DO URBAN STRUCTURES ALWAYS NEGATIVELY IMPACT NATURAL HABITATS? THE EFFECTS OF ARTIFICIAL SUBSTRATES ON THE SPECIES RICHNESS OF FOULING ASSEMBLAGES ON MOOREA, FRENCH POLYNESIA

JUDY LU

Integrative Biology, University of California, Berkeley, California 94720 USA

Abstract. During a time when urbanization is replacing natural habitats with artificial substrates at an alarming rate, it is important to understand the connection between habitat composition and species richness and abundance. It has been suggested that artificial structures added to the environment can increase species diversity by serving as new habitats. This study examined the effectiveness of artificial substrates as surrogates for natural substrates through the fouling assemblages by comparing concrete and high-density polyethylene plastic with basalt and conglomerate substrates on Moorea, French Polynesia. Percent cover of every distinct algae and coral species along with individual count of each macroinvertebrates species found within the quadrats were recorded. Observations shown that conglomerate and concrete exhibit no difference in algal richness and abundance, macroinvertebrate abundance, and coral richness and abundance. In addition, plastic has lower macroinvertebrate and coral richness and coral abundance than conglomerate. Since basalt substrate was only found in locations with lower species richness overall, it was not used to make comparisons with the artificial substrates in the discussion. Observations suggested that concrete has a potential of being surrogate for conglomerate and that plastic is a lesser substitute when compared to concrete.

Key words: fouling assemblages; algae; macroinvertebrate; coral; natural substrate; artificial substrate; basalt; conglomerate; concrete; high-density polyethylene plastic; species richness; species abundance, Moorea, French Polynesia

INTRODUCTION

Habitat quality is an important contributor to species richness and abundance in biological communities. One important factor that influences the quality of a habitat is habitat composition (Connell and Glasby 1999; McGuinness and Underwood 1986). Habitat composition refers to the materials making up the substrate; different substrates support different community assemblages (McGuinness and Underwood 1986). In a time when human alteration of natural habitats is causing species extinction to greatly increase, understanding the role that artificial substrates serve as new habitats becomes increasingly crucial. Artificial substrates are constantly added to the environment throughout the world, but very little research has evaluated the effectiveness of these artificial materials as the foundations of new communities. It has been suggested that artificial structures that are added to the environment can lead to an increase in species diversity by serving as new habitats for a variety of organisms in terrestrial systems (Rebele 1994). Similar research has been conducted in marine systems. A study done in the subtidal zone of Sydney Harbour, Australia, supported the idea that artificial substrates may increase species richness and diversity of subtidal epibiota in the shallow regions of an estuary; however, artificial substrates are not surrogates for natural substrates since they support different biotic assemblages (Connell and Glasby 1999).

A system that is well-suited for the purpose of assessing biotic communities on artificial substrates is fouling assemblages (Mrcelic *et al.* 2012). Fouling assemblages are consisted of sedentary organisms that reside on solid substrates during succession and other benthic organisms that depend on these pioneers for food and shelter (Khalaman 2009). The make-up of each assemblage depends heavily on the materials and properties of the substrate (Khalaman 2009). Therefore, there is a strong connection between the species composition and abundance of the fouling assemblage and the substrate. Studies had shown that the effectiveness of a substrate as fouling collector is correlated to the substrate's porosity and hardness. Smooth and non-porous substrate was less preferred by sedentary organisms (Pomerat and Weiss 1946). Analyzing the properties of the fouling assemblages on different substrates could provide important information on the sustainability of the substrate and give us insight into what extent can urban structures be used to as potential new habitats.

The overall goal of this study was to evaluate the effectiveness of artificial substrates as surrogates for natural substrates (basalt rocks and conglomerate platforms) on Moorea, French Polynesia. There are two artificial substrates that are commonly used in building urban structures in waters around Moorea: concrete and high-density polyethylene plastic. Vertical surfaces of the artificial substrates and the natural substrates were surveyed and compared. The project was designed to (1) measure the richness and abundance of organisms living on artificial and natural substrates and (2) compare species composition between habitats. The hypothesis was that there will be greater species richness and higher abundance of fouling organisms on natural substrate as compared to fouling organisms on artificial substrates. In addition, concrete is predicted to have a higher species richness and abundance when compared to plastic due to its physical properties of high porosity and rough texture.

METHODS

Site description and sampling methods

Fouling assemblages of subtidal zone were studied along the shoreline at six major sites in Moorea, French Polynesia: Gump Station, Hilton Moorea Lagoon Resort and Spa, InterContinental Moorea Resort and Spa, Tiahura motu, Temae Beach, and Tip of Cook's Bay. Data was collected between 20 October 2014 and 20 November 2014. Sites were sampled during low tide to ensure that all

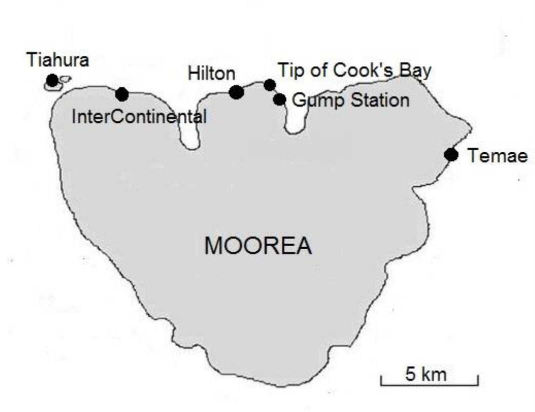

FIG. 1. Map of study sites for species richness and abundance measurements.

organisms studied were part of the subtidal zone. No visible creeks were near any of the sampling sites to avoid significant salinity difference. Vertical surfaces of four types of substrates were sampled: basalt rocks, conglomerate platforms, concrete, and high-density polyethylene plastic. Horizontal surfaces were not sampled to control for shading effects on algae and coral.

Sampling involved identifying organisms in a 10 x 10 cm^2 quadrat on substrate surfaces that were fully submerged during low tide. Six quadrats were randomly selected at each site, and five sites were sampled for each of the four substrate types. In most cases, organisms were identified on-site during the survey. When it was not possible to identify organisms in the field, a single representative individual was collected and transported to the Gump Station laboratory for identification. When it was not possible to collect the organism, such as when there was fragmentation of organisms during the process of removal, photographs and detailed descriptions were taken and used to guide identification.

Study organisms

At each study site, I estimated the percent cover of algae and live coral. Algae was categorized under the subtypes of *Lobophora, Padina, Valona, Codium, Sargassum,* Dasycladaceae, Mastophoroideae, Lithophylloideae, and Melobesioideae by referencing *Algues de Polynésie Française* (Payri *et al.* 2000). Since algae were present in multiple layers, the percent cover of algae can exceed 100%. Coral was categorized under the subtypes *Acropora*, *Porites,* and *Montipora*. The individual count of macroinvertebrates was also recorded. Dendropoma, limpets, snails, and crabs were counted visually in the field. All organisms were identified to the lowest taxonomic level possible.

Statistical analyses

I calculated and compared the average species richness using a box and whisker plot. Using a non-parametric Kruskal Wallis test, I compared species richness and abundance for algae, macroinvertebrate, and coral across all substrates. When there was a significant difference in the data, I performed pair-wise comparison using Wilcoxon rank-sum test to determine between which pair of substrates the difference occurred.

RESULTS

Average species richness

The average species richness across all taxa were similar on basalt (average richness = 12.35±4.221187), concrete, and conglomerate (p-value >0.05; Figure 2); however, there were significant differences between plastic and basalt (p-value = 0.014) and between plastic and conglomerate (p-value = 0.011)

Algal richness

There was no detectable difference between algal richness among the substrates (p-value = 0.1083; Figure 3).

Macroinvertebrate richness

When comparing macroinvertebrate richness, I found that there was a significant difference among the substrates (p-value = 0.02953; Figure 4). Pairwise comparisons showed that conglomerate and concrete both had higher richness than plastic.

Coral richness

Kruskal Wallis test demonstrated a significant difference in coral richness among the substrates (p-value = 0.03132; Figure 5). Pairwise tests showed that concrete had similar richness as conglomerate and plastic had lower richness than conglomerate. Tests also showed that basalt had lower richness than conglomerate.

Algal abundance

Kruskal Wallis test indicated that was no detectable difference between algal abundance among the substrates (p-value = 0.09688; Figure 6).

Macroinvertebrate abundance

There was no detectable difference between macroinvertebrate abundance among the substrates (p-value = 0.1436; Figure 7).

Coral abundance

Kruskal Wallis test demonstrated a significant difference in coral abundance among the substrates (p-value = 0.02119; Figure 8). Pairwise tests showed that concrete had similar abundance as conglomerate and plastic had lower abundance as conglomerate. Tests also showed that basalt had different lower abundance than conglomerate.

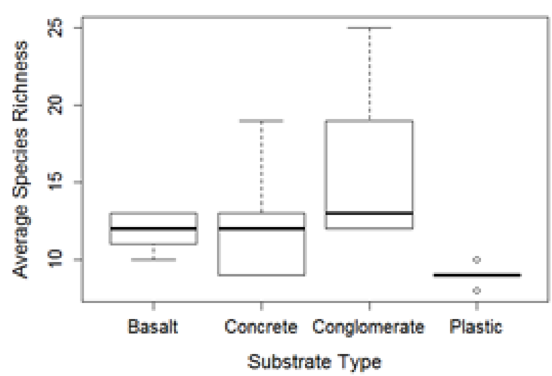

FIG. 2. Box-plot showing the average species richness among the four substrate type. Basalt, concrete and conglomerate exhibit similar average species richness, and plastic has lower species richness than the other three substrates.

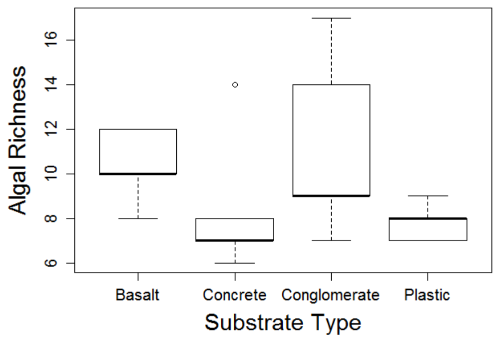

FIG. 3. Box-plot showing algal species richness among the four substrate type.

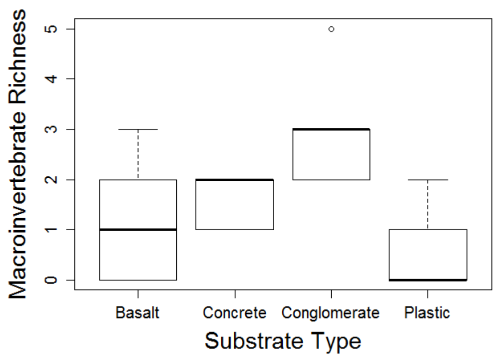

FIG. 4. Box-plot showing macroinvertebrate richness among the four substrate type.

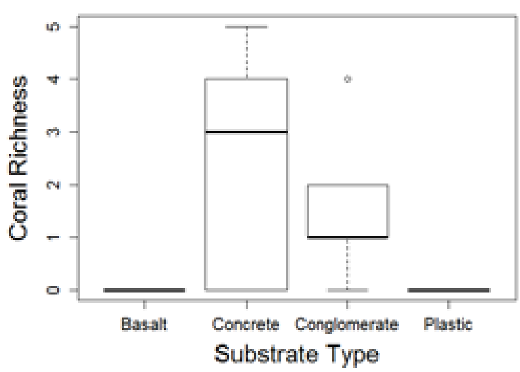

FIG. 5. Box-plot showing coral richness among the four substrate type.

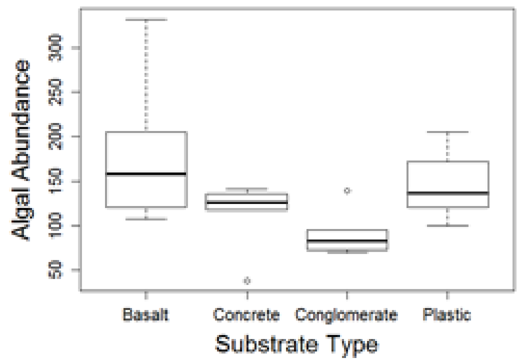

FIG. 6. Box-plot showing algal abundance among the four substrate type.of study sites for species richness and abundance measurements.

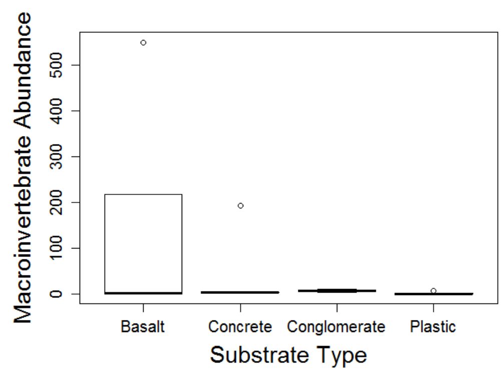

FIG. 7. Box-plot showing macroinvertebrate abundance among the four substrate type.

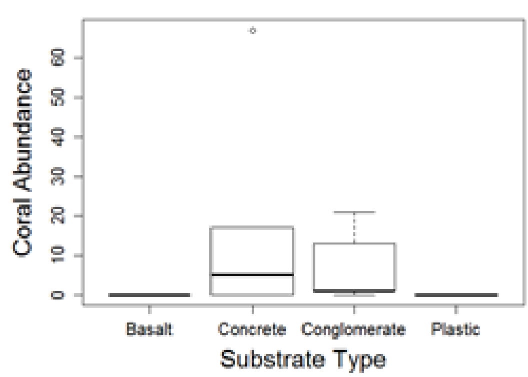

FIG. 8. Box-plot showing the coral abundance among the four substrate type.

Discussion

The data indicated that the conglomerate platform had the highest average species richness, since algae, coral, sea urchins, dendropoma, snails, limpets, crabs, hermit crabs, and cyanobacteria were all able to thrive on this substrate. Plastic generally had the lowest average species richness. A much lower diversity of species was able to grow on this substrate; only algae, coral, limpets, and crabs were found. One coral species also grew on the plastic substrate but outside of the sampling quadrat, so it was not included in the data and the statistical analysis. Overall, conglomerate and concrete showed no statistical differences in their ability to sustain algal richness and abundance, macroinvertebrate abundance, and coral richness and abundance. The observations suggested that, when compared to plastic, concrete is more suited to serve as surrogate for the conglomerate substrate. Concrete's high porosity and rough texture may have allowed for greater species richness and abundance than plastic.

Even though basalt and conglomerate are both natural substrates, the kruskal Wallis test and Wilcoxon rank-sum test both indicated that there are fewer differences between basalt and plastic than basalt and conglomerate. This may be due to the fact that all the basalt substrates that were sampled were only found at sites where lower species richness were recorded across all substrates. A possible explanation why there was surprisingly less difference between basalt and plastic than expected may be due to their similarity in texture and porosity. Both basalt and plastic have smooth surfaces and are less porous than conglomerate and concrete.

Other than the presented disparity in species richness and abundance among substrates, there were also differences observed between each location where samples were taken. Tiahura motu had the highest average species richness and InterContinental Moorea Resort and Spa had the lowest average species richness across all substrates. Numerous reasons could explain this difference. First, there was a greater habitat heterogeneity at Tiahura motu than at InterContinental Resort. A survey conducted in 2004 reviewed eighty-five publications that were published between 1960 and 2003 and found a positive correlation between habitat heterogeneity and animal species diversity (Tews *et al.*). A similar correlation was recorded in the marine environment as well. A study focusing on biological structures as a way of increasing habitat heterogeneity and biodiversity in the deep sea observed that species diversity for fouling assemblages are positively correlated to the complexity of the habitat-forming organism (Buhl-Mrtensen *et al.* 2010). There were a large number of live coral heads and dead coral rocks of various sizes and shapes scattered around the sites sampled at Tiahura motu. In contrast, the sites sampled at InterContinental Resort were primarily surrounded by open sand. There were also a gradation of water depths and variable currents at Tiahura motu, while the waters at the InterContinental Resort were fairly still and lacked the variability in water depths. Human impact may also be a contributing factor to the low average species richness at the InterContinental Resort. Certain coral species and their associating macroinvertebrate species may be sensitive to the chemical changes in the water and not tolerant of the pollution and the trash that tourists add into the marine environment.

Possible sources of error include the imperfection of random sampling techniques. Due to the unexpected size and shape of the sampling site, the protocols designed for sampling could not be followed exactly. It was also hard to definitively determine whether all the artificial substrates that were sampled had reached an equilibrium with the environment that they were placed in. For example, floating docks made out of high-density polyethylene plastic could have been cleaned periodically and did not have enough time in the water for coral species to colonize. Maximum water depth at sampling sites was also not accounted for in this experiment. Different depths of waters might carry different assemblages of pre-attachment fouling organisms.

Further research needs to be done on comparing concrete with conglomerate and basalt to better support the idea that concrete can potentially serve as surrogate for those two natural substrates. A recolonization study could be done to see whether the sequence of colonists arriving on those three substrates are similar. Future studies could also include a phylogenetic component to compare the assemblages on the three substrates. If concrete is determined to be a potential surrogate for the natural substrates, then more investigation needs to be conducted to evaluate the impact of cement structures on biodiversity in the marine waters.

In conclusion, there was no difference in algal richness and abundance, macroinvertebrate abundance, and coral richness and abundance between conglomerate and concrete. Additionally, plastic exhibited lower macroinvertebrate and coral richness than conglomerate. The observations suggested that concrete has a higher potential of being surrogate for the conglomerate substrate than plastic.

ACKNOWLEDGMENTS

I thank Professor Stephanie Carlson, Professor Brent Mishler, Professor Jonathon Stillman, and Professor Vincent Resh for their guidance and support. I thank Jason Hwan, Jenna Judge, and Seth Kauppinen for helping me with statistical analysis. I thank Rona Chen, Katya Frazier, Ruth Jean Ae Kim, Amy Moulthrop, and Lea Pearlman for helping me with data collection. Thanks to the University of California, Berkeley's Richard B. Gump field station for giving me this wonderful research opportunity.

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