxygen habitat preferred by bacteria and worms.

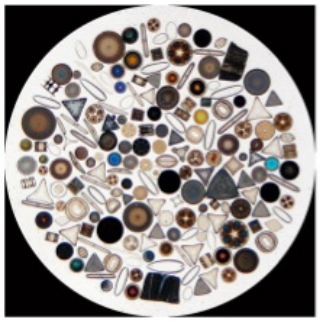

Figure 3 **Single Cell Diatoms – A multitude of shapes**

***Corophium*; A key example of the many benthic grazers.** There have been several studies that deal with the benthic habitat here in Willapa and one was notable in its duration and completeness. Kenneth Brooks, working out of our facilities in 1993 did extensive sampling to fulfill requirements of the EPA data call in for the carbaryl permit (Brooks, 1995). Even though Ken's work was directed at impacts to specific benthic animals in relationship to carbaryl treatment to control burrowing shrimp, the data can be mined for other useful information. For example, how numerous a particular species is and the rate they can re-establish on to the intertidal. Brooks sampled shrimp infested oyster grounds that had been harvested and left barren from the day of treatment until after the 50-day sample. The data by Brooks is very useful in the case of *Corophium* to give evidence of just how abundant this amphipod is on those mudflats (see graph below). The 10,000 individuals per square meter are over six per square inch and the data shows abundance was sampled at over 40,000 per square meter. To support this number of one crustacean, *Corophium,* requires a robust diatom population. A single individual can consume up to 4000 diatoms (ranging in size from 5 to 63 microns =.005 to .063 mm.) per hour. In two hours the six *Corophium* per square inch might consume 50,000 diatoms (however, they take two hours to digest one hour of feeding). The *Corophium* abundance increases from July to September and probably reflects the daytime hours of sunlight exposure during low tides and the warmer temperatures. Note *Corophium* abundance on shrimp infested bed vs control (Fig 4).

Ken Brook's data on *Corophium* from two oyster beds treated for shrimp (and in effect other crustaceans) and a nearby-untreated oyster bed for control. Treatment was on day zero. Sampling before and after the July treatment showed *Corophium* on two areas to be treated lower than the control the apparent suppression of Corophium (and diatoms) by burrowing shrimp. Note the recovery after shrimp removal to over 10,000 individuals per sq. meter at the 50th day sample. On the untreated control bed the increase of *Corophium* from around 10 to over 40 thousand individuals per meter is probably in response to the higher temperature and sunlight during the summer daytime low tides. The excavation of burrows by *Corophium* and other micro benthic burrowing organisms probably plays an important role in the release of nutrients from the sediments thus aiding in the culture of their food source such as diatoms.

10,000 Corophium per sq. meter is over six per sq. inch.

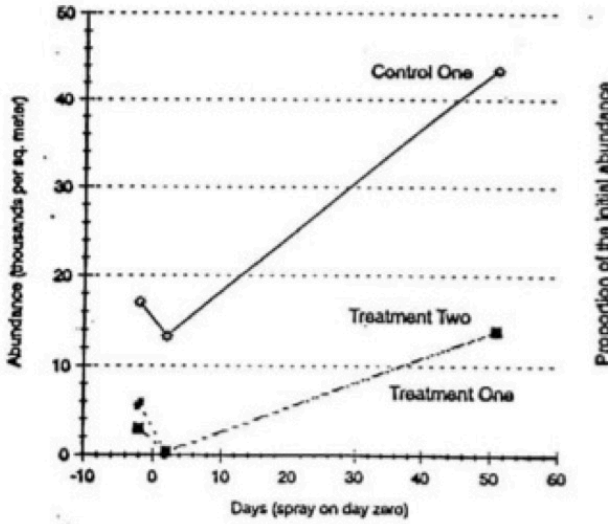

Figure 4 **(a) absolute abundance** ***Corophium***

There are several studies devoted to the biology of *Corophium*. The focus here will be on how and what our amphipod consumes and the importance of *Corophium* as a prey species and very important to the food chain. A research report by Gerdol and Hughes, 1994, helped to answer some of the questions such as; how does this gangly amphipod sticking out of its shallow U-shaped burrow catch a diatom or feed on organic 'debris'? Earlier work tried to figure out what percent diatoms played in the diet of *Corophium* even though there was not direct evidence of what they preyed on. No intact or identifiable diatoms could be found in the gut until tests were performed using radioactive labeled diatoms. It was eventually learned *Corophium* munches its diatom prey with a set of mandibles, which apparently they were not known to have. *Corophium* also is a deposit feeder by raking the surface (Figure 5) sediment and organic material into the burrow where it sorts though it for the correct size particles (including diatoms). *Corophium* can use those long antennae to snare food particles in suspension or it can scrape organic material (diatoms included) off of sedimentary particles (e.g. sand grain) using teeth-like structures on the first pair of feeding limbs (Gerdo, et al.). The relationship of *Corophium* and diatoms seems well established and thus this amphipod becomes a key indicator of diatom abundance and intertidal health.

The vita of *Corophium*: It was interesting to learn that a major reason several research studies were initiated on the amphipod *Corophium,* occurred after confirmation that large populations of shorebirds in the Bay of Fundy were dependent upon this crustacean as a critical component in their high lipid diet. This is the same situation here in Willapa Bay, which is a critical wintering and feeding stop for migrating shorebirds especially the Dunlin as in Figure 9. This has been an omission in most benthic studies and the impact statements most likely due to the lack of connecting the importance of the diatom, crustacean and shorebird relationship.

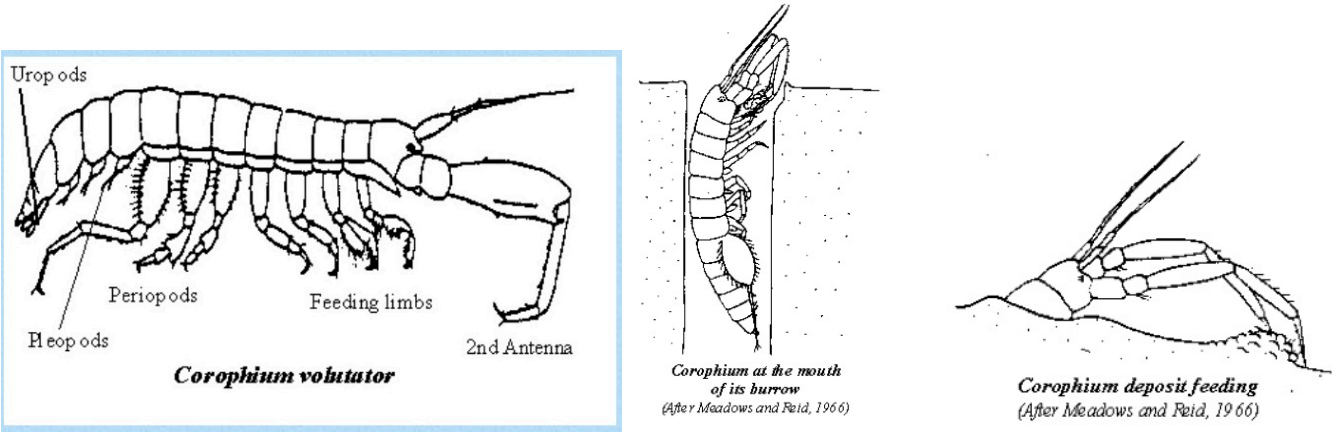

Figure 5. *Corophium;* a crustacean amphipod with a body length ‡3-12mm (‡1/8 to 3/8+ inch). Depends on a diatom source and in turn becomes a very important food for many estuary forms. Of note it is especially important for juvenile crabs and fish (salmonids) and migrating shorebirds, which in Willapa Bay number in the tens of thousands.

Corophium is a small amphipod crustacean with body length ranging from 1mm in the first instar up to 12 mm (nearly ½ inch) for an adult, which does not include the long antenna (that do not look like antennae). An important aspect of *Corophium* behavior is the deliberate actions they take in selecting the place where they burrow. The research pointed out the two considerations *Corophium* requires when considering a burrow site, namely, the sediment characteristics and the availability of food (diatoms). The importance of the sediment must include how easy to burrow first and when constructed will the structure hold up. The sediments must be chemically compatible with proper pH and a supply of well-oxygenated water when the tide is in. This amphipod is reported to spend time outside the burrow to change locations as they molt and become larger. Apparently they like to find a larger burrow and might even challenge an occupant. As noted in Brooks data (Figure 4) showing movement back to the treated area after shrimp control. The burrow they construct is a tiny U-shaped two opening structure. Burrow size varies with inhabitant but is usually a few millimeters in diameter and extends to a depth of 6 or so centimeters (‡2.5 inches). As one report stated, '*Corophium* is not just looking for a good stable home (sediment type) but one with a self stocking larder also'. This is the important relationship of sediment composition and a diatom source to this important grazer. This relationship is disrupted and probably eliminated entirely by *Z. japonica,* which allows the deposit of soft organic rich deposits essentially isolating that critical sedimentary surface needed by both crustacea and diatoms.

It is also important to point out additional benefits *Corophium* provides to the mudflat habitat aside from being an important food source for crabs, birds and fish. Their burrowing and excavations help provide a healthy sediment surface. They help mix the below surface nutrients and minerals used by the primary producers. They can also influence the productivity of the mudflat by maintenance and cleaning of the sediments and surface layers of the organic secretions and leavings by diatoms and bacteria (muccopolysaccharides). The link to Bay of Fundy Ecosystem Partnership report http://www.bofep.org/corophiu.htm provides interesting reading on the life and loves of *Corophium* in its benthic habitat. Japanese eelgrass and burrowing shrimp reduce over time and eventually can eliminate both the diatom food source and necessary sedimentary habitat of this important crustacean.

The Mudflat Habitat and what is lost with Japanese Eelgrass: Hopefully the three mudflat aspects, e.g. sedimentary, single celled plants and first order consumers (represented by *Corophium*) will serve to represent one of the important interactions on the highly productive mudflat. It is this example of just one interconnected lines of productivity that needs to be stressed in the EIS and other permitting documents. It is key to the estuary biota. There are of course a multitude of other players within the three examples of producer – consumer levels but tracing one interconnected sequence should make this very complex interacting sequence understandable. With probably hundreds of thousands of diatoms and tens of thousands primary gazers such the crustacea and larval forms per square meter they would still not be obvious to anybody walking by. The focus on *Corophium* as one example of a diatom grazer which in turn becomes one of many essential prey zooplankton utilized by many animal groups such as other crustacea (like crabs), shorebirds, and juvenile salmon. The importance of the benthic mudflat to the primary plant photosynthesizes (algae, mainly diatoms) is huge. It is not hard to imagine constructing a similar sequence for on dozens of interdependent species, as their interactions are known. It starts with who collected and transformed the solar energy then becomes a question of who consumes whom. It is fair to say much of this entire food web started with algae and much from the benthic of the sedimentary interface.

Zostera japonica replaces those forms on the open mudflat but possibly just as important decreases then stops the contribution from the area where it grows to the water column and other parts of the bay. There would no longer be the motile algae and zooplankton grazers for the entire food web. Although some claim Z. japonica provides a useable habitat there seems little proof that even if true it would not begin to mitigate the immense damage it creates by converting and thus eliminating the productive mudflat habitat.

Ferraro and Cole, 2011, in their Grays Harbor study compared the habitats on the basis of macrofaunal usage and summarized; "Across-habitat patterns on mean benthic macro faunal species richness, abundance, biomass, abundance of deposit, suspension and facultative feeders, a dominance and a diversity index for the five habitats common to both studies were the same on a rank measurement scale: eelgrass & oyster > mud shrimp > ghost shrimp & subtidal." Their involved statistical evaluation however, does not account for the micro biota elements and their contribution to the overall adjoining marine habitats and inhabitants. It is helpful and does allow a comparison of physical characteristics of the benthic based on types of consumers. Ironically, consumers that happen to be within the eelgrass patches or meadow most likely depend upon the mudflat for a food source.

For several seasons the Univ. of Washington research team of Armstrong, Doty, and Dumbauld sampled various intertidal habitats for young Dungeness crab in Willapa Bay. Their detailed sampling compared the habitat value for survival based on number of individuals of the newly settled crab and found them much higher among oysters with open mud areas than in eelgrass. These small first instars (6 to 20 mm approx.) require nearby protection, as well as, a ready food source (such as *Corophium*). Protection is found among (between and under) the oysters growing on our grounds. In fact, the ratio of young crab survival on a planted oyster bed with shell was many times greater than other habitat types including eelgrass. The point here is that a Z. *japonica* meadow lacks the diatom - crustacean population the latter being an important and critical juvenile crab food source. The combination of high lipid crustacea (e.g. *Corophium*) and protection for the early crab instars to avoid predators such as fish and birds is found on an oyster growing area and not eelgrass meadows. The important stage of the Dungeness crab is yet another important habitat function disrupted by the growth of Japanese eelgrass.

Hosack, et al. 2006, produce a report that indicated it would help answer some questions of habitat value between eelgrass and other intertidal areas. Their papers set out to show how aquatic vegetation (eelgrasses) provides trophic resources and hiding places and in short were key to most macro forms of the marine aquatic system. These were also important considerations in their prior studies in Willapa Bay. They quote in their introduction, "Productivity and complex

structure within estuaries created by sea grass and other submerged aquatic vegetation (SAV) provide trophic resources and predator refugia, allowing small fish and invertebrates to reach greater density and diversity relative to unstructured habitats, such as mudflats," This introduction left a many unanswered questions. What about that diatom/crustacean area that was replaced? Then, their conclusion and abstract seemed to point to a different conclusion. Also, like many previous studies, the Hosack report focused on the large visible forms and used fish and decapod usage not primary productivity or the multitude of life below a few millimeters. After ten or so pages of statistical analysis their concluding statement in the following statement help clarify:

"The composition of fish and decapods caught by fyke nets showed strong spatial associations, but there was no relation with respect to intertidal habitat type. The similar CPUE of fish and decapods observed between habitats may reflect different uses of these habitat types by fish and decapods, such as for foraging and migration. While both eelgrass and oyster habitats yielded higher densities of invertebrates, fish and decapod prey than mudflat at the scale of the habitat patch, fish and decapod distributions at low intertidal elevations are affected by large-scale landscape patterns beyond the focus of this study."

The Hosack, et al. abstract: "The species composition of fish and decapods was more strongly related to location within the estuary than to habitat, and fish and decapod species composition responded on a larger landscape scale than invertebrate assemblages. Fish and decapod species richness and the size of ecologically and commercially important species, such as Dungeness crab (*Cancer magister*), English sole (*Parophrys vetulus*), or lingcod (*Ophiodon elongatus*), were not significantly related to habitat type." This study was well done in several respects and confirms what we see in Willapa and in particular that certain species are not necessarily reliant on eelgrass. I did not see any reference to the importance of the open mudflat in their work, which is often omitted or perhaps not understood. They did not approach important questions such as: What does a particular habitat at a point in time mean to the overall health, food web, and productivity of the bay? Considering all biota regardless of size and their biological interactions in a habitat type can we judge generally the most beneficial? How and which botanical elements transfer solar energy to other parts of the marine environment? A bigger question seems to be, does *Z. japonica* have any positive contribution to the marine biota within or outside the habitat it has taken over?

A recent paper by Shafer, et al. (2013) was most disappointing on the topic of habitat composition and value. This public agency report for sale on the internet of twelve pages seems more of a personal a summary listing some ninety references. The few lines devoted to the invertebrate benthic *Z. japonica* community seem very incomplete. They state this invasive grass supports diverse benthic assemblages and in turn give reference to other studies that show species diversity and abundance was greater in meadows of *Z. japonica* than in adjacent sediments. This is incorrect and misleading, as I have tried to point out by mention and specific example of other animal and plant groups. The study above by Hosack, et al., concluded that the densities of 'invertebrates, fish and decapods' at various intertidal elevations was influenced by 'landscape patterns' and not the fact that eelgrass was present. There was no mention in the Shafer paper of any displaced habitat of the productive and beneficial diatom community. Shafer, et al. discuss *Z. japonica* as invasive and recommend peer-reviewed research to elevate its status as a good habitat. A far better scope of research might be to show the harm the increase of *Z. japonica* is responsible for. In the summary, the Shafer paper perhaps overestimate their contribution to this discussion when they infer the information and recommendations they provided could serve as a basis for providing scientific data in order to develop better informed management decisions and aid in defining a uniform management strategy for *Z. japonica.*

When the intertidal is covered with *Z. japonica* natural cycling of key nutrients and availability of sunlight could change the important role of the exposed intertidal mudflat. Those who judge the habitat change by the invasive dwarf eelgrass more 'valuable' than this important area for diatom production are probably not just in error but risk being party to and thus enabling irreparable harm to the marine near shore.

Many have reported that *Zostera japonica* meadows increase deposition and retention of organic matter (see the dark particles in the microscope images). This would seem the normal result from the sea grass decreasing tidal and wind currents that would remove the soft buildup of both sediment and organics. This in turn creates an unsuitable habitat for buried bivalves due to hypoxic conditions and enhanced sulfide concentrations even at the sediment surface. This has been observed on clam growing areas inundated with *Z. japonica*. Growers report a decrease in recruitment, growth and survival in the crop. The build up of this softer fluffy sediment within the eelgrass areas along with the presence of worms and bacteria are part of the modification by *Z. japonica*. This is not the habitat

type for diatoms or grazers like *Corophium*. Evidence of this comes from studies such as Ferraro and Cole comparing the benthic area under various habitats in Grays Harbor. Under the *Z. japonica* the most abundant animal form was a worm *Pseudopolydora* in contrast to a nearby area characterized by the mud shrimp, *Upogebia,* (with open sediment areas) where the most abundant form was *Corophium.* Also note that reducing or removing the benthic diatoms and their near bottom presence within a Japanese eelgrass area not only takes away the closeness of that vital food source for bivalves but would restrict water movement from tides, currents, and wind for planktonic algae such as diatoms to move within the eelgrass area.

I have used the following picture (Figure 6) of an oyster bed taken prior to removal of the oysters to show an intertidal area of high productivity and biological abundance and diversity. This is one of our oyster beds. In this instance it shows the two plus year stage in the rotational nature of our crop when the tide is out. When the tide returns it will bring many more motile species to participate in the productive nature of the bed. The oysters provide a vertical stable place of attachment, as well as, a place of protection for a host of both plants and animals. Note the larger algal forms such as *Ulva* (a green algae) and eelgrass with open mud areas available to accommodate the diatoms and their grazer following. Most of the species are probably not visible without finding their place of concealment or with a microscope. A host of small invertebrate forms would be found attached to, protected under or among the oyster clusters. However, this scene is a stage, which cannot be held constant or sustainable as a habitat but rather must be recreated in a cyclic manner, which is what we do when we farm oysters. Our shellfish require being a part of this healthy assemblage to be the best they can be and in turn, the oysters make a positive contribution to others in the benthic environment.

Figure 6. Oyster bed with crop nearly ready for harvest or transplant and also a biologically rich area with macro algae and eelgrass as part of a thriving diatom, micro and macro assemblage. This oyster bed needs periodic shrimp treatment on about a 5 to 7 (two crop) year basis. When the oysters are removed the cycle repeated with the planting of more seed (small oysters (spat0 on an old oyster shell (cultch). It takes a year or so for the process of renewal to build to optimal abundance and biomass but return of the diatoms and small grazers happens immediately. The area is not allowed to become unproductive by transforming to a thick meadow of eelgrass with associated sulfide sediment buildup or the sediments completely modified to a non supportive habitat by burrowing shrimp. This particular oyster ground has been farmed for over 100 years and most likely as productive today as when first used for Native Oysters.

The Burrowing Shrimp: Another affront to the critical benthic habitat:

There is available a large volume of information on the destructive nature of our two species of burrowing shrimp and their alteration of the benthic sediments. Thus, the attempt here is to avoid repetition but emphasize and expand on some, as well as, point out other impacts to the productivity and biotic diversity of bays such as Willapa. Often people are left with the impression that the Ghost and Mud shrimp only take up residence on oyster ground. This is totally wrong as unfortunately, Willapa Bay is home for thousands of acres occupied and modified by burrowing shrimp that have never been used for oyster culture or were abandoned for shellfish culture. Like the invasive Japanese eelgrass the burrowing shrimp take away the sedimentary mudflat for valuable productivity for the entire bay.

Figure 6. Photo of intertidal ground with burrowing shrimp. There are thousands of barren acres such as above in Willapa Bay.

Beside the physical liquefaction or 'softening' of the benthic sediments there also are additional impacts. The sediments as noted for the Japanese eelgrass bring to the estuary those valuable nutrients and literally store or keep them from washing from the shallows to the open ocean. These fossorial shrimp change the sediment composition in their actions to develop a liquid like sand water mixture in which to move within as they graze on the attached algae near the surface. Gone are the finer particles such as the platy-crystal clay minerals with entrapped nutrients such as silica salts (metasilicates), etc. When new sediments are introduced from the erosional activities of the watershed streams they are quickly disrupted and worked out of the intertidal areas and thus not available to the primary producers such as diatoms. Algae and especially the benthic diatoms are a major factor for the entire estuary on which the food chain is based. These diatoms depend upon the stability of the sediment surface in the intertidal to utilize the two key components, the solar radiation and nutrients. The burrowing shrimp reduce or eliminate the critical mixed benthic sedimentary structure turning the sediment into a mostly homogenous sand thus ridding it of the finer silt, organics, clay that would confine after entrapment minerals, elements and nutrients necessary for growth in an upland farm. This coupled with the constant agitation of the sediment over every tide eliminates those valuable areas necessary for diatoms on the sedimentary surface. Furthermore the shrimp, especially the ghost shrimp create a situation, which is difficult or

impossible for zooplanktonic grazers, such as the crustacea, to find diatoms or exist on or near the surface of an unstable sedimentary surface.

There are thousands of acres occupied and modified by dense populations of burrowing shrimp, which are not being utilized for shellfish culture or have been abandoned because of the shrimp. These extensive acreages not only make the ground appear barren (Figure 1) but in reality, it is. Even the microscopic benthic biota, so critical for estuary productivity, is greatly reduced or absent. Figure 1 shows how the sedimentary composition when the finer components are removed by the shrimp is converted to a sand size composition and thus subject to wave and current action (note the wave/ripple marks). A second photo (Figure 7) shows mud shrimp on an oyster area within minutes after treatment, which causes some of the dying shrimp to move to the burrow entrance at the sedimentary surface.

Figure 7. Approx a one-forth meter square mud shrimp area after treatment with mud shrimp at borrow entrance.

The sedimentary area occupied by mud shrimp is not as disturbed as the ghost shrimp modification even though the mud in Figure 7 would be difficult to walk through and oysters would sink. The mud shrimp constructs a static U-shaped burrow but does soften the sediments by creating the below surface voids. This shrimp and their colonies often occupy hundreds of acres with abundance often exceeding 100 per sq. meter. A second major negative impact the mud shrimp impart on other inhabitants of the estuary involves constantly drawing in seawater into the burrow, filtering out much of the plankton by capturing it within the seta (bristle like) structures on their appendages then exhausting it out the other opening. In so doing they filter out planktonic food such diatoms along the surface. In short they clean the water column and in so doing probably take out a large part of the food so vital to many other members of the biota (including of course shellfish).

In contrast to the intertidal mud flats dominated by burrowing shrimp, which have had most if not all the benthic biota removed and the sediments modified is the oyster grounds such as below. This bed has been farmed for over 100 years but since the early 1960's has had periodic burrowing shrimp control.

Figure 8. This is a bed that needs to be treated for the predictable increasing numbers of burrowing shrimp about every 5 to 7 years.

Figure 8 was taken in early spring and in the foreground are Dunlins, a shorebird that overwinters in and around Willapa bay. The Dunlins are probably feeding on benthic crustaceans and in particular the amphipod *Corophium,* which in turn, gives indication of the diatom-covered surface as noted in the *Z. japonica* remarks. The lower image (Figure 9) shows a close view during the summer period of the above oyster bed. One would find dozens of different plants and animals (many species of algae and micro zooplankton) living among, under or attached to the oyster clusters and a microscope would be required to see most of the species. It is this benthic habitat that is very critical to young Dungeness crab for survival in the first instar periods after metamorphing from the water column to the benthic existence. Again portions of the fauna will arrive and leave with each high tide (e.g. fish looking for small crabs or big crabs looking for a tasty oyster).

Figure 9. Close up of a healthy oyster growing area nearly free of shrimp.

In Figure 9 some larger marine vegetation (e.g. *Ulva* and *Zostrea*) is present with the oysters, which is common and part of the oyster farm assemblage on the growing area and is not a problem. Contrast this benthic habitat to the one modified by burrowing shrimp in Figure 1.

While burrowing shrimp inhibit at best and eventually eliminate shellfish on the surface by sedimentary modification and competition for food they have a similar if not identical impact to many of the other benthic organisms. Often this impact involves the removal or elimination of strategic shelter or support structures of other species. The oyster for example provides a hiding place for the first instars of crab, barnacle attachment and anchor for the large algae (see Figure 5). The open mud in between becomes a place for diatom and crustacea to be protected from wave action while in turn being a food source for others in the assemblage. Without the shrimp it is a healthy interactive assemblage and one we should work to maintain.

A final note or two: Submission of these comments is to emphasize the deleterious impacts *Zostera japonica* as well as burrowing shrimp have and will continue to have on the flora and fauna of marine areas. The comments are not restricted to commercially farmed shellfish areas but specifically call attention to many other important species of plants and animals being displaced or eliminated by these expanding species. Again we need to emphasize that even though shellfish are impacted by Japanese eelgrass and burrowing shrimp it is also impacting many other species. Conversely, shellfish and shellfish farming add and contribute to a productive benthic area. As the biological and economical damage to other than commercial shellfish beds is being better understood the need to use a proven control tool will become even more critical. It is important to understand the effect the reduction or loss of these high intertidal areas of primary productivity where sunlight is converted by the plant kingdom and in turn is passed onto the numerous species in the estuary. Shellfish are just a part of the mix along with dozens of other forms such as the crustaceans, birds, fish etc. Shellfish growers are trying to call attention to the damage being imposed on the benthic areas by Japaneses eelgrass and burrowing shrimp as they did with Spartina. Those interested in the environment and the resource agencies should listen.

Of special note is this winter photo of hundreds of Dunlin utilizing the first area to go dry to start feeding. A couple of years before this picture was taken this area was totally covered with a thick *Spartina* meadow (note the dark root remnants) and was not available to the shorebirds. The micro biota have returned as evidenced by the feeding shorebirds. Wilson Point in background and native marine grass in foreground. The shorebirds were the winners by careful removal of an invasive grass.

Figure 10 represents Dunlin utilizing some of the first intertidal to uncover as the winter tide ebbs.

When people such as owners of near shore areas, or agencies charged with marine resources, or environmentally minded, including myself a birdwatcher and one time board member of the our Audubon chapter, realize the degree of population degradation which happened with Cord Grass (*Spartina*) it seems obvious the need for a safe and proven way to periodically control, if not to eradicate, Japanese eelgrass, which is inflicting similar widespread damage. Allowing this eelgrass to continue to destroy important productive high intertidal areas is enabling the decline of productivity and species abundance. Over the past few years Zostrea japonica has expanded to over 9,000 acres (I have heard) in Willapa and is steadily increasing. What we do to continue to seek safe control methods for both the pests discussed here, should prove extremely important, especially if and when others realize the long-term impact to our marine near shore areas.

A personal summary might be that the extensive fine marine sediments (aka mudflat) provides the key conditions and location for small transitory phytoplankton to convert solar radiation for the energy essential to a large segment of the important marine fauna. As Japanese eelgrass becomes established it diminishes and eventually eliminates that access to the primary producers and grazers by modifying sedimentary composition, benthic chemistry and solar access. The burrowing shrimp species play a similar role in destruction of a sedimentary habitat for production of algae and their following of zooplankton grazers. Both convert large areas of the estuary from diverse assemblages and rich substrate to a monospecific habitat and modified sediments. The marine intertidal productivity, so critical to the marine near shore biota, is greatly reduced by the continued expansion of Japanese eelgrass and burrowing shrimp. The burrowing shrimp and Japanese eelgrass could be considered analogous to a cancer. Normally, when their numbers (as with cells) are in check and not spreading throughout and consuming other organs or areas there is no problem. When they are given the chance or are allowed to expand, they modify, exclude or eliminate critical areas of the marine body – just as a cancer.

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