MACROINVERTEBRATE SUCCESSION ON DECOMPOSING *TURBINARIA ORNATA* ON THE SHORES OF MOOREA, FRENCH POLYNESIA

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Abstract. What impact does allochthonous inputs have on the biodiversity of an ecosystem? This study examined the change in invertebrate communities inhabiting a brown macroalgae (*Turbinaria ornata)* as it decomposes on the shores of Moorea, French Polynesia. My hypothesis was that as decomposition increases over time in *T.ornata*, the succession of fauna will change from a marine to a terrestrial origin. Over a four week period, a collection of *T. ornata* was placed on shore for weekly observations on the stages of decomposition and sampling to determine the changes in community composition. *T. ornata* was collected in the middle of Cooks Bay (17 30 S, 149 50W) and gathered from a floating vegetation raft. Then, 10-12 fronds of *T. ornata* were placed into 15 wire cages on shore a few meters from the bay. These cages were placed in areas containing white sand substrate. Every week, five cages were randomly selected to observe what colonized the decomposing *T. ornata*. Results indicate that there is a change in succession of origin (terrestrial or marine) over time and clear evidence of changes in species dominance. The species abundance within the cages varies in a sinusoidal pattern during the 4 weeks of decomposition. The diversity along the weeks decreases in a linear pattern. This experiment has implications in the studies of marine wrack as an allochthonous input that affects the biodiversity of the shorelines of this region.

Key Words: *Turbinaria ornata; macro invertebrates; succession; ecology; decomposition; Moorea, French Polynesia*

INTRODUCTION

Allochthonous inputs are contributions from one habitat to another. These inputs in natural systems can alter food webs and population (Huxel and McCann 1998). Nutrient movement among habitats strongly influences community dynamics, and consumer- resources (Polis et al. 1997). Allochthonous inputs are a source of productivity that is important to food webs that are in areas of low productivity since it can alter the consumer's rate of consumption (Huxel and McCann 1998).

Some allochthonous inputs are between fresh water and terrestrial systems. Fish in forested streams depend on terrestrial invertebrates for 90% of their consumption

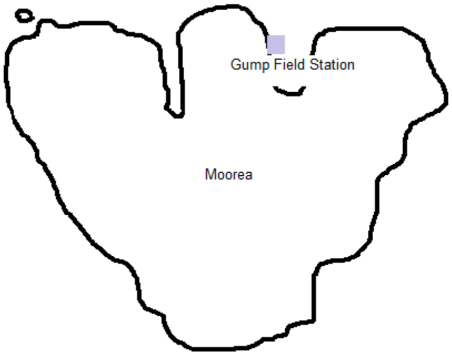

FIG. 1. Map depicting the study and collection site for *Turbinaria ornata* and the University of California Berkeley Gump Field Research Station on Moorea, French Polynesia.

(Kawaguchi *et al*. 2003). Another study discovered that changes in season can affect which predator feeds on an aquatic insect and allows both aquatic and terrestrial food webs to include the same aquatic insect, causing a reciprocal subsidy (Kawaguchi et al. 2003).

Another example of allochthonous input is from marine to terrestrial. Helfield found that salmon transport nitrogen that is marine-derived to the trees and shrubs of the fresh water rivers in which they spawn (Helfield and Naiman 2002). Even within small islands, terrestrial and marine food webs can interact: Spider populations on islands use energy primarily from prey in ocean food webs to expand their abundance(Polis and Hurd 1995b). Another example of ocean energy input can be found in ocean wrack: mats of dead plant material that spiders and other terrestrial invertebrates can feed on that are found along coastal shores and in shallow waters. Marine inputs of algal wrack on islands causes the arthropods to be 85-560 times more abundant in the supralittoral zones than inland due to a terrestrial system that is less productive (Polis and Hurd 1995a). Another example of this dependence on marine inputs can be seen on the beaches of southern California where wrack is consistently removed to clean. This causes the species that rely on this wrack to become less abundant than in areas that there was no grooming (Dugan *et al*. 2003). This in turn leads to a lack of prey available for vertebrate predators, such as shorebirds, and causes a change in the food web (Dugan *et al*. 2003).

Turbinaria ornata is a macroalgae that lives in the lagoon of Moorea, French Polynesia and tends to wash ashore and become wrack, an allochthonous input to the shore. *Turbinaria ornata* has the ability to easily detach and float long distances in French Polynesia allowing it to reach even nutrient-poor, isolated atolls (Stiger and Payri 1999). People view this algae as a blemish on beaches but it hosts many communities of terrestrial and marine organisms that are important for shore biodiversity.

The goal of the present study was to understand changes in invertebrate communities inhabiting this alga as it decomposes on the shores of Moorea. One hypothesis was that as decomposition increases in *T.ornata*, the succession of fauna will change from marine to terrestrial origin.

METHODS

Natural history

Turbinaria ornata is a brown macro algae located in the Pacific and Indian Ocean and has a tendency to live on dying coral heads (Bittick *et al*. 2009). In Moorea, French Polynesia, recent decades have seen repeated coral reef disturbances from crown of thorns sea star outbreaks, coral bleaching events, cyclones, and even anthropogenic stresses (Chin et al. 2011). These disturbances allow *Turbinaria ornata* to invade and take advantage of disturbed coral, which has been in high abundances since the 1980's (Stiger and Payri 1999). Current and weather (particularly wind storms and cyclones) cause these *T. ornata* to detach from the coral head and become aggregated on the ocean surface, leading to the formation of a vegetation raft. Currents and wave action then move these rafts onto the shores, where they are deposited. Once out of the water, the deposited *T. ornata* begin to decompose and provides an allochthonous input of nutrients from the marine environment to the terrestrial environment.

Experimental procedure

Over a four week period, a collection of *T. ornata* was placed on shore for weekly observations on the stages of decomposition and the changes in community composition. The *T. ornata* was collected by kayaking to the middle of Cooks Bay and gathering from a floating vegetation raft (17 30 S, 149 50W). Afterwards, 10-12 fronds of *T. ornata* were placed into 15 wire cages, sized 17 x17 x12 cm, at the shore of the Gump station (Fig. 1). These cages were staged into the shore containing white sand substrate. Every week, five cages were randomly selected to observe what lives within the *T. ornata*. Pictures were taken of the *T. ornata* as it went through different stages of decomposition to decide rot categories. In order to control for the colonization of the cages, six additional cages were placed on the shore and analyzed weekly. Half of these cages contained brushes with similar textures as the T. ornata and the other half were empty for comparison to the experimental cages.

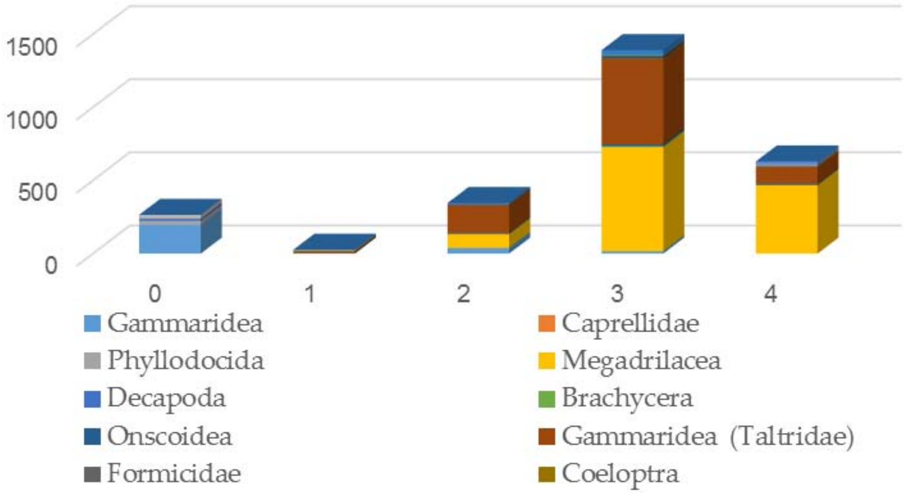

FIG. 2. Family abundance within all 5 cages each week.

Analysis of samples

T. ornata was washed with a hose into 500 micrometer sieve to catch the organisms. The contents were then placed into a container to be analyzed under the microscope. Counts for every organisms in the Phylum's Arthropoda, Annelida, and Mollusca were recorded and vouchers were collected for every new species.

Statistical analysis

I conducted ANCOVA tests to observe the patterns in the data for richness and abundance between terrestrial and marine taxa during the weeks of decomposition. Multivariate ordinate analysis was used to create cluster diagrams that would compare the beta diversity and similarity of the samples between weeks. I estimated Shannon's diversity, using EstimateS 9.1.0, among the weeks of decomposition. I then ran a linear regression, to analyze the relationship between week and diversity. All statistical tests were performed in R version 3.1.2.

RESULTS

The analysis of the relative abundances of each week show the trend of the data for the decomposition as the weeks progress (Fig 2).

The data appears to have a sinusoidal curve as the week's progress where the abundances of individuals drop in weeks 1 and 4. Week 0 from the vegetative raft contain a large abundance of the marine *Gammaridae* and within the next two weeks the terrestrial *Gammaridae* (taltridae) were the most abundant species on the algae. By week 3 and 4 the *Megadrilacea*, a terrestrial worm, was observed in even higher abundances than any of the *Gammaridae* and were the most dominant family living on this decomposing algae over the 4 weeks.

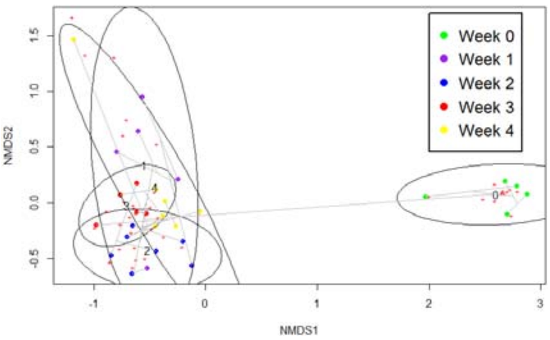

FIG. 3. Cluster diagram between weeks.

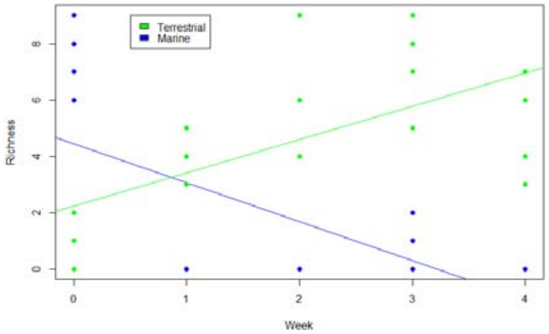

FIG. 4. Species richness (number of species) of marine vs terrestrial species with every week of decomposition.

Using multiple ordinal analysis, I compared the amount of variance of species composition and abundance between the weeks (Fig. 3). This diagram shows the weeks in a multiple dimension space that compares how different the species composition are within two dimensions. There is noted overlap in weeks 1 and 4. Week 0, however, is further distanced from all the other weeks by 1-2 units in the NMDS1 direction preventing any overlap from occurring. For marine organisms there was a negative relationship between week and richness (Fig. 4). There was a 1.38 loss in taxa for marine species per week. For terrestrial organisms there was a positive relationship between week and richness. There was a 1.18 increase in taxa per week for terrestrial organisms and they started at 2.2 on week 0. ANCOVA indicated there was a linear relationship between richness and week (Figure 1, $p< 0.001$). We found an effect of origin (marine or terrestrial, $p< 0.01$) and interaction between origin and week ($p< 0.001$). The intercepts for marine and terrestrial are not significantly different from one another ($p >.1$). The slopes for marine and terrestrial are significantly different from one another ($p<0.001$).

For marine organisms there was a negative relationship between week and abundance (Fig. 5). There was a 9.92 loss in taxa for marine species per week with the individual counts beginning at 30.6. For terrestrial organisms there was a positive relationship between week and abundance. There was a 52.72 increase in taxa per week for terrestrial organisms. The slopes of marine and terrestrial individuals are significantly different from each other ($p<0.001$). Our analysis in ANCOVA also indicated there was no linear relationship between abundance and week. Two cages from week 3 had high species counts that affected the whether there was a linear relationship between abundance and week.

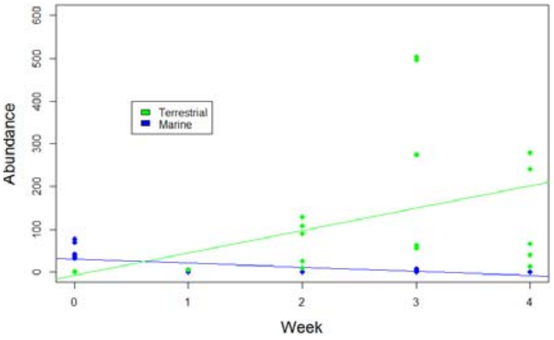

FIG. 5. Species abundance (number of individuals) of marine vs terrestrial species with every week of decomposition.

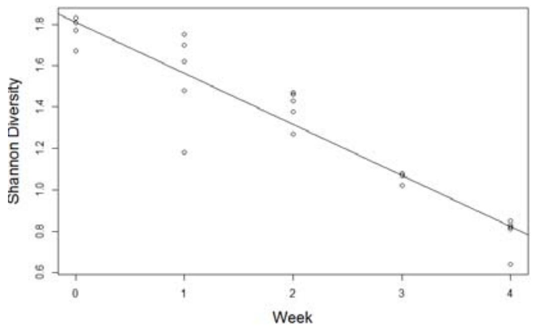

FIG. 6. Shannon's Diversity index of diversity vs week.

Shannon's diversity between the weeks indicated a strong linear relationship between diversity and week of decomposition (Fig. 6). The plot shows a decline in diversity from week 0 to 4. The R squared values were 0.897 with a p value < 0.001.

DISCUSSION

It is shown that when variations in climate cause harm to some species, competitors that are unharmed increase and cause a variation in species abundance (Tilman 2014). When the marine invertebrate family of *Gammaridea* could not continue to be a dominant family, due to the lack of water, the terrestrial *Gammaridea* family of taltridae took over that niche of inhabiting the decomposing algae as seen when mapping the abundances of the families. The observed patterns of dominance of families during each week suggests that they were fulfilling a specific niche in aiding the decomposition of Turbinaria ornata by consuming or breaking down this material. This could explain the differences between *T. ornata* decomposition rates that appeared to be dependent on the abundance of dominant species during the weeks by some of the cages that had less access to these families because weeds overtook them. Some examples of this can be found in similar studies of leaf litter decomposition rates due to the composition of the invertebrate communities within streams (Dangles and Malmqvist 2004).

This cluster diagram shows that week 0 is different in species composition than weeks 1-4 in both the NMDS1 and NMDS2 directions. It also shows that week 1-4 have a lot of overlap in composition but weeks 1 and 4 differ in the vertical direction (NMDS2) and creates this more widespread ellipse. This ellipse could be due to the decrease in abundance of taxa in weeks 1 and 4. The cluster diagram shows that there are similarities in the species compositions between weeks 2, 3 and 4 and no relation for week 0 which is due to the fact that its species composition came from the vegetation raft and should change as it decomposes on land.

As the weeks progress there was a shift from marine to terrestrial taxa in richness and abundance living on this decomposing algae. This is likely because of the location of the cages. They were placed on the shore far enough away from the tide coming in an out where most of the natural *Turbinaria ornata* that stays on the shore and decomposes. The marine invertebrates that were discovered within these vegetation rafts cannot survive without access to water. Therefore, the placing of the cages prevented any marine influences from being able to enter the cage and add to its numbers. The nonlinearity of the abundance shown in mapping the abundances and plotting it in ANCOVA shows the stages of succession on *T. ornata.*

There was a noticeable difference between cages that contained more sand than those with weeds growing into the cages. The inability to maintain the natural weeds from growing in the cages as the month progressed could have skewed the data for weeks 3 and 4 by preventing the natural amount of substrate that would have entered the cages and with it more invertebrates.

Looking at the findings for Shannon's diversity index it showed that the diversity as the weeks went by decreased. This suggests that colonization diversity was at its highest in weeks 0 and 1 when there are more nutrients and usable materials from this algae than when it began it stages of decomposition.

Other difficulties with the experimental design was finding a way to accurately quantify the invertebrates within the cage. The sieve used to filter through the samples was easy for amphipods to jump out of and the annelids to weave in and out of the holes making counts difficult. Counts for different species for Mollusca were not properly completed since it was uncertain if empty shells contributed to the decomposition of Turbinaria ornata so that were not included in the analysis.

In an observational portion of the study it was noticed that different communities of invertebrates do live on the algae based on the substrate they are located in. More analysis would have been needed to compare these communities to those within the cages.

In order to continue to monitor the shore diversity as the year's progress studies could continue to compare differences along substrate. Other studies should repeat this study and compare the diversity of the substrate near the cages and further from the cages to see if there is an actually increase in the richness and abundance of species along the shore. Similar studies could also look into *Turbinaria ornata* as a cost effective compost material for the island since it could increase invertebrate abundances.

CONCLUSION

As ocean acidification and global warming continues, the biomass of this algae will increase due to the weakening of coral which will lead greater accumulations of vegetation rafts to wash ashore. With this increase of Turbinaria onshore, I would postulate that the invertebrate communities will also increase in richness and abundance on shore. This increase of allochthonous nutrients into the terrestrial habitat should continue the growth and biodiversity of shore invertebrate communities. This will in turn could increase the food web for the ecosystem.

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APPENDIX A

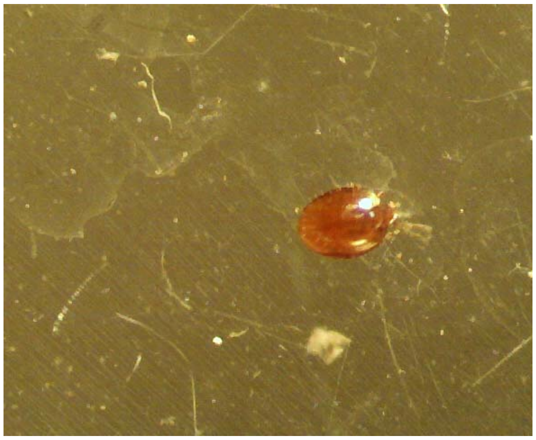
Picture of organism studied: *Turbinaria ornata* collected fresh from a vegetation raft.

APPENDIX B

Sample pictures of specimens from each family.

Gammaridea

Oribatid



Phyllodocida

Megadrilacea

Decapoda

Bracycera

Onscoida

Gammaridea (taltridae)

Formicidae

Dermanoptra

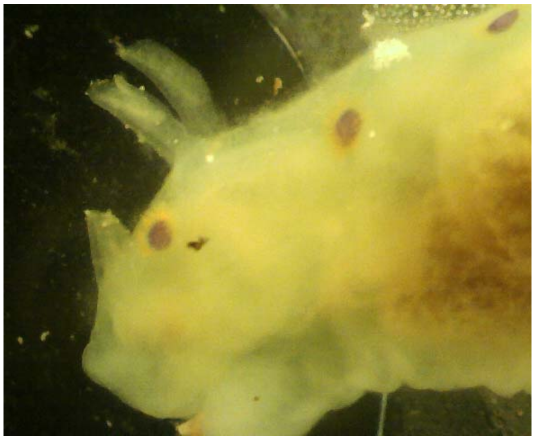
Gryllidae

Apidea

Geophilomorpha

Carabidae

Nudibrachia



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