Differences in gonad somatic indices with depth in Pacific Northwest invertebrates

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Abstract:

Drift algal material exported from kelp beds plays a significant role in nearby ecosystems. Phenotypic traits such as gonad index and jaw diameter can be indicators of diet consistency and nutrient uptake and thus can be used to assess the possible role of exported kelp. In this study, individuals of an herbivorous (*Strongylocentrotus droebachiensis*) and a filter feeding (*Balanus nubilus*) species were sampled from near the kelp beds in the shallow subtidal photic environment (SSPE) and far from the kelp beds in the deep subtidal environment (DSE). Urchins in the DSE had significantly larger gonads and jaws in comparison to individuals in the SSPE. I conclude that urchins in the DSE were getting better fed, whether through quantity or quality of food, suggesting that drift algae was being exported from nearby kelp beds. There was no significant difference between barnacle gonad indices with depth suggesting that their particulate organic matter food was equal at both depths. Future studies could examine gut contents to determine if there are diet differences between the two depths.

Introduction:

Coastal and marine ecosystems provide numerous services to humankind. From food reserves, to water sources, to climate control we are very dependent on the ocean. These ecosystems are closely connected with others; if a key part of this web were destroyed, it could alter the system around it irreversibly (Chen et al. 2011).

Kelp beds can define an ecosystem. They act as food sources and nursery grounds for many species and can greatly increase species diversity (Rogers-Bennett et al. 2011, Burrows 2012). They can significantly alter their surrounding environment by modifying water flow and light levels (Morrow and Carpenter 2008). The survival of juvenile kelps can also be affected by water flow (Duggins 2001). Herbivory also can be a critical factor in kelp beds because urchins, consumers who by grazing significantly control open space in benthic communities, can remove an entire kelp bed and so have deleterious effects on the ecosystem (Feehan et al. 2012, Elahi and Sebens 2012). The importance of kelp beds extends beyond their actual boundaries because large quantities of detrital kelp are transported beyond the kelp beds as drift algae, and provide food sources to herbivores in low-productivity environments, such as the deep subtidal environment (Kelly et al. 2012).

Evidence of this exported detrital material is not only found along the ocean floor, but also within herbivorous species. If detritus is in large enough quantities, excess nutrients, along with fatty acids, consumed by herbivores are transferred into gonads, which are used for both reproduction and nutrient storage (Hughes et al. 2011, Kelly and Schiebling 2012, Russell 1998). Therefore, gonad weights are a good indication of the long-term nutrition of an individual. Jaw length and diameter in urchins is also an indicator of relative food availability, with larger jaws being an indication of less food over time (Ebert 1980).

Food limitation is a key factor in the output of gametes. For example, in urchins, inconsistent food resources during periods of early gamete production can result in infertile gametes, whereas these same conditions after initial gamete production reduce overall gamete output (Dodge and Edwards 2012). In *Strongylocentrotus* in the Pacific Northwest, March through May are optimal times for measuring gamete output as spawning generally occurs in April through July (Strathmann 1987).

Drift algal material is present in abundance at depths below the photic zone in the San Juan Archipelago, with accumulation in piles at depths greater than 90 meters

(Britton-Simmons et al. 2012). In *Strongylocentrotus franciscanus*, 80% of gonad somatic indices (GSI) did not vary between the shallow subtidal photic environment (SSPE, depths <15 meters) and the deep subtidal environment (DSE, depths >80 meters) (Britton-Simmons et al. 2009). This is surprising because kelp beds, which are considered to be high productivity zones, usually do not extend deeper than 20 meters. The high GSI in deep urchins suggests that stockpiles of drift material may be providing a consistent diet for herbivores not living within the photic environment. Despite this seemingly consistent food source, urchin density declines with depth, likely due to reduction of their preferred substrate, bedrock (Britton-Simmons et al. 2012).

My objectives were to examine two species, an herbivore and a filter feeder, at two different depths, one within the photic environment and the other outside, to determine the effects of depth on gonad weight and urchin jaw diameter (as an indicator of nutritional state). In comparing gonad weights between two depths during this time of year, it should be possible to estimate consistency of food availability at each location. I hypothesized that, for both species, gonads will be larger in the SSPE than in the DSE due to abundant local food sources. I also hypothesized that urchin jaw diameter will be larger in those samples collected from the DSE because food is not as readily available.

Methods:

Sampling:

Individuals from the DSE were collected from Cattle Pass, between Lopez and San Juan Islands, Washington State, USA by means of a trawl at a depths between 87m and 114m. A dive team collected SSPE animals nearby, at King's Point off Lopez Island.

This site was selected because of its accessibility at both depths and the presence of both *Strongylocentrotus droebachiensis* and *Balanus nubilus*. *S. droebachiensis* selected from the DSE totaled 54, and 39 were selected from the SSPE. *B. nubilus* collected totaled 50, with 25 collected from each depth.

Animals were held in tanks without additional food until dissection. Urchin dissections and measurement of wet weights followed procedure outlined in Kelly et al. (2012). Gonad indices (GI) for urchins were calculated as (gonad wet weight/total wet weight) *100. I also measured test and jaw diameters using calipers. Urchins that had spawned were removed from the data set, leaving 49 DSE animals and 33 SSPE animals. Barnacles were dissected to remove the ovaries, for which both wet and dry weights were taken. Length (LOP) of the first opercular plate and width of the opercular plates (WOP) were taken and multiplied in order to create an individual size matrix with which to compare the gonad weights. Gonad indices for barnacles were calculated as (gonad dry weight/(LOP * WOP)) * 100.

Statistical Analysis:

Sea urchin gonad indices were compared with a 1-way ANOVA using depth as the fixed variable. This was repeated for jaw-to-test ratios by depth. Barnacle gonad indices with depth were also compared using a 1-way ANOVA.

Results:

In urchins, for which only the wet weights were measured, gonad indices showed significant variation between depths, with urchins in the DSE having nearly twice the average gonad index as those in the SSPE (Table 1, Figure 1). Jaw to test ratios were also significantly different (Table 1) by depth, with those urchins in the DSE having larger jaws for their test size (Figure 2). The barnacle gonad indices, Figure 3, showed no significant difference between depths (Table 2).

Discussion:

The objectives of this study were to determine if there was a significant difference between nutritional condition at two different depths in an herbivorous species and a filter feeding species. The data suggests that, contrary to expectations, deep-water animals do not show any decline in condition relative to shallow-water animals. In urchins, gonad indices of animals from the greater depth were actually higher than those from shallow depths. Interestingly, the jaw ratio in DSE animals was also higher than those in SSPE, which would indicate that food resources were lacking. This contradiction could mean that urchins, who use gonads for nutrient storage as well as reproduction, need more nutrient storage in the DSE because food is abundant in drift piles, but lacking in between. These gonad indices could also suggest that algae within the shallow water kelp beds are not as accessible as thought or that drift algae in deeper water are abundant enough and have high enough nutritional value to support production of large gonads. Another possible explanation is that DSE urchins are supplementing their diet with other foods such as invertebrates, which might explain the high ratio of orange fecal particles found in DSE animals compared to SSPE in this study (Knip and Scheibling 2007, personal observation).

In the filter feeding species, *B. nubilus*, gonad indices did not vary significantly between depths. This indicates that particulate organic matter, whether primarily of algal detritus or other sources such as phytoplankton, is a consistent food resource at both depths. This is surprising because filter feeders are generally thought of as consuming phytoplankton, which is not present in abundance in deeper waters. Therefore, filter feeders in the DSE must be getting their food resources from a different source, one that likely integrates particulate organic matter (POM) from decaying detritus as a regular part of their diet. This is important to note because POM, such as consumed by filter feeders, fills a very different ecological role in the DSE than drift algae.

My results are consistent with the hypothesis that drift algae and other forms of kelp such as particulate organic matter can serve as an effective food source in environments outside of the kelp bed, such as the DSE. Interestingly, a similar study in the north Atlantic showed the opposite, that animals shallower and closer to the kelp bed had larger gonads than those deeper (Kelly et al. 2012). They also found significant variation between sites, and we only tested one site in our study. However, in Kelly et al. (2012), all sites exhibited a decline in gonad indices with depth, whereas our one site showed an increase with depth. One hypothesis to explain these differences is that certain phenotypic traits such as smaller gonads in *S. droebachiensis* may be predator-induced (Selden et al. 2009). This predation trend, if different at different depths and sites, might explain differences in results between studies and sites. Another hypothesis to explain this variation would be that detritus may be sinking and aging more rapidly in our system, and bacterial colonies on aging kelp may account for higher nutritional content.

This research is significant because it strongly suggest that drift algal material is being exported from nearby kelp beds and utilized in other habitats. Herbivorous species are strongly supported by this drift material and, in some cases, appear to have better diet consistency and quantity than those living within the kelp beds. Filter feeders are also as well supported in the DSE as in the SSPE, suggesting that particulate organic matter is equal at both depths. In the future, this study could be expanded by growth trials of urchins fed on diets of solely kelp or invertebrates would allow for more accurate comparisons of relative gonad growth per diet, and could help explain the differences we saw between DSE and SSPE. Also, we could look at gut contents and fatty acids, which could inform diet differences between the DSE and the SSPE, further implicating kelp beds as a critical resource for ecosystems beyond the physical boundaries of the bed.

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Tables and Figures:

Table 1. Results of 1-way ANOVA test on gonad indices and jaw to test ratio of the urchin *S. droebachiensis*.

Variable	Source	Degrees of Freedom	Mean Square	F-Ratio	p-Value
Gonad Index	Depth	1	82.180	86.451	<0.001
	Error	80	0.951		
Jaw/Test Ratio	Depth	1	0.001	6.605	0.012
	Error	80	0.000		

Table 2. Results of 1-way ANOVA test on gonad indices of the barnacle *B. nubilus*.

Variable	Source	Degrees of Freedom	Mean Square	F-Ratio	p-Value
Gonad Index	Depth	1	0.001	0.234	0.631
	Error	48	0.005		

Figure 1. Variation in gonad indices with depth in the urchin *S. droebachiensis*. Error bars are one standard deviation.

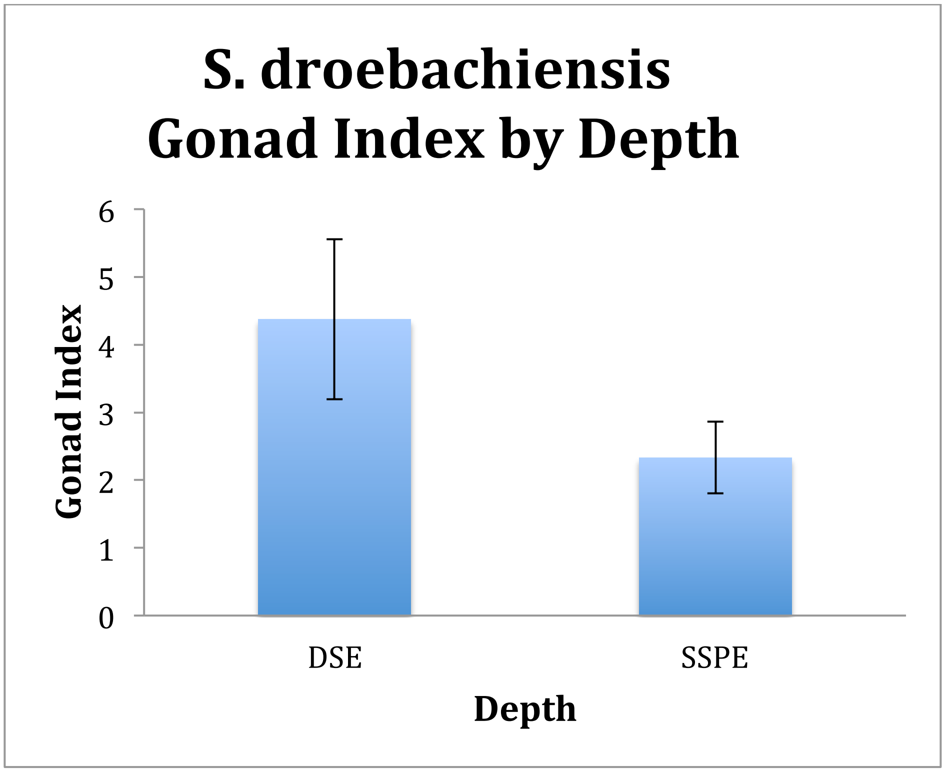

Figure 2. Variation in jaw-to-test ratios with depth in the urchin *S. droebachiensis*. Error bars are one standard deviation.

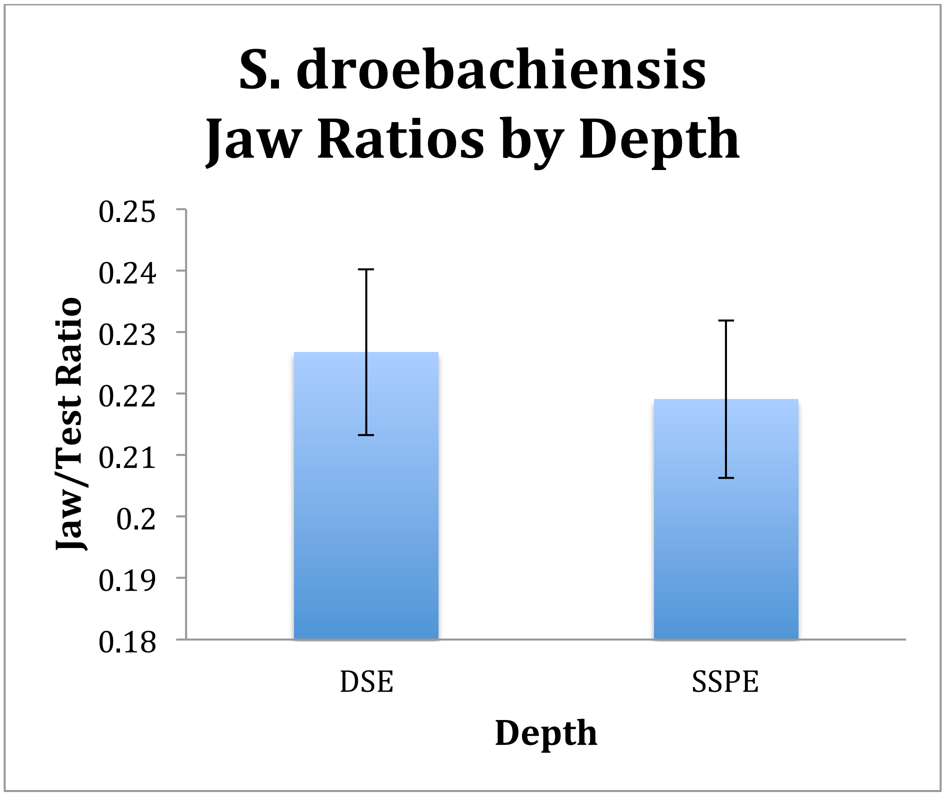

Figure 3. Variation in gonad indices with depth in the barnacle *B. nubilus*. Error bars are one standard deviation.