Capture Efficiency of Various Species and Sizes of Drift Macrophytes by Red Urchins, *Strongylocentrotus franciscanus*

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Abstract

In the San Juan Islands, drift macrophytes from shallow waters represent a significant spatial subsidy provided to the subtidal zone. This organic matter is a potential food source for deep dwelling herbivores like the red urchin *Strongylocentrotus franciscanus*. Little is known about how urchins capture and use drift material. A racetrack flume was used to examine the capture of drift macrophytes of various species and size by *S. franciscanus*. No species-specific selectivity was found, but urchins caught 100% of small macrophyte pieces. A significant decrease in capture efficiency was noted as drift algal size was increased, probably due to the urchins' inability to fight current drag acting on pieces with larger surface area.

Introduction

Large, nearshore macrophyte-dominated ecosystems are some of the most productive on Earth (Leigh et al. 1987). However, only about 10% of the biomass produced by macrophytes is consumed by herbivores at the source of production (Mann 1988). The remainder of this biomass is dispersed to many other nearby ecosystems, including the subtidal (Duggins et al. 1989), intertidal (Rodriguez 2003), pelagic (Kaehler et al. 2006), and terrestrial (Polis & Hurd 1995) habitats. In these ecosystems, macrophyte detritus is an important food source, especially in deeper waters where light limits photosynthesis. Drift material can have elevated levels of nitrogen (Mann 1988) and decreased amounts of defensive chemicals (Duggins and Eckman 1997) compared to fresh algae, making it a good nutritional source for animals that can capture the material. Thus drift algae may be an important form of secondary production. Detrital masses can support large numbers of herbivorous species at aphotic depths (Vetter 1995, Britton-Simmons et al. 2009). Thus, macroalgal detritus may represent a significant spatial subsidy, or linkage of nutrients and energy between adjacent habitats, when transported to the aphotic subtidal zone from shallower nearshore communities.

The San Juan Archipelago in Washington, USA is an area where macrophyte biomass supports secondary production at depths in the subtidal where there is no primary production. This secondary production is common in environments like the San Juans (Okey 2003, Britton-Simmons et al. 2012). The high tidal fluctuations, strong currents, and steep, glacially carved bathymetry of the islands allow for large numbers of benthic species to subsist on algal detritus subsidies (Britton-Simmons et al. 2012) including commercially harvested species such as the red urchin *Strongylocentrotus franciscanus* (Pfister and Bradbury 1996).

Red urchins are large and ecologically important herbivores in the San Juan system, growing to more than 15 cm in diameter. They are common in the shallows where macroalgae are dominant and productive, but their range extends to depths of more than 100 m (Britton-Simmons et al. 2012), well below the photic zone. Britton-Simmons et al. (2009) observed urchins in these deeper zones feeding on drift algae, and subsequent *in situ* measurements found more than 60% of individuals in the deep subtidal to be in possession of drift algae. Gut content testing found macroalgae in 96% of urchins sampled at 23 m below MLLW. Conversely, Mattison et al. (1977) found that only 15% of urchins at similar depths near giant kelp forests in California were in possession of drift material. The San Juan Islands experience very strong tidally generated currents (Britton-Simmons et al. 2009). Storm waves also influence water motion in the area, although that effect is limited to the shallow subtidal (Eckman et al. 2003). Comparatively, the currents acting on coastal California are much weaker than in the San Juans (Washburn et al. 1999). Because the currents carry the macroalgal detritus to the urchins, these differences in current and shoreline location could explain why red urchins in the deep subtidal of the San Juans are much more likely to capture drift algae than their counterparts in California.

While red urchins in the San Juan Islands are adept at capturing drift algae, there is still much that is unknown about what they do with the algae once it is caught. Britton-Simmons et al. (2009) found that 12% of deep subtidal urchins were holding algae but were not actively feeding, while another 17% were feeding but holding multiple pieces at the same time, when (presumably) they can only eat one piece at a time. This indicates that the urchins are most likely catching more algae than they can utilize, possibly to “stockpile” resources. There is noted local seasonal variation in the availability of drift algae, with a significant drop in late winter and early spring (Britton-Simmons et al. 2009). These seasonal variations, along with short term changes in tides and currents could explain why the urchins stockpile algae: they may need to catch and hold as much as possible when conditions are favorable. This way, they have a source of food when currents change and drift algae are not immediately available.

There is also species-specific variation in the abundance of drift mass. The top contributors, according to Britton-Simmons et al. (2009) are *Saccharina subsimplex* (37% of total biomass sampled in the deep subtidal), *Agarum fimbriatum* (11%), *Fucus distichus* (9%), and *Desmarestia munda* (7%). No other species represented more than 5% of the measured total biomass. However, the most abundant algae may not necessarily constitute good food for consumers. For instance, urchins have distinct feeding preferences. Vadas (1977) found that red (*S. franciscanus*) and green (*S. drobachiensis*) urchins rank these algae from most preferred to least: *Nereocystis luetkeana, Costaria costata, Saccharina latissima, S. groenlandica, Monostroma fuscum, Opuntiella californica, Agarum fimbriatum*. *Fucus distichus* was not used in Vadas’ testing. Thus *Agarum fimbriatum,* while one of the most abundant drift species (Britton-Simmons et al. 2009), was among the least preferred (Vadas 1977). This contrast leads to questions about deep subtidal urchin behavior. Do urchins simply catch everything that floats by and stockpile it for later, or do they catch what they can reasonably eat before something else drifts past? Do the urchins selectively catch specific species of algae?

How efficient are urchins at catching drift algae? I tested two hypotheses about drift algal capture by *S. franciscanus.* First, that urchins will selectively capture more pieces of preferred species (*N. luetkeana*) than a less preferred species (*Agarum* sp.). Secondly, capture of smaller pieces will be significantly more efficient than capture of larger pieces.

Methods

Red urchins (*Strongylocentrotus franciscanus*) were collected from subtidal sites near the University of Washington Friday Harbor Laboratories on San Juan Island, USA (48°32’39.92”N, 123°00’39.60”W). They were housed in flow-through seawater tanks and not fed prior to trials. A minimum of one day after capture, urchins were used for drift capture trials in a 4000 liter racetrack paddle flume, which allowed controlled flow rates. Each urchin was only used for a single trial and then allowed to feed until it was released. Separate trials addressed three issues. The first and second sets were designed to test whether the urchins showed species specific selectivity when capturing drift algae. The third set examined the role played by the size of the drift algae in capture efficiency. For all three, flow rate was about 10 cm/s. This speed was chosen for two reasons. The first was that it is a conceivable (albeit low) natural flow speed in the local environment. The second was that it was a low enough speed to avoid triggering an urchin streamlining behavior for withstanding strong currents in which the animals lower spines to the substrate and point upper spines downstream along the current to make themselves more hydrodynamic and avoid being dislodged (Steward and Britton-Simmons 2011).

For the first set of trials, an urchin was placed in the flume with a flow rate of about 10cm/s and allowed 30 minutes to acclimate. Four local algal genera were used: *Agarum* sp., *Nereocystis luetkeana, Saccharina* sp., and *Ulva* sp. Non-reproductive blades of the test species were cut into 15 cm x 6.5 cm pieces. 5 pieces of each species in random order were released about 10 cm upstream for potential capture by an urchin, for a total of 20 attempts per urchin. Each attempt was recorded as either a touch, in which the blade strikes the urchin with a reasonable chance of capture but is not held for greater than 90 seconds, or a catch, in which the urchin holds the blade for more than 90s. After each attempt there was a one minute break until the next attempt. This way, catch/touch ratio could be used to estimate average catch ability for the urchins and test for selectivity. In all three trial sets, each piece of algae was only used once and discarded.

In the second set of trials, the same four genera of algae were used, plus a plastic control of the same size and shape. The plastic was cut from trash bags, and was roughly as thin as *Ulva* sp. Urchins were again given 30 minutes to acclimate to the flume, which was set to about 10cm/s. Each attempt consisted of two pieces, randomly selected from the five drift categories, delivered simultaneously. The pieces were the same size and shape as in section one. The same catch/touch criteria and procedure were used. Again, each urchin was used for 20 attempts in a randomized order with equal numbers of attempts for each species/control.

In the third set of trials, only *Agarum* sp. and *Ulva* sp. were used, again with a plastic control, with the focus on the effect of the size of the drift algal piece on capture efficiency. The algal species were selected for morphological variation. *Ulva* sp. are extremely thin (most are a single cell thick) and flat, without bullation, thus very flexible and easier for urchins to manipulate with spines and podia. *Agarum* sp. is much thicker, with bullations and perforations throughout. Pieces of each species were measured for surface area and then weighed to obtain a weight-to-surface area function (Figure 1). This function was used to estimate surface area of randomly selected pieces of algae by weight. These algae were then sorted into six size groupings: 1-100cm^2, 101-500cm^2, 501-1000cm^2, 1001-1500cm^2, 1501-2000cm^2, and >2000cm^2. Ten pieces of plastic, two per size group, were used as controls. Each urchin was again allowed 30 minutes to acclimate in the flume, where the flow rate was about 10cm/s. Each urchin was given seven of each of the trial groups (*Ulva, Agarum*, and Plastic), again in a randomized order, for a total of 21 attempts per urchin. Only one piece was used in each attempt. At least one piece of algae from each size group was used on each urchin.

During each of the three sets of trials, environmental conditions and urchin morphology were noted. These included date, time, salinity, water temperature, flow rate, average spine length (mean of 10 randomly selected spines), and urchin test diameter.

Results

During the first set of trials, nine urchins were used, for a total of 172 attempts. However, data from the second urchin were omitted because I experimentally ran the flume at 14.93 cm/s, about 50% faster than the flow rate of all other trials. Of the remaining 152 attempts, 100% were successful catches.

During the second set of trials five urchins were used, for a total of 88 attempts. Again, the urchins had a 100% catch rate: 176 pieces of algae/plastic were caught in 88 opportunities (2 pieces per trial) by five urchins, without missing a single piece.

The third set of trials resulted in varying average catch rates (Figure 2). Capture rates in the smallest algal size class for all three treatments were: 100% for *Agarum* sp., 90% for the plastic control, and 85.7% for *Ulva* sp. Capture frequencies for all three treatments remain reasonably high until the fourth size group; larger pieces of algae/plastic were caught much less often (Figure 2). A logistic regression was used with all data points (i.e., not grouped by size) and can be used to predict catch probability by surface area and treatment (Figure 3). All three algal "species" were less likely to be caught at larger sizes. For the logistic regression, *Agarum* P= 0.0006, Plastic P= 0.0021, *Ulva* P= 0.0497 (Chi square tests).

Discussion/Conclusions

Data from the first two sets of trials did not demonstrate selective capture of specific algal species, but have important implications for using urchins as a sampling method of drift algal abundance in a given area. The fact that under these experimental conditions urchins were able to successfully catch 100% of pieces of algae/plastic of the size offered shows that, assuming the algae are of catchable size, species caught by urchins are indicative of the local drift abundance as a whole. Given that urchins were readily catching both plastic and *Agarum*, taste is not a factor. However, as the third set of trials showed, researchers should be wary of this assumption given that urchins struggle to successfully catch larger pieces of drift algae. Any "selectivity" of drift capture by urchins is due more to size and morphology of a given piece of algae than to algal species. The *Ulva* sp., as a much thinner and more flexible alga, seemed to more readily get stuck on a spine and wrap around, whereas the more rigid *Agarum* had a tendency to bounce off a spine. It would be interesting to use multiple urchins at once and see if that increases the probability of catching large pieces of algae.

The morphological differences among species of algae could influence their "catchability" and thus influence their catch rate relative to general drift abundance. The concept of catchability requires further study. Because an urchin presumably cannot sense oncoming drift algae and/or move into a position where it is best able to catch algae, it was difficult to standardize delivery of pieces to give the urchin the same chance at any given catch. Another source of variation could also be urchin “hunger level.” The urchins used for the first two trial sets were collected in a different location than the urchins for the third set. These urchins may have been less well fed and more “determined” to catch everything.

These data suggest that subtidal urchins seem to catch and hold any potential food item if it is physically possible for them to do so. While their shallow dwelling counterparts may seek out preferred algal diets, those relying on drift algae seem to be more opportunistic feeders who attempt to hold on to anything that floats by. This lack of selectivity could be important for estimating the composition of drift algal biomass in different locales, as well as changes in urchin diet/growth in response to yearly fluctuations in drift algal abundance and type.

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Figures

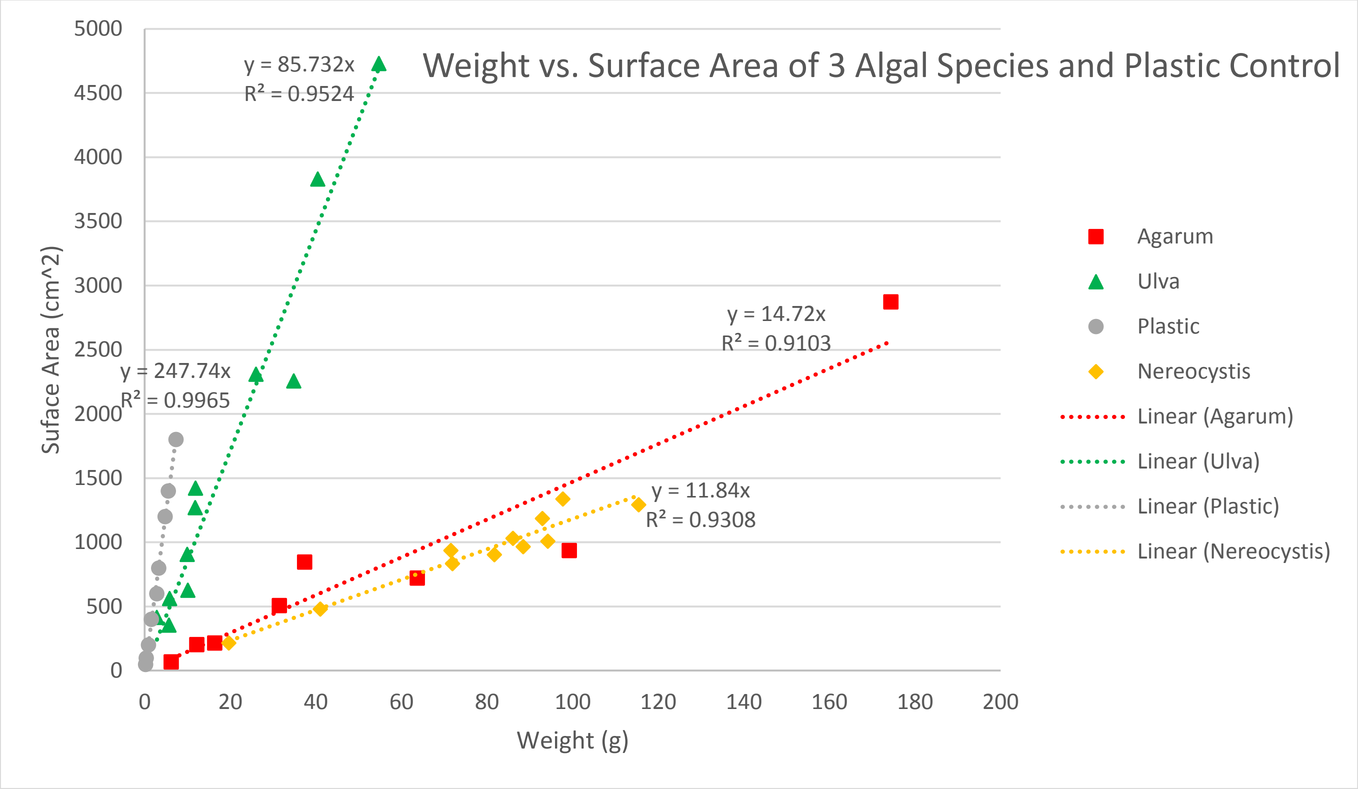

Figure 1: Weight(g) and surface area(cm^2) of 4 possible treatments. Lines of best fit were used to formulate equations for conversion from weight to surface area, with R^2 values for each line displayed.

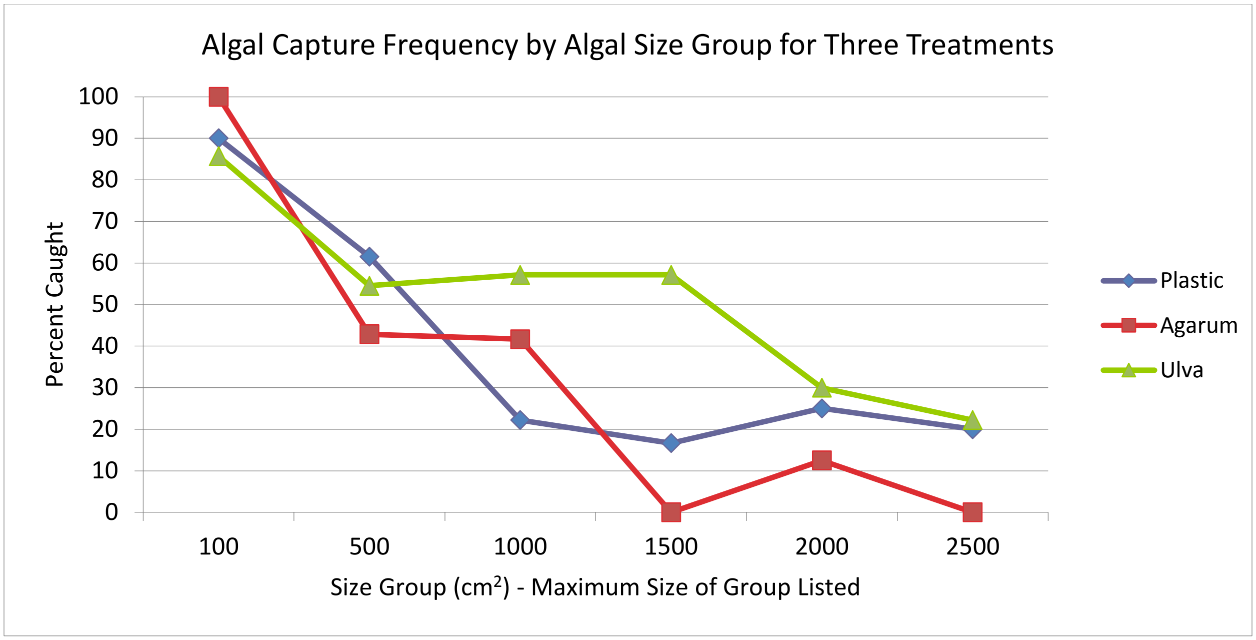

Figure 2: chart showing mean capture rate by size group. Maximum surface area in cm^2 for each group is listed on horizontal axis and percent catch is represented on vertical axis.

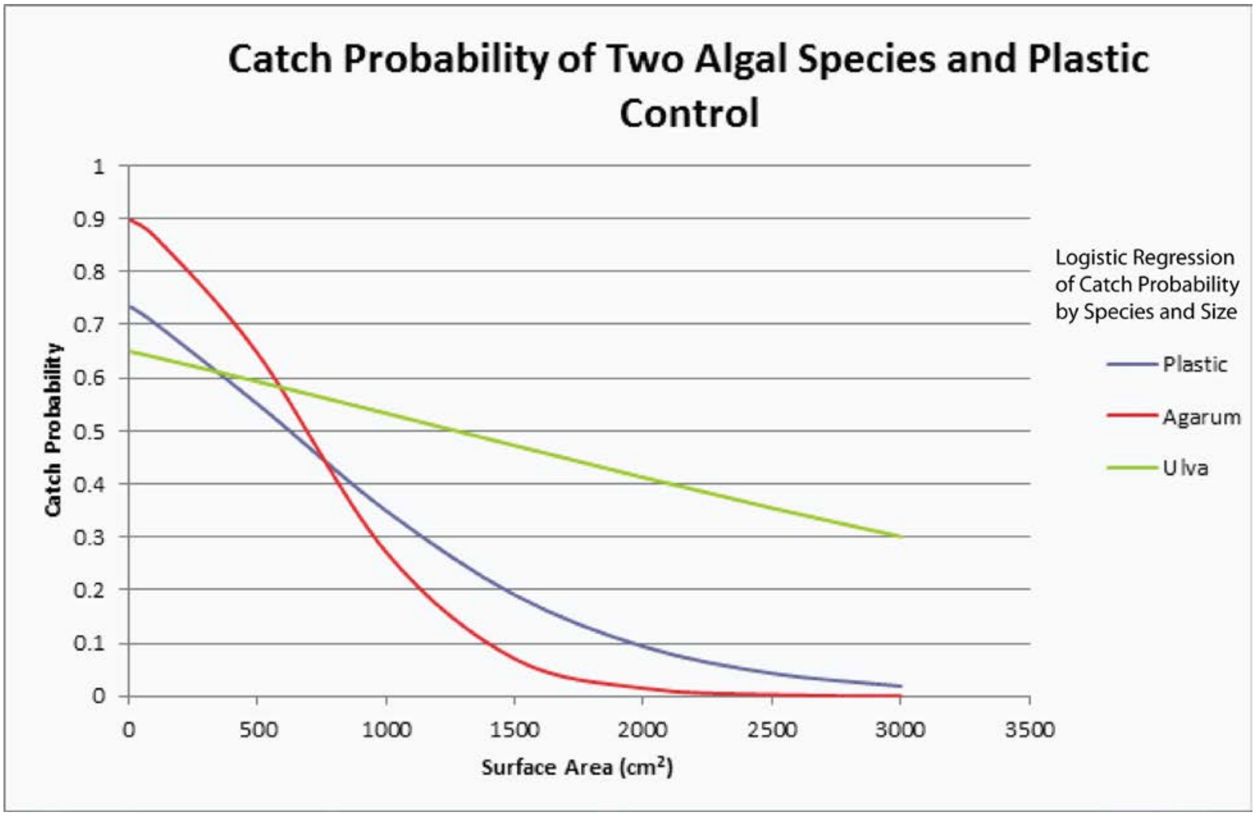

Figure 3: Logistic regression curve predicting catch probability of drift algae with a given surface area.