

Abstract

Our study focused on what factors affect macroalgal cover in the Line Islands, specifically Christmas Island, Washington Island, Palmyra Atoll, and Kingman Reef. Macroalgal cover can be influenced in three ways: from the top-down by herbivory, from the bottom-up by nutrients, and by the amount of available spores. Using ceramic settlement tiles, we estimated algae spore recruitment. We estimated herbivore biomass and algae cover using snorkeling line transects, and we used ceramic settlement tiles to estimate algae spore recruitment. We found that the human population gradient across the four islands reduced herbivore biomass in accord with the varying degrees in fishing pressure. Christmas Island had an estimated herbivore biomass of 233.84 g/m², Palmyra Atoll, Washington Island, and Kingman reef with a biomass of 11.9%, 82.4%, and 85.1% less than Christmas respectively. In addition, we found ample spore supply at each island we tested. However, our results found no overarching relationship between herbivory and algal cover, nor did it find a solid correlation between the amount of available spores and algal cover. Therefore, we speculate that human impact on algal cover takes the form of adding nutrients to the water rather than in the form of localized fishing pressure causing a trophic cascade. Further research on nutrient levels is necessary to test this hypothesis

Introduction

Macroalgal cover is often used as an indication of reef coral reef health. A high increase of macroalgal cover can lead to the deterioration of reef health by interfering with coral recruitment, taking up settlement areas (Hughes, 1989; Lewis, 1986). Jompa and McCook found that coral tissue mortality rate rose when algae was present, and the mortality rate rose when herbivores were not present (2002). High macroalgal cover can even cause a “phase-shift” from a coral dominant community to an algae dominant community (Stimson et al., 2001). In addition, macroalgal blooms can last for a very long time: In Waquoit Bay, Massachusetts, blooms of *Cladophora* and *Gracilaria* lasted for more than 20 years. (Valiela et al, 1992). Such long-lasting blooms last much longer than microalgal blooms, and can affect and even change reef habitats entirely (Valiela, 1997).

It is then doubly crucial that macroalgal cover should not increase to the extent that they bloom and change the environment. There are three factors that affect algal cover; the top-down approach, or through grazing, the bottom-up approach, or through the availability of nutrients, and the amount of spores, or the origin of algal cover. Thus, human impact can take the form of either fishing pressure affecting the top-down processes, or the addition of nutrients through human waste and nutrient runoff.

A number of studies have established a correlation between macroalgal cover and grazer biomass at mid-depth reefs in the Caribbean (Williams and Polunin, 2001). They found that there, the overfishing of herbivores and the sudden loss of the sea urchin *Diadema antillarum* due to disease had contributed greatly to the macroalgae bloom. In Jamaica, overfishing of herbivores caused an increase of fleshy macroalgae from 4 to 92% along the shallow coasts that were previously coral reef. (Hughes 1994) Other studies have drawn conclusions that the bottom-up processes determine algal cover; In Kaneohe bay, Hawaii, nutrient enrichment from domestic sewage lead to overgrowth of corals by green bubble alga *Dictyosphaeria cavernosa* (Banner 1974)

Our hypothesis was that, as in the Caribbean, algal cover would be most affected by herbivore biomass, and that human impact would show most in fishing pressures. We believed

that the fishing pressures would affect the number of predators, which would also affect the number of herbivores, which in turn would affect the grazing rates and the control the herbivores have over algal cover. We predicted higher macroalgal cover in more populated areas such as Christmas Island and Washington Island, and that there would be a marked decrease at Palmyra and Kingman due to lack of human impact.

Our research was conducted along the Line Islands, surveying a total of 14 sites. We had 4 sites at Christmas Island (1° 50'32.48" N 157°21'1.72"W), 3 at Washington Island (4°41'14.25"N 160° 22'53.07"W), 5 at Palmyra Atoll (5° 52'52.09"N 162° 4'42.26"W), and 2 at Kingman Reef (6°22'1.98"N 162° 32'49.48"W). The depth of each site averaged between 3.5m and 6m. The sites at Kingman reef were deeper, between 7 and 10m. At each site we did 1 to 2 transects for parrotfish, surgeonfish, damselfish, and sea urchins. The transects allowed us to estimate the biomass of herbivorous fish in these islands as well as the role that sea urchins have to play as invertebrate herbivores. We used quadrats to assess algal cover, and tiles to see the amount of spore settlement and further macroalgal recruitment.

Methods

Our data collection had four components; visual transects to estimate herbivorous fish biomass, visual transects to determine sea urchin abundance, quadrats to estimate macroalgal cover, and tiles to quantify algae recruitment. At Christmas Island we surveyed three sites and conducted a total of six transects. The sites we used at Christmas and Palmyra were based off the sites that Stevenson et al. used in their studies of apex predator biomass. At Washington and Kingman we chose sites randomly. In the fish transects we investigated surgeonfish (family *Acanthuridae*, parrotfish (family *Scaridae*), and damselfish (family *Pomacentridae*) as the primary grazers of these reefs. Two snorklers swam down a line transect 50m long, each looking 2m to the right and left of the line for the target fish. We identified the fish down to family and categorized them into size classes of 10-20cm, 20-30cm, 30-40cm, and 40-50cm, and fish larger than 50cm. The lengths were then converted into biomass using the average of a and b constants in *FishBase* for each family, slotted into the biomass formula of $W = aL^b$. We disregarded fish smaller than 10cm, since Williams and Polunin found that herbivorous fish less than 12 cm in length account for only 10% of the biomass and are negligible in terms of grazing pressure (2000). Similarly, in a previous study in the Pacific Line Islands on surgeonfish and parrotfish, the fish that were under 10 cm comprised significantly less than 10% of the total biomass (Egan and Tellez, 2005). We also investigated the density of sea urchins. Two snorklers dove to look into the crevices of the rock and coral along the first 20m of the 50x 4m transect line.

The amount and type of algal cover was estimated using a 50x50cm quadrat strung every 10cm, with a total of 16 intersections of the strings within the quadrat. We counted what the proportions of the intersections had algae under them. We categorized algae into green, red, and brown (*Chlorophyta*, *Rhodophyta*, *Phaeophyta*) and within each category we further divided them into turf, fleshy, and encrusting. Five quadrats were laid down every ten meters along each transect. We conducted 4 transects that included quadrats on Christmas, 3 transects on Washington, 5 transects on Palmyra, and 2 transects on Kingman.

We laid out algae recruitment tiles at Christmas Island, Palmyra Atoll, and Kingman Reef. Each of the tiles remained in the fore reef area between 28 and 48 hours at a depth ranged from 2-5 meters, and after collection put immediately in seawater filtered through a 20

micrometer filter, supplemented with Guillard's F/2 enrichment solution; 140 ml of enrichment solution for 5 liters of filtered sea water. The water was changed every four days, and the tiles were exposed to an aquarium light for 18 hours a day. After 6 days we observed the tiles under the stereoscope under 25-times magnification, and from each tile took 12 random samples of the surface; each sample was of a circle of 1cm in diameter. Each sample consisted of all that we observed within the lens, and we counted the number and different types of germlings. The germlings bore little resemblance to their mature form, so we were unable to note whether they were turf, fleshy, or encrusting. However, we were able to clearly distinguish the germlings by color.

Our methods remained consistent at Christmas Island, Washington Island, and Palmyra Atoll. However, at Kingman Reef we were unable to replicate our methods for the transects or the quadrats. Since the seas were rough, we had two snorkelers hanging off either side of a small boat as we drifted what estimated to be 50m. The snorkelers then reported on how many fish and sea urchins they saw as well as the types of algae. However, the snorkelers were farther away from the bottom of the reef than with the other transects, and so they probably missed some of the smaller fish, underestimating herbivore biomass density in the area. Moreover, they were unable to use quadrats and dive to survey algal cover or to look into rock crevices for sea urchins, and thus the numbers are not precise. Therefore, the herbivore biomass and algal cover for Kingman Reef should be considered a general estimate without the same level of accuracy as the other sites. In addition, although we were not able to lay out tiles in Washington, the tiles laid out in Kingman Reef were analyzed in the same way as the tiles from Christmas Island and Palmyra Atoll. One-way ANOVA was used to determine statistical significance between herbivore biomasses and algal cover between the Line Islands.

Results

We found that the mean algal cover percentage in Christmas Island, Washington Island, and Palmyra Atoll ranged from 47% to 50%, whereas there was significantly less macroalgal percentage cover in Kingman Reef of only 1.625% cover (Figure 1). Percentage cover between the four islands were not statistically significant (Anova, $P=0.057$). However, Christmas, Washington and Palmyra's relationship with Kingman were statistically significant (Anova, $P\leq 0.05$). The composition of the types of algae varied widely. Christmas Island and Palmyra Atoll had roughly the same percentage of turf algae cover of 51.56% and 49.75% respectively, but Palmyra had more encrusting algae of 3.25%, and Christmas had the most fleshy algae of all four islands with the coverage of 8.75%. Washington however, exhibited the most percentage of encrusting algae of 31.67%. We did not observe any turf algae at Kingman, but it is possible that this is due mostly to the fact that the snorkelers were not able to dive and look closely at the algae. For the same reason, it is possible that we underestimated the amount of algae at Kingman, but from our observations it was very clear that there was still far less algae at Kingman than at the other three islands (Figure 1).

Herbivore biomass among the sample sites varied significantly (Figure 2). Christmas and Palmyra shared an equally high herbivore biomass of 233.84 g/m² and 206.11 g/m² respectively, greatly exceeding that of Washington and Kingman. The herbivore biomass relationship between Christmas, Washington, Palmyra, and Kingman were statistically significant (Anova, $P=0.015$).

Although in the figure Christmas seems to have higher herbivore biomass than Palmyra, the difference is not statistically significant (Anova, $P=0.65$).

Family composition of herbivorous fish was also varied between each island (Figure 1). Christmas and Palmyra had similar surgeonfish biomass density, whereas Washington and Kingman had far less. Palmyra had the highest parrotfish biomass, followed by Christmas and Kingman. Washington had very little parrotfish biomass, and was instead dominated by damselfish. Washington also had very low surgeonfish biomass, lower even than that of Kingman Reef. At Kingman we saw mostly parrotfish and surgeonfish, but we may have observed less damselfish because we were farther away from the reef and so missed the smaller size classes.

The average size of fish were also quite different in all the islands. Parrotfish can grow to as much as 60cm, or even larger. Surgeonfish are generally between 20 to 30cm, but can be as large as 40cm. Damselfish are usually about 10cm, and can grow to be nearly 25cm in rare cases. Christmas and Washington were dominated by fish of the smaller size classes among all three families, although there were many damselfish that were larger than 10cm. In contrast, we observed many parrotfish and surgeonfish of the larger size classes in Palmyra and Kingman.

Sea urchins were most abundant at Washington with a density of 0.42 urchins/m², where there was the lowest herbivorous fish biomass. Christmas Island had the next highest sea urchin density of 0.29 urchins/m², which was large enough to be considered a central part of the grazing community. Kingman had the 3rd highest density with 0.1 urchins/m². Interestingly, we did not observe any sea urchins in Palmyra (Figure 3).

We were able to place tiles in three islands; Christmas, Palmyra, and Kingman. Overall, Kingman Reef, which had the least algal cover of about 1.625%, had the most germlings (69.67 germlings/ site). On the other hand, Palmyra had only half the number of germlings the other two islands had (31 germlings/ site). All the tiles were dominated by brown germlings, and Kingman had a strikingly large amount compared to the others (Figure 4). Christmas had the most green algae, followed by Palmyra and Kingman. Conversely, Kingman had the most red algae, followed by Palmyra and Christmas.

Discussion

Christmas Island has a population of 8,000, with extensive reefs that are fished unevenly. It has at least 6.8 times the length of reef space that Washington has in the reefs surrounding the island alone. On top of that, Christmas Island has additional reef areas within the lagoon, whereas Washington Island is small and does not have a lagoon. Therefore, we believe that even though Washington has a smaller population of around 1000, the reef is subject to higher fishing pressure. Palmyra is currently a National Wildlife Refuge with a negligible population of 4-20 people. Kingman Reef is another special case in that the entire reef is very remote from human habitation and is thus relatively untouched. Neither experience the constant local fishing pressure that the reefs on Christmas and Washington experience.

As can be seen in Figure 2, each of the islands has varying herbivore biomass and fish composition. We speculate that this is because the fishing pressures are different at the populated islands. We believe that the people at Christmas fish mainly for predators and some large herbivores such as parrotfish, whereas in Washington, both predators and larger herbivores such as surgeonfish and parrotfish targeted. This would explain why in these islands there were

very few fish of the larger classes, and also why there are so few parrotfish in Washington. The exceptionally high damselfish biomass there can be attributed to the fact that damselfish are small and are not targeted for food, added to the lack of herbivore competition. In the unpopulated Palmyra and Kingman, parrotfish and surgeonfish of the larger size classes remained intact.

Figure 5 shows very little relationship between total herbivore biomass density and percentage algal cover. Even though herbivore biomass in Washington is nearly half that of Christmas and Palmyra, the percentage of macroalgal cover remains constant. In addition, algal cover in Kingman was far lower than in the other islands despite the fact that there were fewer herbivores. These results suggest that herbivores do not control the amount of algal cover, countering our original top-down approach hypothesis.

In contrast to Figure 1, Figure 6, showing the relationship between the percentage cover of fleshy algae's relationship with herbivore biomass density, exhibits a strong correlation between the two factors. The herbivore biomass density rises and falls with the rise and fall of the percentage of fleshy algal cover. This points to the possibility that the herbivores are aggregating in areas that have fleshy algae cover, rather than that the herbivores determining the amount of algal cover. We included this graph because fleshy algae have particular significance in the type of algal cover we wish to look at. Most herbivores, excluding parrotfish, favor turf and fleshy algae over encrusted. In addition, turf and encrusting algae are part of the reef structure, but fleshy algae are usually the algae that responds quickest with the introduction of new nutrients and create blooms, causing reef degradation (LaPointe 1997; Hughes 1994; Valiela et al, 1992). Therefore, the amount of fleshy algae present in an area can also be a more precise measure of reef health than just overall percent cover. From the two graphs showing the relationship between algae and herbivore biomass, it is apparent that there is little or no top-down control of algal cover by herbivores.

Among the three islands that we were able to lay down tiles, Christmas and Palmyra had similarly high algal cover, whereas Kingman had very little. However, the most number of germlings were observed on tiles from Christmas and Kingman. If spores dictate the amount of algal cover, there should be more algal cover where there are the most spores. On the contrary, what we actually observe is high algal cover in Palmyra where there are fewer spores than at the other two islands, and very low algal cover in Kingman where we found a high number of spores.

In the introduction, we mentioned the three factors that affect macroalgal cover; herbivores, spores, and nutrients. Among these, we researched the herbivores and the amount of available spores. However, neither of the two factors we studied gave us results that pointed to one or the other being more influential in determining the amount of algal cover. Fishing pressure did not affect algal cover at all, but there seems to be some other factor at play. From these conclusions, we offer a different hypothesis; that it is the nutrients that control algal cover from the bottom-up.

We speculate that Christmas, Washington, and Palmyra share a similar amount of algal cover because there is a similar amount of nutrients in the water, and that algal cover in Kingman was so low because it did not have the nutrients that the other islands did. There is general scientific consensus that human population correlates directly with the amount of extra nutrients that run into the water (Banner, 1974). Therefore we believe that human impact changes algal cover through added nutrients in the water rather than through fishing pressure as we had first believed. Christmas and Washington both have populations that heavily affect their reefs on a

regular basis, not only in terms of fishing, but in nutrient runoff and human waste as well. In addition, these two islands both have nesting bird colonies that would drop nutrient-rich guano into the waters surrounding the islands. Palmyra has a small human population that tries to limit the impact they have on the atoll. However, it too has a number of large nesting bird colonies. These factors may work together in order to create equally nutrient-rich waters that support the algal cover on these islands.

On the other hand, Kingman Reef likely has no such ample sources of nutrients. There is little exposed land, and what is exposed is made of coral rubble. This allows for no sediment runoff or other sources from which nutrients can be introduced. There is no human or bird habitation, and the lagoon waters are very clear and can be seen to great depths. All these facts suggest that Kingman is poor in the amount of available nutrients. Further studies are necessary to determine the amount of nutrients in these islands in order to back up this new hypothesis.

Conclusion

Our original hypothesis was entirely disproved. However, we were able to determine that neither top-down processes nor spores determine algal cover. Although fishing pressures do not seem to affect algal cover, humans may still be impacting the reef environment by introducing additional nutrients into the water. Therefore we have a new hypothesis that nutrients control algal cover. Additional research will be necessary in order to determine that the bottom-up approach is the most influential.

Figures

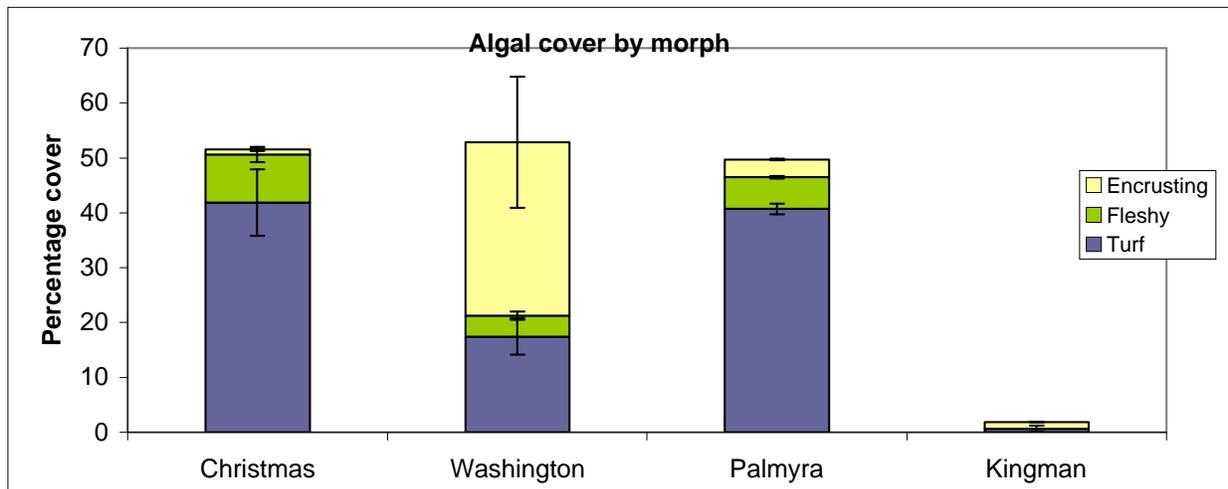


Figure 1. Mean macroalgal percentage cover described by morph; encrusting, fleshy, and turf. Average number of samples (n=20). One-way ANOVA to determine significance ($P=0.05$). Error bars are $\pm SE$ of mean.

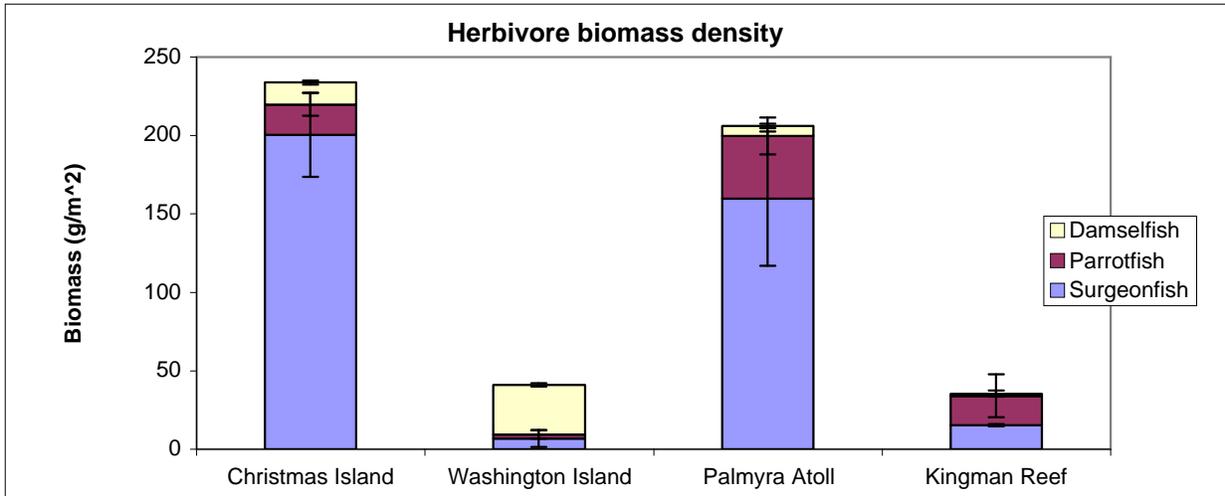


Figure 2. Mean herbivore biomass density (g/m²) on 50x4 meter transect. Biomass categorized into three herbivorous fish families. Mean number of samples for each island, $n=4$. Error bars are $\pm SE$ of mean.

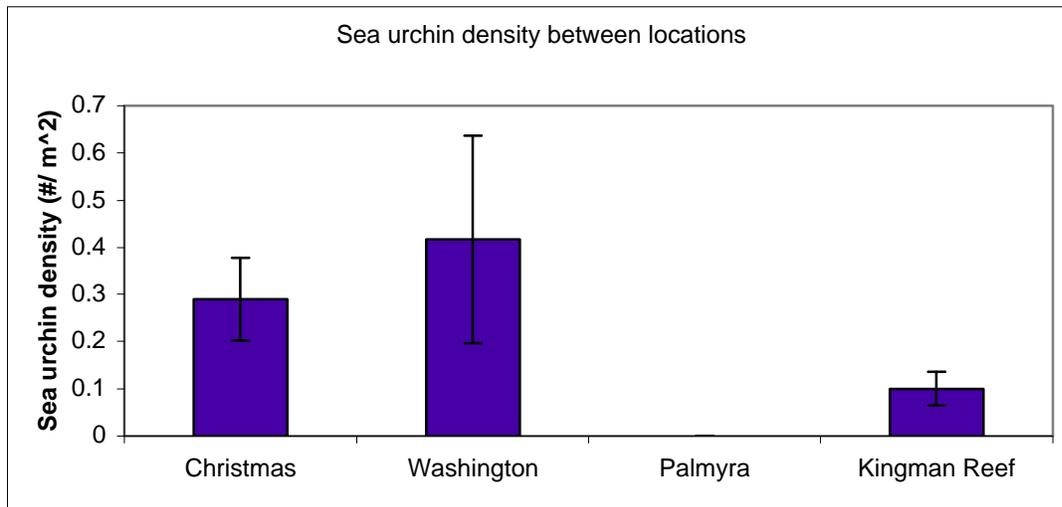


Figure 3. Mean number of urchins (number/ m²) on 20x4m transect. Mean number of samples for each island, $n=4$. One-way ANOVA to determine significance ($P=0.038$). Error bars are $\pm SE$ of mean.

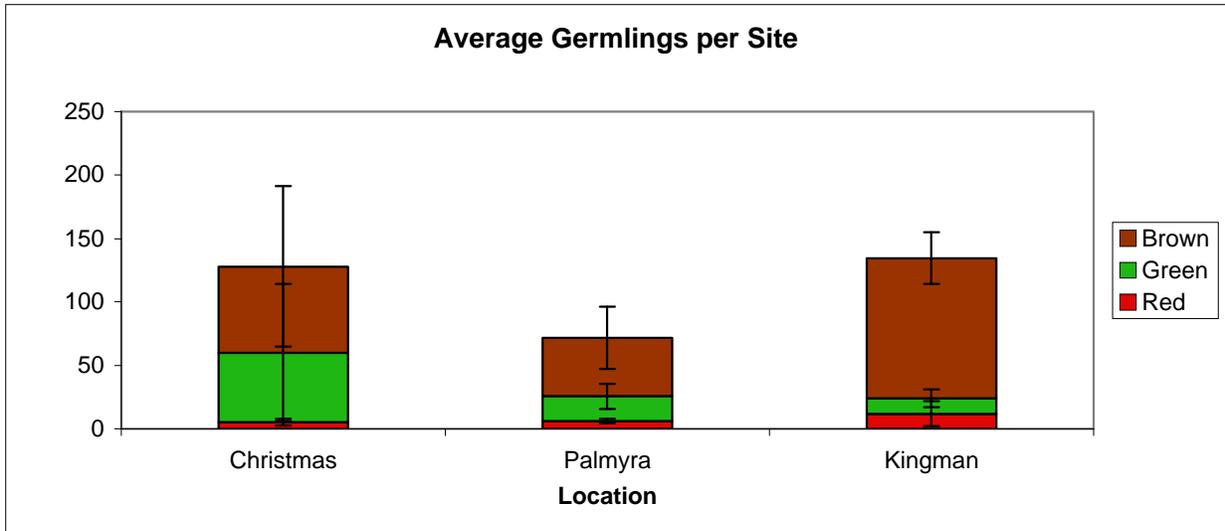


Figure 4. Average number of germlings, algal recruitment on settlement tiles collected (germlings/ site). Germling count subdivided to phylum brown, green, and red. Mean number of samples for each site, $n=8$. One-way ANOVA to determine significance ($P=0.0015$). Error bars are $\pm SE$ of mean.

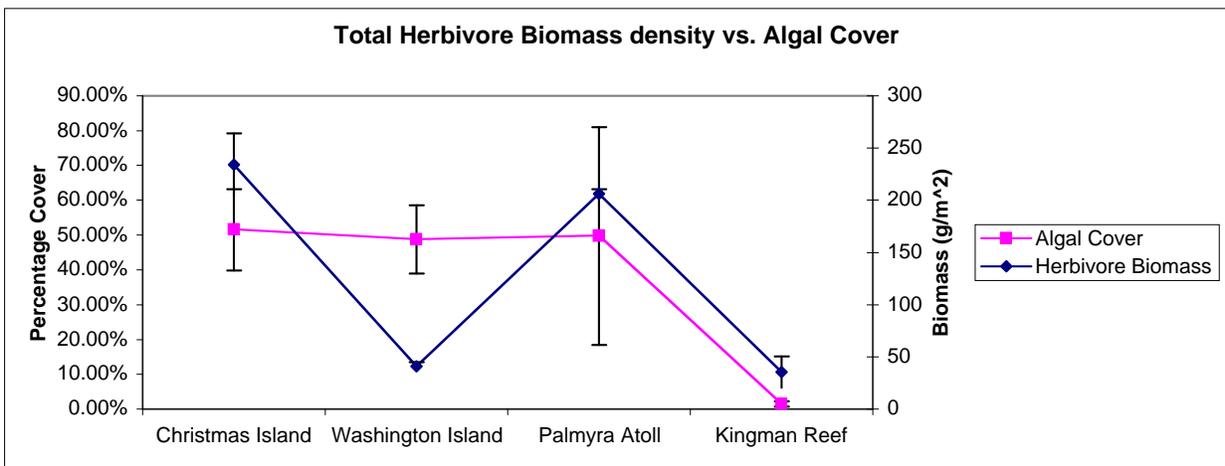


Figure 5. Mean of total herbivore biomass (g/m^2) in relation to mean of total macroalgal percentage cover among the Line Islands, $n=4$. Error bars are $\pm SE$ of mean.

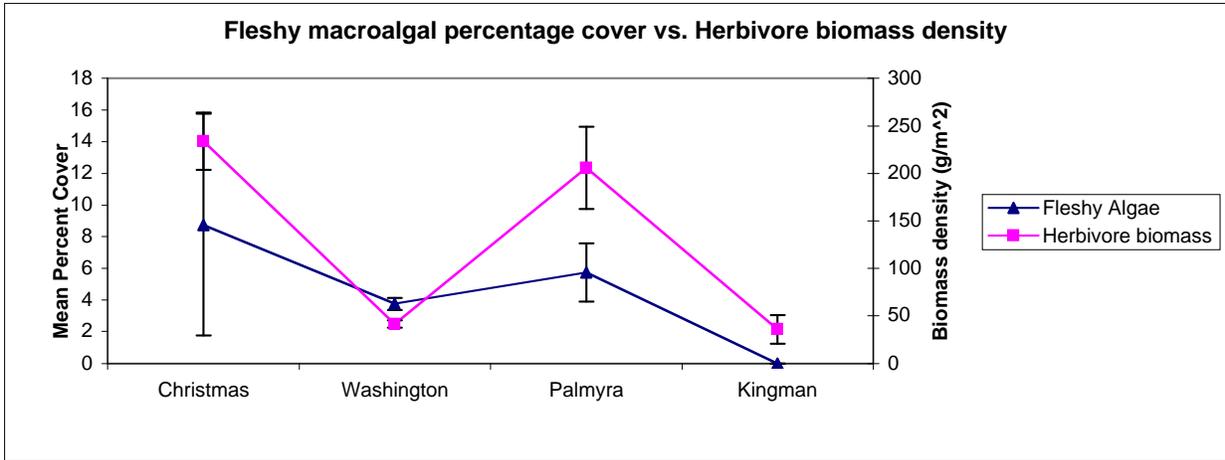


Figure 6. Percentage macroalgal cover in relation to Herbivore biomass, $n=4$. Error bars are \pm SE of mean.

Citations

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