Beach Wrack Nutrient Leaching and Community Composition on Gravel Beaches

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Abstract

Beaches world-wide have low primary production due to a stressful environment and action of strong hydrodynamic forces. For this reason, input from marine wrack as well as terrestrial debris is an important source of production in food webs. Wrack can also provide food and habitat for meiofauna that help transfer nutrients up the food web. These interactions have been examined on sandy beaches, but not on gravel beaches. I examined the relationship between beach wrack type, nutrient leaching, and meiofauna colonization on a gravel beach in San Juan County, WA. I used three different types of wrack: *Fucus disticus, Zostera marina,* and leaves from *Prunus avium* (Cherry). I conducted two different experiments: a nutrient leaching experiment by measuring nitrate and phosphate leaching from wrack over seven weeks relative to seawater controls with daily tidal simulation, and a community composition experiment using wrack-filled packets placed on a gravel beach. Both nitrate and phosphate showed similar patterns across all wrack types. Nitrate was absorbed by all wrack types at the beginning of the experiment, released in the middle, then absorbed again at the end. Phosphate was absorbed by *Zostera* and *Fucus* (though released by cherry) at the beginning, then released by all types of wrack, then all types had similar nutrients as seawater. Diversity of meiofauna was significantly correlated with final weight of the wrack inside the packets. Diversity of meiofauna changed significantly across type of wrack by date sampled. My data suggest that external factors such as bacteria, weather, and decomposition are more important than wrack type in nutrient leaching and community composition.

Introduction

Sandy beaches around the world are generally devoid of primary producers due to the action of strong hydrodynamic forces (McLachlan 1981, Houle 1997). Thus, dead material from outside sources such as organic materials supplied by adjacent coastal ecosystems are especially important in supporting beach food webs (Delgado et al. 2014, Orr et al. 2005).

On wave-exposed sandy beaches input from marine wrack and terrestrial debris is an important source of production in food webs (Dugan et al. 2003). Little is known about the nutrient input from wrack on gravel beaches (Orr et al. 2005). Furthermore, the rate of nutrients leaching from wrack, the residence time of such nutrients within the substrate, and whether they influence community composition on mixed-sediment or wave-protected coastal environments have been insufficiently addressed (Orr et al. 2005, Heerhatz et al. 2014).

Inputs of organic debris, both marine and terrestrial, to intertidal environments provides food and habitat space for many invertebrates, including talitrid amphipods, insects, and worms (Heerhartz et al. 2014). It is important to examine the link between beach wrack type, nutrient leaching, and community composition to determine how beach wrack impacts nutrient cycling on gravel beaches. Previous work has suggested that nitrogen content of nutrient leaching may impact community composition, though the exact relationship is unknown (Dugan et al. 2011).

Medium-sized “meiofaunal” consumers may have important effects on the breakdown and trophic integration of nutrients in beach wrack (Dugan et al. 2011, Lastra et al. 2008). For this reason, colonization of wrack by invertebrates has been examined in detail, particularly for sandy beaches (see Colombini et al. 2009, Olabarria et al. 2010). While Colombini et al. (2009) found no direct dietary link between *Posidonia oceanica* wrack and macroinvertebrates, Macmillan and Quijón (2012) found that macrofaunal organisms colonized wrack-associated sediments preferentially according to wrack nutrient value. However, these studies did not incorporate the role of nutrient releases from beach wrack.

Dugan et al. (2011) found that different types of beach wrack may have different nutrient leaching rates and thus different impacts on productivity and marine soils. They found that concentrations of dissolved organic nitrogen and dissolved inorganic nitrogen were positively correlated with total biomass of marine macrophyte wrack, but the study did not test different wrack types individually.

I examined the relationship between wrack type, nutrient leaching of nitrate and phosphate, and community composition of the wrack. I examined these factors on gravel substrate rather than the previously-studied sandy substrate.

Autotrophs differ in tissue composition (structural and chemical) (Dethier et al. 2014, Mann 1986. Papenbrock 2012) so it is plausible that they decompose differently and therefore release nutrients into the environment at different rates and concentrations. I hypothesize that meiofauna such as amphipods and insect larvae will colonize different types of beach wrack, with fauna colonizing macrophytes leaching out more nutrients preferentially (as an indication of decomposition state and nutrient value) as seen in previous studies (Macmillan and

Quijón 2012, Dethier et al. 2014). This may lead to higher abundance and richness, as well as higher species diversity of wrack-associated invertebrates.

Methods

Location

Two experiments were conducted at University of Washington Friday Harbor Labs, (48.5466, -123.01275). Most beach sediments in the San Juan Islands are derived from glacial deposits and include a heterogeneous mix of clay, silt, sand, and gravel, supplied primarily from bluff erosion (Shipman 2010). Sources of beach wrack are primarily terrestrial vegetation from the marine riparian zone, seagrass from extensive beds in the shallow subtidal zone, and algae detached from low-shore and subtidal cobbles (Heerhatz et al. 2014).

Lab Experiment

Three types of fresh material were harvested from around Friday Harbor Labs: the brown alga, *Fucus distichus*, seagrass *Zostera marina*, and leaves from a wild cherry tree, *Prunus avium*. Wrack was soaked in fresh water for no more than 24 hrs in order to kill existing living organisms before being cleaned and blotted dry. 125 g bin $^{-1}$ wet-weight (WW) of each wrack type was placed in 25 x 15 x 13 cm plastic bins filled with approximately 2 in of thoroughly rinsed gravel collected from a nearby beach. Gravel-only bins were used to control for ambient nutrients in seawaters. Each treatment was replicated three times. Holes were drilled at the bottom of each bin and mostly left open to allow for rain drainage.

To simulate semidiurnal tides, bin holes were plugged twice daily and wrack was submerged 1 L of ambient of seawater. Wrack soaked for 5 minutes before the bins were drained. Once per week for seven weeks this drained water was collected for nutrient sampling. All nutrient sampling equipment was acid washed (10% HCl) before sampling to avoid sample contamination. Water samples were filtered through 45µm pore-sized filter paper and frozen until tested.

Water samples were tested with Hach Nitrate Cadmium Reduction Method (8192) powder pillows and Hach Phosphorous Reactive Absorbic Acid (8048) Method powder pillows with 15ml and 10 ml samples respectively. Reacted samples were measured with a DR6000 spectrometer in 10ml sample cells. Standards were tested according to the standard solution method provided by Hach (Hach 2014a, Hach 2014b).

Average precipitation across seven weeks sampled at Friday Harbor as reported by US Climate Data was not significantly different (One-Way ANOVA, p>.05).

Field Experiment

The species used for the laboratory experiment were also used for field experimentation. 100 g WW of each species was placed into individual 20 x 10 cm (approx..) burlap bag packets. Packets were placed 0.7 m apart on a gravel beach near Friday Harbor Labs, anchored to chain with zip-ties at mid-high tide wrack line, approximately 6 ft above Mean Lower Low Water. Packets (replicate of 3 per wrack type) were collected from the beach after 1, 2, and 5.5 weeks, frozen, then carefully examined for invertebrates. Invertebrates were identified to morphospecies and counted. Wrack WW was re-measured to estimate decomposition rates.

Statistics

Average nutrient concentrations for each sampling occasion for the control bins (with gravel) were subtracted out from the observed nitrate and phosphate concentrations in order to get nitrate and phosphate relative to ambient water samples (Sampled Wrack Nutrient Value – Average Control Sampling Value For Sample Day = Adjusted Wrack Nutrient Value).

Two-way repeated measures ANOVA was runn for both nitrate and phosphate relative to ambient seawater across sampling date within algae type, and Tukey Post-Hoc tests were conducted for significant results. A single-factor ANOVA was ran to determine significant differences in weight loss between bins (beginning weight-end weight).

Two-way repeated measures ANOVA was also ran for morphospecies in packets for Shannon-Weiner diversity index, richness, evenness, average number of organisms across date collected within wrack type. Weight loss for wrack type over sampling date was also analyzed using a two-way repeated measures ANOVA.

A linear regression model was run between diversity and weight lost for all replicates.

Results

Nutrient Leaching

Both nitrates (N) and phosphates (P) showed significant differences across sampling date (Nitrate: $F = 0.004577$, $DF = 6$, $p < 0.0001$; Phosphate: $F = 4.772$, $DF = 6$, $p < 0.001$) and wrack type (Nitrate: $F = 13.125$, $DF = 2$, $p < 0.0001$; Phosphate: $F = 5.496$, $DF = 2$, $p < 0.01$) with no significant interaction between sampling date within wrack type for either nutrient (Nitrate: $F = 1.849$, $DF = 12$, $p = 0.074$; Phosphate $F =$

1.963, DF = 12, p = 0.056) (Figure 1). Nitrate concentrations showed a pattern over the seven weeks of beginning as lower than the control for all wrack types, then changing to higher than the control, then returning to lower than the control. Phosphate showed a pattern of *Fucus* and *Zostera* beginning lower than the control (cherry leaves as higher than control), then all wrack species higher than the control, then all rack species very similar to control nutrients (Figure 1).

Phosphate released from cherry leaves was significantly higher than that released from *Fucus* and *Zostera* ($F = 5.49$, $p < 0.01$); Nitrate leached from *Zostera* was significantly more positive than the wrack of both *Fucus* and cherry leaves ($F = 13.125$, $p < 0.001$).

With regard to degradation, *Zostera* lost significantly more weight than cherry leaves, and *Fucus* lost an intermediate amount of weight ($t=-4.011$, $p=0.0163$) (Figure 2). The *Zostera* appeared more degraded, as it was bleached and much thinner upon examination than at the beginning of this experiment. The cherry leaves looked similar to the start of the experiment, the *Fucus* bladders were degraded but otherwise it looked similar to the beginning of the experiment.

Community Colonization of Wrack Packets

Few organisms were found in wrack packets. Most individuals in packets were amphipods and ogliocheates, with some *Litorina spp*., limpets, and insect larvae. (Figure 3) (Appendix 1). There was no real distinguishable trends between meiofauna type and wrack type over time, though cherry leaves did seem to have noticeably few meiofauna, though due to low sample sizes there was no statistical significance.

Diversity was found to vary significantly across type and across date within type (Repeated Measures ANOVA, Type: DF = 2, F = 3.979, p = 0.041, Type by Harvest: DF = 3, F = 4.456, p = 0.019) (Figure 4). Diversity in *Fucus* increased significantly from the first to the second week, then remained the same for the fifth week. Diversity in cherry leaves and *Zostera* did not change significantly over sampling weeks. Diversity in *Fucus* was significantly higher than in cherry leaves, and *Zostera* had intermediate diversity. Similar results were found for evenness (Figure 4).

Average weight lost varied significantly over date collected and between wrack types but not across wrack type by date collected (Date collected: F = 40.31, DF = 1, $p < .001$, Type: F = 35.35, DF = 2, $p < .001$) (Figure 5, Figure 6). The average weight that cherry leaves lost was significantly less than the average weight lost by *Zostera*, which was significantly less than the average weight that *Fucus* lost (F = 35.35, DF = 2, $p < .001$) (Figure 5). The average weight lost in the bags collected on week 5.5 was significantly lower than the weight in the first and second weeks (F = 40.31, DF = 1, $p < .001$) (Figure 6). However, there were no packets of cherry leaves collected at week 5.5 due to high winds and large waves washing packets away.

Meiofaunal diversity was negatively correlated with wrack weight lost (Linear regression model, F = 5.334, df=22, p=0.03054, $r^2 = 0.1954$) (Figure 7). No significant results were found for total number of organisms or species richness across time or wrack type (Repeated measure ANOVA, $p > 0.05$).

Discussion

Nutrient Leaching

Fibrous material, often lignin or cellulose in seagrass and terrestrial biomass, has a very low content of nitrogen, which makes it less valuable to consumers (Mann 1988). All terrestrial plants tend to have a large quantity of fibrous material (Papenbrock 2012). *Fucus* does not have large quantities of fibrous material, as it is an alga, but *Zostera* does, as it is a seagrass. *Zostera* lost more biomass than *Fucus* and cherry leaves, which is interesting because *Zostera* has more lignin than *Fucus* (Papenbrock 2012). *Zostera* also appeared to be more fully decomposed than either *Fucus* or cherry leaf biomass, showing bleaching of the blades as well as clear loss of weight. However, *Zostera* has phenolic acids that may act as a barrier to or inhibit microbial growth (Quackenbush et al. 1986). It is unsurprising that the cherry leaves did not decompose, as cherry leaves have even more lignin than *Zostera*, as well as cuticles (Davies et al. 2007, Gessner and Chauvet 1994). Cherry leaves from *P. avium* also contain small amounts of cyanogenic glycosides, which may also inhibit decomposition (Rushforth 1999).

Both fungi and bacteria colonize wrack and speed the break down process (Mann 1988). Microbes play a key role in cycling of organic matter by making it more nutritious for consumers (Fenchel 2008). The high levels of nutrient absorption in the first two weeks may be because of microbial communities, made up of bacteria and fungi that can digest cellulose, Sosik and Simenstad (2013) found that microbes on decomposing kelp blades utilize nitrogen from detritus; my data support their hypothesis that bacterial communities uptake nitrogen from decomposing *Fucus*. However, Sosik and Simenstad (2013) did not find that bacterial communities went through a cycle of nitrate uptake and release as suggested by my data (weeks six and seven), where nitrate values were negative again relative to seawater control.

My results also indicate that bacterial communities may take up phosphorus, which is another important nutrient in the shoreline trophic cycle (Dugan et al. 2011). While cherry leaves consistently released phosphates and absorbed none, both *Fucus* and *Zostera* absorbed phosphate then released it, indicating perhaps that the bacteria that took up phosphorus were more present on *Fucus* and *Zostera* than cherry leaves.

A factor in nutrient release may have weather patterns. The similar patterns of nutrient leaching over all wrack types indicate that there was an external factor working on all of them, causing them to produce similar results. Because my experimental wrack bins were exposed to weather, and because they were open systems (allowing water to drain), rain may have washed away unabsorbed (by bacteria) nutrients from wrack bins, lowering overall nutrient amounts, making it seem like bacteria absorbed more nutrients than they actually did. However, the average precipitation over the weeks that I ran the test was not significantly different. Temperature also may have been a factor, because the weather got colder as my experiment progressed; in week 6 the low temperature dropped below freezing for several days. This may have halted decomposition and triggered the abrupt difference between weeks five and six/seven, because without decomposition, additional (unabsorbed) nutrients that were still present in the wrack would not have leached out.

Community Composition Colonizing Wrack

Numbers of organisms found in mesh packets placed on the wrack line and collected were surprisingly small in relation to number of organisms found in beach wrack on sandy and cobble beaches in other studies (Colombini et al. 2000, Heerhartz et al. in review). This may have been due to the mesh packets used, where other studies used naturally occurring wrack, experimental cylinders, or tube traps. However, meiofauna have been found to be significantly related to the C:N ratio, and low nitrogen leaching (as found in my study) can impact the number of meiofauna colonizers either positively or negatively (Dufour et al. 2012). Studies on sandy beaches have also found meiofauna in sediments underneath wrack (Olabarria et al. 2010), and though I collected gravel sediments from under my experimental packets, I found no meiofauna underneath the wrack . This might have been caused by prevention of small pieces integrating in the sediment by the mesh bags. This may also have caused lower diversity, as it has been hypothesized that organic matter filtered through sand is a primary source of nutrients for trophic webs (Dugan et al. 2011, Macmillan and Quijón 2012).

Fucus and *Zostera* were more attractive to meiofauna than cherry leaves. It is possible that this is because of the aforementioned differences in chemical or structural composition. Though *Zostera* degraded more rapidly than *Fucus* in the nutrient leaching experiment, the average weight lost of *Fucus* for all packets was significantly more than the average weight lost of *Zostera* for all packets, implying a higher rate of herbivory of *Fucus* than *Zostera*.

The correlation I found between diversity of meiofauna and decomposition of wrack as measured by weight loss is supported by previous work by Dufour et al.

(2012) and Heerhartz et al. (*in review*). Wrack decomposition clearly significantly impacts meiofauna colonization.

Conclusion

External factors seem to be more important in wrack nutrient leaching and decomposition than wrack type. Microbial communities and weather interactions are the most likely factors that led to the trends in nutrient concentrations that I observed. If the nutrient concentrations were caused by microbial communities, my results support the conclusions of Sosik and Simestead (2013) that microbial decomposition significantly affects chemical composition of detrital kelp.

Wrack type does seem to have an impact on organism colonization, most likely due to preferential grazing on wrack with less structural compounds. Though *Zostera* degraded more in the nutrient experiment, *Zostera* has phenolic compounds which may inhibit herbivory as well as microbe growth (Quackenbush et al. 1986). The microbial colonization of *Fucus* may have made it more attractive to herbivores, and thus decreased *Fucus* biomass and may be cause for the increased diversity of meiofauna.

Further examination of microbial communities on wrack is necessary in order to clarify the role of beach wrack in gravel beach trophic systems.

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Figures

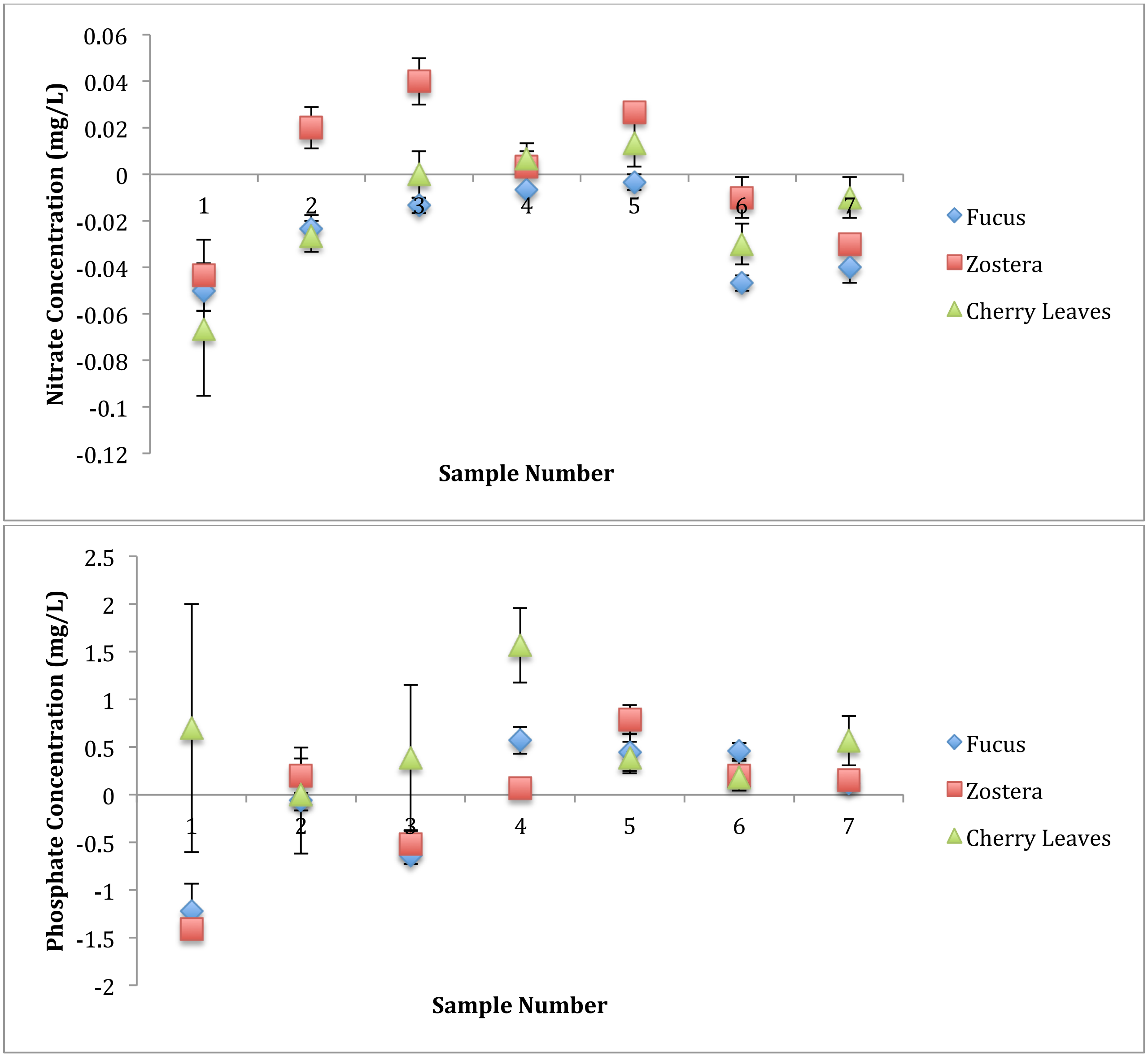


Figure 1. Nutrient Concentrations of Algae Types Over Sampling Period. Average values of phosphate and nitrate in seawater for each sample date was subtracted from the observed wrack-type nitrate and phosphate values. For both phosphate and nitrate, average nutrients leached were significantly different between species, and significantly different over time, but there was no significant

interaction factor (Repeated Measures ANOVA, Nitrate: Date: DF = 6, F=16.592, p < .0001; Type: DF = 2, F = 13.125, p<0.0001, Phosphate: Date: DF = 6, F =4.772, p < 0.001; Type: DF = 2, F = 5.496, p < 0.01). Error bars +/- 1 SE (n=3).

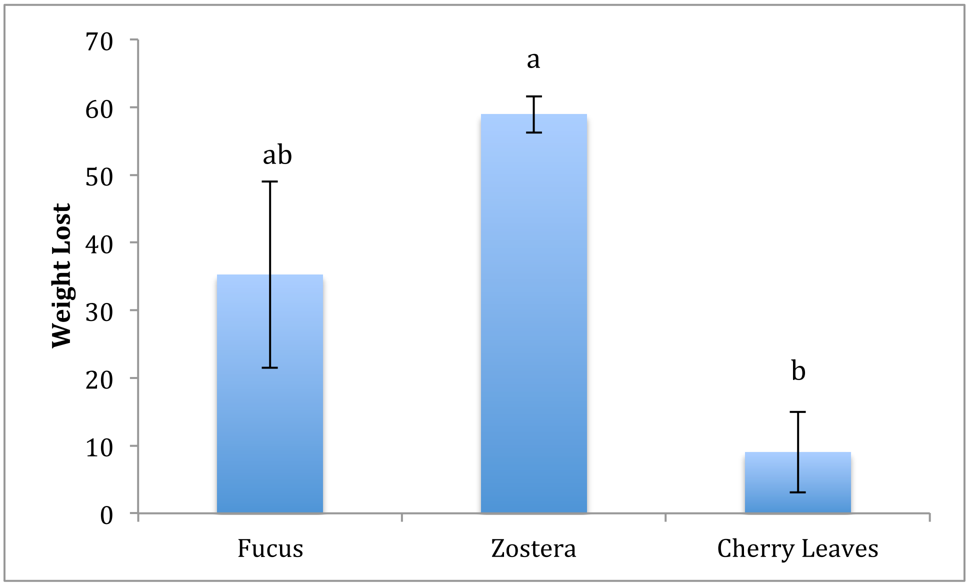
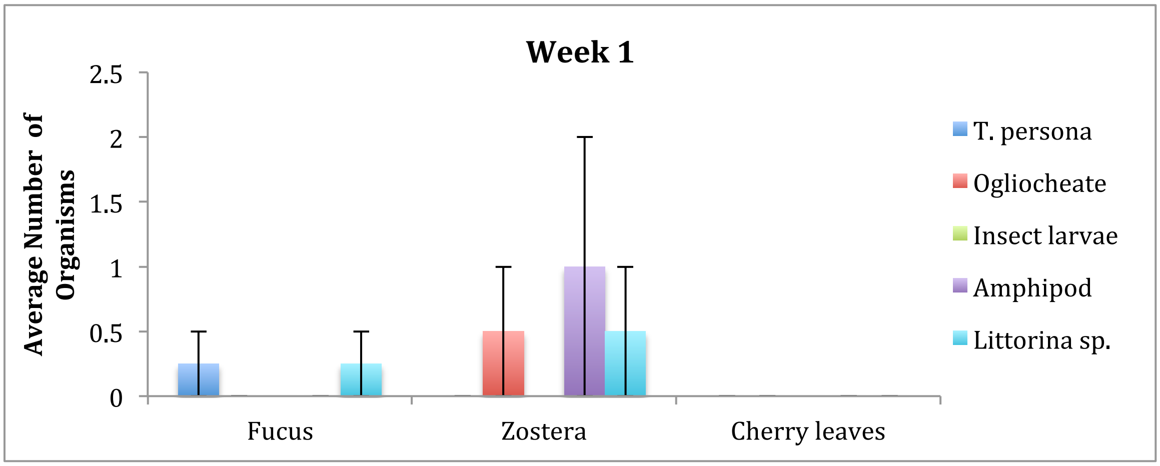


Figure 2. Average weight lost over seven weeks across wrack type. Letters indicate significant differences (one-way ANOVA, t=-4.011, p=0.0163). *Zostera* lost significantly more weight than cherry leaves, with *Fucus* in the middle. Error bars +/- 1 Standard Error (N=3).



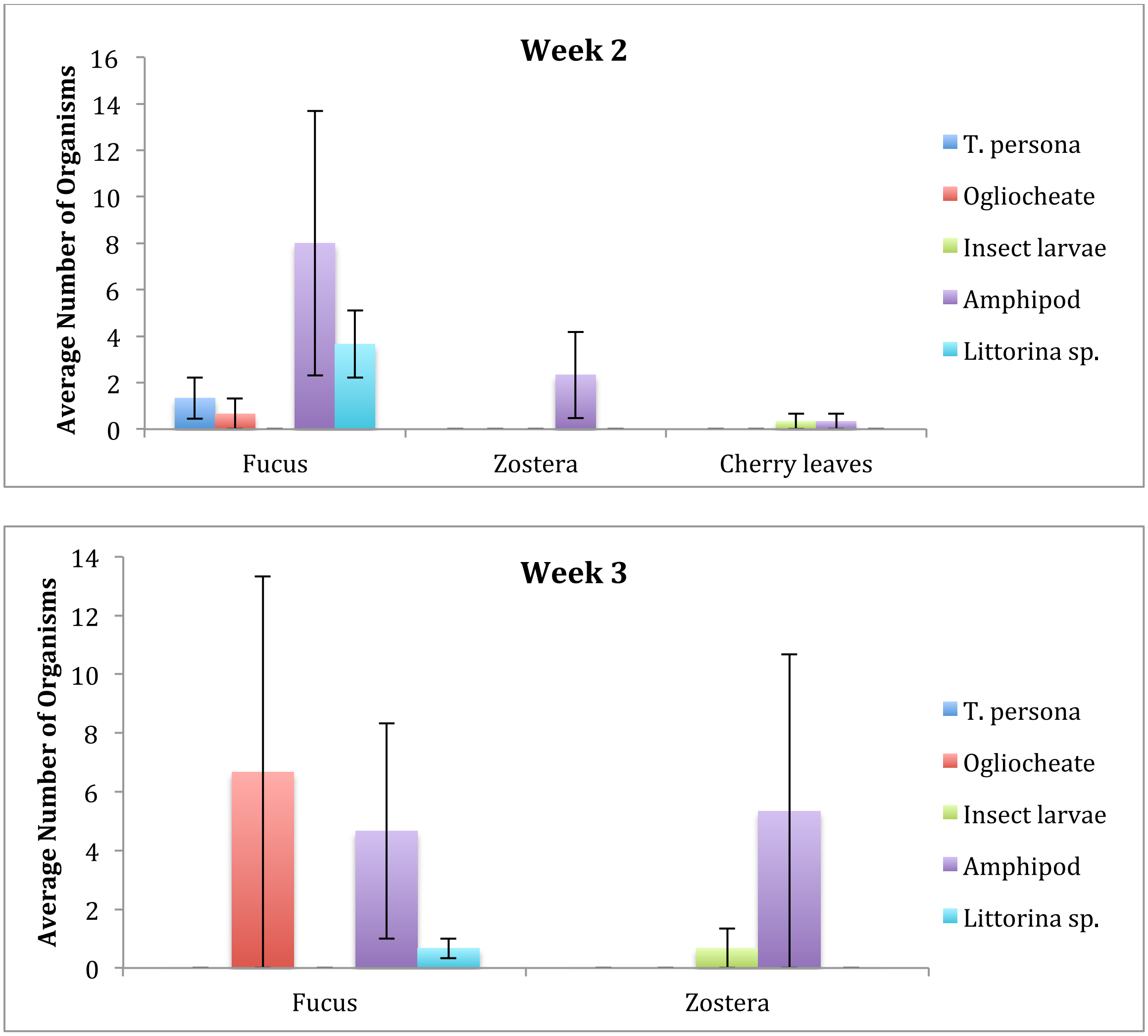


Figure 3. Species composition of major species found in packets across wrack type and sampling date. Similar genus combined for graph simplicity, similar families combined as well. Error bars +/- 1 Standard Error (n=3). Cherry leaves data missing for week three due to packets washing away.

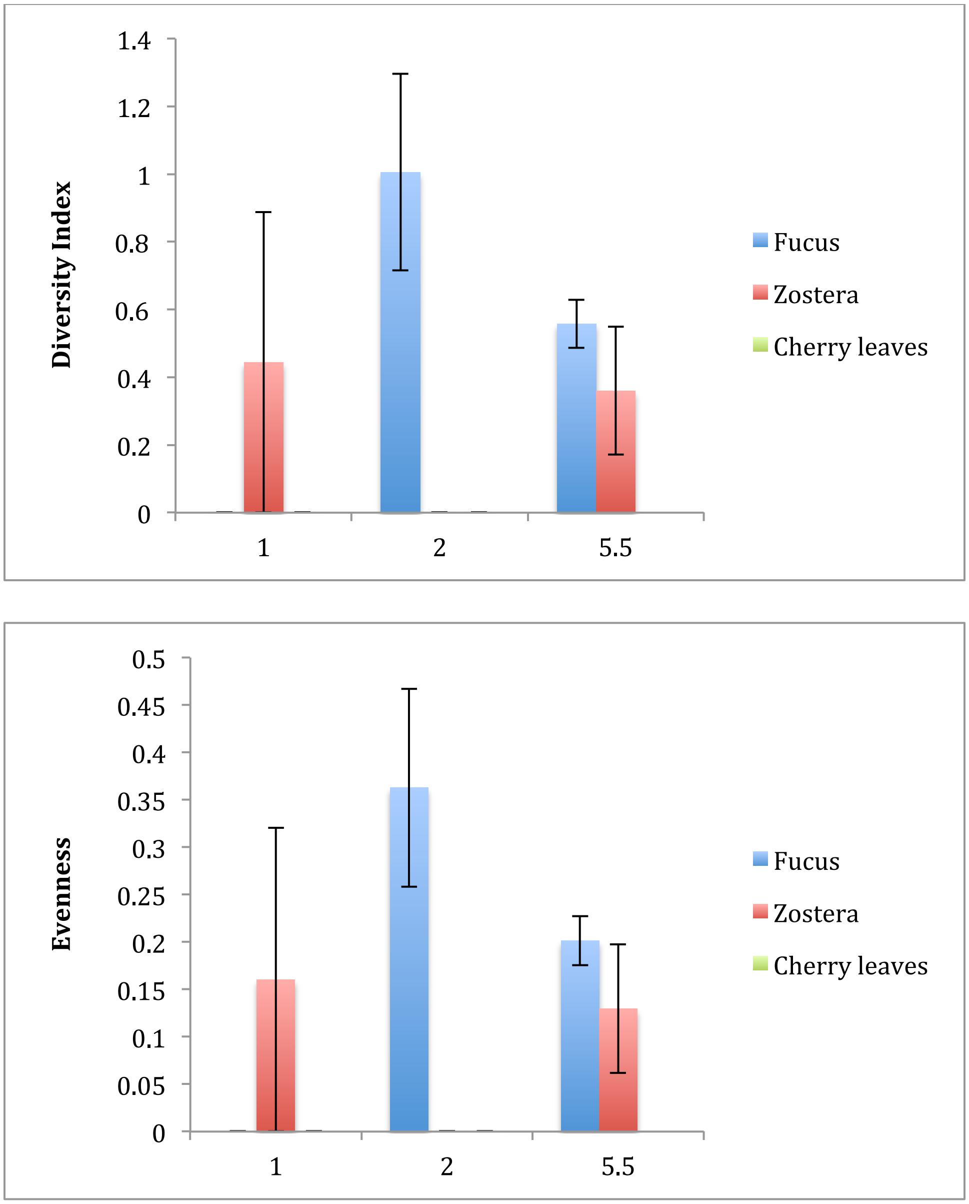


Figure 4. Average diversity (Shannon-Weiner Index) and evenness for packet replicates collected over three weeks. Diversity and evenness changed significantly for different types of wrack across time sampled (Repeated Measures ANOVA, Diversity DF = 3, F = 4.46, p = 0.019; Evenness DF = 3, F =4.588, p = 0.017) . Error bars +/- 1 Standard Error (N=3).

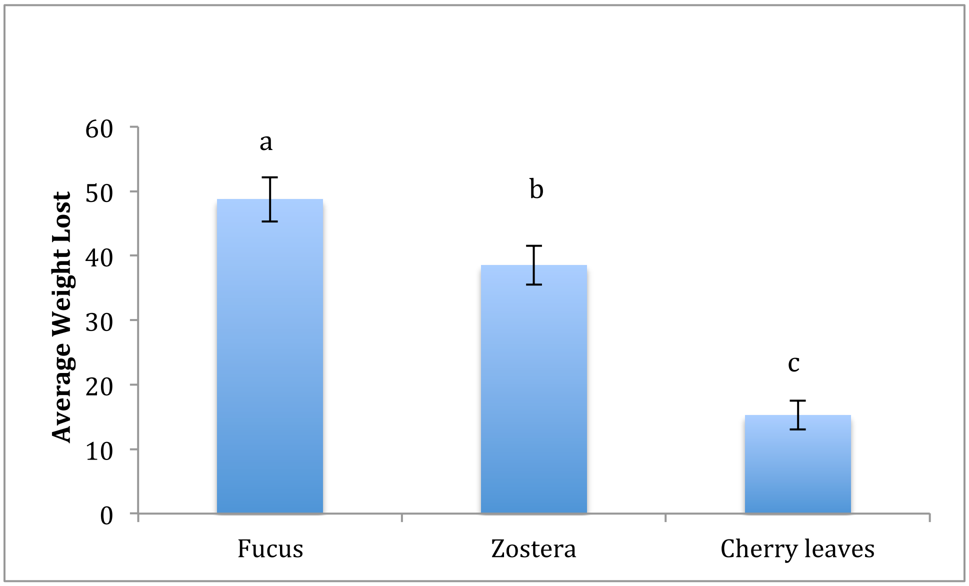


Figure 5. Average weight lost of Fucus, Zostera, and cherry Leaves averaged over all dates collected. Letters show significant differences (MANOVA, Tukey Post-Hoc, F = 35.35, DF = 2, p < .001). Error bars +/- 1 Standard Error (n=3).

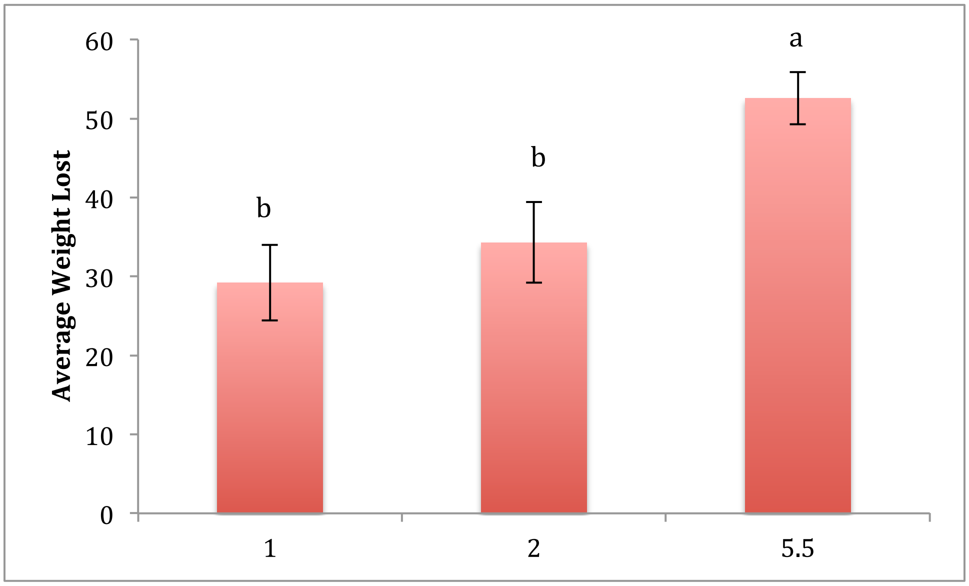


Figure 6. Average weight lost of all wrack types averaged over three sampling dates. Letters indicate significant differences (MANOVA, Tukey Post-Hoc, F = 40.31, DF = 1, p < .001). Error bars +/- 1 Standard Error (n=3).

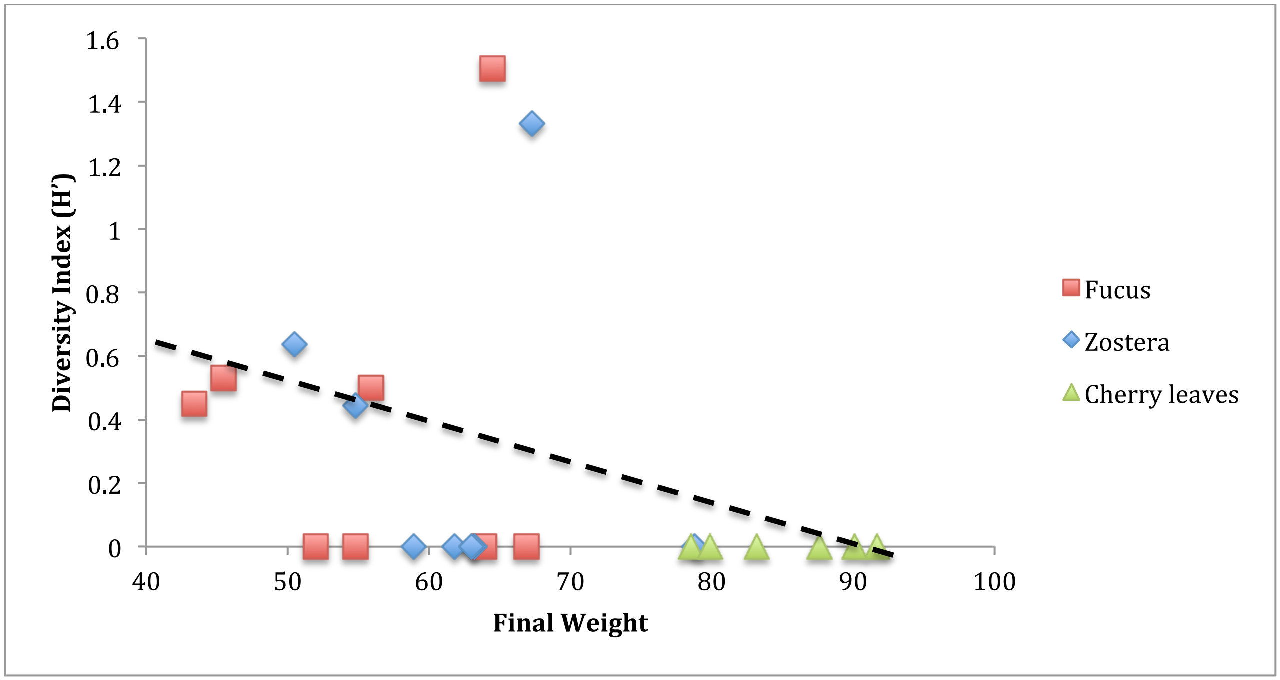


Figure 7. Correlation of Final Weight and Diversity. For all packets across all sampling periods, diversity of meiofauna was significantly correlated with final weight of the packets (Linear Regression Model, df=22, p=0.031, r=0.1954).

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Appendix

Table 1. Total numbers of observed meiofauna morphospecies found in packets collected on a gravel beach over three time intervals: 1 week, 2 weeks, and 5.5 weeks.

Harvest	Type	Nu	Litorina Sitkana	Masked Limpet	Amphipod S1	Litorina Scutulata	Marine mite	Ogliocheate	Ribbonworm	Amphipod (S2)	Amphipod (S3)	Isopod-Idotea	Amphipod (S4)	Insect larvae	Amphipod (S5)	Mussle	Crab Larvae	Plate Limpet
1	Fucus	1		1														
1	Fucus	2																
1	Fucus	3	1															
1	Fucus	4																
2	Fucus	1	4	1														
2	Fucus	2	6		17			2		2								
2	Fucus	3		3	3	1					2	1						
3	Fucus	1				1									1			
3	Fucus	2			10								2					
3	Fucus	3	1					20							1	1		
1	Seagrass	1			2	1	1	1										
1	Seagrass	2																
2	Seagrass	1			6													
2	Seagrass	2																
2	Seagrass	3											1					
3	Seagrass	1			15								1				1	
3	Seagrass	2																
3	Seagrass	3												2				1
1	Cherry leaves	1																
1	Cherry leaves	2							1									
1	Cherry leaves	3																
2	Cherry leaves	1																
2	Cherry leaves	2												1				
2	Cherry leaves	3			1													