Conquest of the Intertidal

Impacts of Invasive Algae on Native Algae

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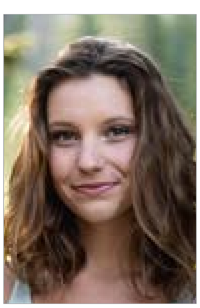
The intertidal zone is a competitive environment for benthic dwelling organisms. On the south shores of O'ahu, these zones contain a diverse array of algal species. Native and invasive species compete for space on the intertidal bench. Surveys were carried out by the OPIHI (Our Project in Hawai'i's Intertidal) citizen science program, which collected data on community composition and species abundance at intertidal sites around O'ahu. This data was analyzed from 2017–2019 at the 'Ewa Beach site to determine if native algae species cover is reduced by the invasive algae species Acanthophora spicifera, Gracilaria salicornia, *and* Avrainvilla lacerata. *The cover of native algae species was found to be negatively impacted by the increasing cover of the invasive algae species. The species richness analyzed at another site, Diamond Head, determined that both sites have similar community diversity and did not have a significant difference. The increased cover of invasive algae can negatively impact intertidal communities due to the decrease in diversity through habitat modification and displacement of native species. Invasive algae species have the potential to dominate the intertidal community due to faster reproduction methods, resilience, and adaptability to changing environments.*

The Hawaiian Islands are isolated in the Pacific, allowing the shores to house a diversity of algae species, and are unique due to their high amounts of endemism. There has been an increasing amount of nonindigenous algal species overrunning the intertidal areas (Cox et al. 2013). The intertidal zone encompasses the area where the ocean and land meet as the tides fluctuate, harboring an abundance of organisms (La Valle et al. 2020). The tropical rocky shores have high species richness, yet are a neglected area of study (Macusi and Deepananda 2013). Intertidal research is important for community structure due to distinct compositional gradients of organisms (La Valle et al. 2020). Intertidal habitats have a wide range of diversity, composition, and abundance of organisms that are ideal for examining community structure due to the frequent fluctuations in conditions (Cox et al. 2013). Because of the varying wave action, light and nutrient availability, algae is abundant among the intertidal zone (La Valle et al. 2020).

Algal species are critical to intertidal zones as they pro-



From a young age I have been passionate about marine conservation and research. I graduated Spring 2021 with a bachelor of science in Marine Biology and would like to pursue graduate school studying shark ecology. During my senior year I worked with the program Our Project in Hawaii's Intertidal (OPIHI) studying marine algae and invertebrate biology throughout Hawai'i's Intertidal ecosystems. Through this work I gained an appreciation for the foundational work marine algae provide for the success of all organisms. Algae species are under-appreciated, and many times overlooked, yet they are critical to maintain a healthy environment. This study demonstrates the harmful impacts of invasive algae on local intertidal communities and the effect on native algae.

vide food for grazers and structure for the ecosystem (Smith et al. 2002). Although Hawai'i contains numerous endemic algae species, there has been a rise of nonindigenous algal species (Smith et al. 2002, 2004). The three most common alien algal species observed on the island of O'ahu are *Acanthophora spicifera* (prickly seaweed), *Avrainvillea lacerata* (leather mudweed), and *Gracilaria salicornia* (gorilla ogo) (Smith et al. 2002) (Figure 1). As a result of experimental aquaculture, two red algae genera were intentionally introduced and are now considered a nuisance species (Smith et al. 2004). These genera have the ability to propagate and establish rapidly and were used for experimentation in Kāne'ohe Bay for the carrageenan and agar industries (Smith et al. 2004; Conklin and Smith 2005). Other nonindigenous species have been introduced into local ecosystems since the 1950s, and their source is widely unknown, but most likely suspected to originate from ship transport (Smith et al. 2002, 2004). The nonindigenous species often overrun native species (Smith et al. 2004), can pose a large threat to coral-dominated habitats and have the potential to damage nearshore ecosystem structure through reduction in biodiversity (Smith et al. 2002).

The most common nonindigenous algae species have been inhabiting Hawaiian coastal reefs for decades, some as early as the 1950s, demonstrating resilience and ability to thrive in foreign environments (Smith et al. 2002, 2004). These species have been found in different distributions and abundances throughout the Hawaiian Islands, and still remain a problem in intertidal environments today. Many of the nonindigenous species have the ability to reproduce asexually through vegetative propagation, assisting in their dispersal throughout O'ahu (Smith et al. 2002). *Acanthophora spicifera* is a red algae species that was introduced to Pearl Harbor in 1952 (Smith et al. 2002). This species has spread throughout the island and is most common in intertidal areas (Smith et al. 2002). *Avrainvillea lacerata* is a green alga that was found at Koko Head after 1981 (Smith et al. 2002). This algae species co-occurs with an endemic Hawaiian sea grass and is threatening to become a conservation problem (Smith et al. 2002). *Gracilaria salicornia,* is a red alga with unique dispersal patterns, demonstrating the ability to dominate local areas, but has not yet been observed to spread over long distances (Smith et al. 2002). A*vrainvillea lacerata, Gracilaria salicornia,* and *Acanthophora spicifera* can reproduce through fragmentation allowing them to travel far and settle in many areas. This life history strategy contributes to the difficulties in eradicating harmful blooms.

The tropical rocky intertidal on the south shore of O'ahu houses a diversity of algal and invertebrate species (Cox et al. 2013). These intertidal zones have not been thoroughly studied, yet the work of Our Project in Hawai'i's Intertidal (OPIHI) has involved citizen scientists in collecting community structure and composition data. Involving the local community in ecological research has raised awareness about their surrounding flora and fauna (La Valle et al. 2020). The OPIHI participants include school students (grades 6–12), teachers, and community members that are assisted by undergraduate and graduate students at the University of Hawai'i. The work of the citizen scientists is valuable towards intertidal research as it can be time intensive and enables hands-on work for community members (La Valle et al. 2020).

Our research goal is to investigate the abundance of the three main invasive algae species at two sites on the island of O'ahu ('Ewa Beach and Diamond Head) and compare it to the native species abundance. It was hypothesized that the higher the invasive algae species abundance, the lower the native algae species cover. An analysis of data dating from the 2017 to 2019 OPIHI studies demonstrated habitat shifts of species diversity across the three locations. Due to the fragility of intertidal ecosystems and Hawai'i's high endemism rates, it is important to investigate the impacts of nonindigenous algae. Comparing the relative diversity seen at the sampling sites, 'Ewa Beach and Diamond Head, could provide further information on the consistency of algae cover by season, year, or decade.

Materials and Methods

Site Description

Rocky intertidal sites, on the island of O'ahu, Hawai'i ('Ewa Beach and Diamond Head) were surveyed by the citizen science program OPIHI. This survey data was collected from

Figure 1. (a) *Acanthophora spicifera* (prickly seaweed) (b) *Avrainvillea lacerata* (leather mudweed) (c) *Gracilaria salicornia* (gorilla ogo)

Figure 2. Survey locations on the island of O'ahu 'Ewa Beach (21°18'51.80'N 158°00'14.57"W) and Diamond Head (21°15'19.57"N 157°48'38.60"W)

2017 until 2019. The sites are rocky intertidal benches 10m long and 15m wide in the littoral zone with rocky and sandy substrates. Due to tidal changes, the flora and fauna in the area varies. The community composition was identified in the collection sites by OPIHI participants. 'Ewa Beach had more consistently available data for invasive species and was therefore used for the abundance analysis.

Benthic Algal Surveys

Community-level compositional data was collected for each site by OPIHI participants. The abundance of benthic algal species were collected through point-transect sampling. The transects were 10m long and laid out perpendicular to the shore into the littoral zone. The transect location was not fixed in the intertidal zone at each site and were spaced 2m apart in order to adequately cover the site. To determine the substrate and organisms directly below, gridded quadrats ($0.09m^2$) with 25 intercepts were set at intervals along each transect. Some algal species were unable to be identified without a microscope and were either identified to genus or characterized as "turf algae," "brown crust," or "cyanobacteria" using field identification guides (La Valle et al. 2020).

Algal Abundance Analysis

The percent cover of the invasive and native algae species was calculated to compare the composition of algae cover between the study sites and throughout each year of data collections.

A Simpson's Diversity Index was calculated for each site to determine the algal abundance and diversity at that site. A t-test was run on the diversity data to determine if the sites differed in composition. A regression analysis was performed to determine the strength of the relationship between the abundance of invasive species versus the abundance of native species at each site.

Results

The percent cover of invasive algae species affected the percent cover of the native algae species at 'Ewa Beach from 2017–2019. A linear regression demonstrated a negative relationship between invasive and native algae species cover from 2017 to 2019 (Linear Regression; n=249, df=248, R^2=0.6161, F=398.067, p<0.001, Figure 3). The data accumulated from 2017 and 2021 demonstrates a higher average invasive species cover. The increase in invasive algae species significantly affected the native algae species at 'Ewa Beach in 2021 (Linear Regression; n=36, df=35, R^2=0.9996, F=86714.73, p<0.001, Figure 4).

The average Simpson's Diversity index indicated that there was high species diversity throughout 2017–2019, how-

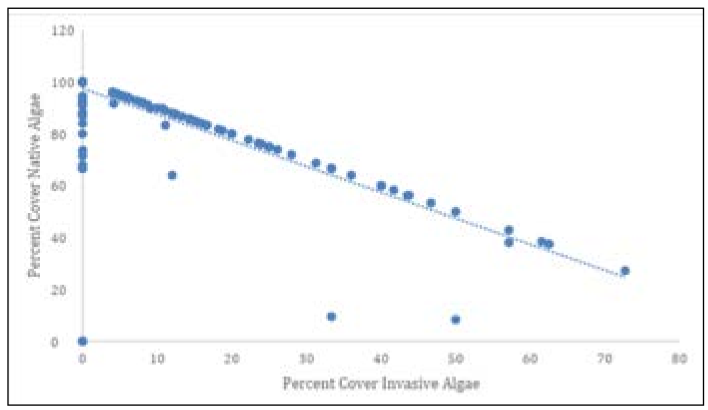


Figure 3. Linear Regression of percent cover invasive algae species and percent cover native algae species cover at 'Ewa Beach from 2017 to 2019.

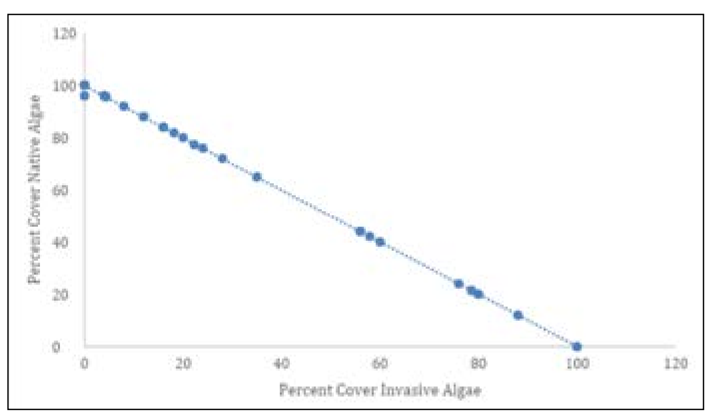


Figure 4. Linear Regression of percent cover invasive algae species and percent cover native algae species cover at 'Ewa Beach in 2021.

ever no significant differences in diversity between sites were detected. Diamond Head species diversity was consistent with ‘Ewa Beach, except in 2016 where ‘Ewa Beach experienced a lower index of 0.717 compared to Diamond Head 0.828 (Figure 5). The t-test indicated no significant difference among the diversity of algal species at both Diamond Head and ‘Ewa Beach from 2016–2019 (Figure 6).

Discussion

The community structure and composition vary each year throughout the ‘Ewa Beach location. The abundance of each algal species differed each year, yet the same species are seen throughout the analysis timeline. The regression analysis reveals that there is an effect on the cover of the native algae species due to the three invasive algae species. From OPIHI surveys conducted from 2017–2019 the native algae species experienced a decline when there was an increase in the invasive algae species cover (Figure 3). The most recent data collected in the spring of 2021 showed the ‘Ewa Beach site was dominated by *Avrainvillea lacerata*. This species is commonly

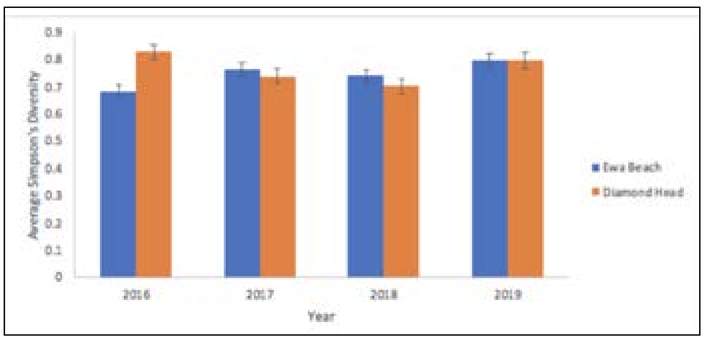


Figure 5. Average Simpson’s Diversity Index from 2016–2019 at ‘Ewa Beach and Diamond Head.

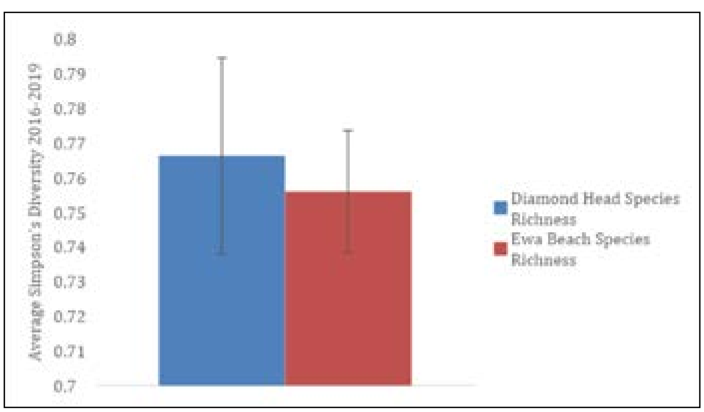


Figure 6. Compiled Simpson’s Diversity Index from 2016–2019 at Ewa Beach and Diamond Head. (Student’s T-test; n=4, df=6, t_{stat}=0.309, p=0.768)

observed in deeper waters and has expanded cover near the shoreline (Foster et al. 2019). The 2021 dataset had the highest amount of invasive species cover compared to the previous years sampled. The negative relationship from 2017–2019 and 2021 suggests that as the percent cover of the invasive algae species increases, the percent cover of the native algae species decreases. There were high amounts of native brown algae cover at the Diamond Head site with a mass covering of *Turbinaria ornata* and *Sargassum sp*. From 2016–2019 Diamond Head and ‘Ewa Beach had similar species diversity indices, yet presence of the three invasive algae species was higher at ‘Ewa Beach. The native algal species presence is beneficial for each intertidal site because it indicates ecosystem structure and the ability for diverse algal settlement. When invasive algae propagate and settle, substrata are taken up, disrupting the structure and preventing native algae from settling (Smith et al. 2002; La Valle et al. 2020).

Limitations in the experimental design include the amount of data available for each site per year. The 2020 datasets were not present due to the COVID-19 pandemic hindering participants from collecting data. The intertidal zone is impacted by tidal changes and wave actions, therefore replicating the transect and quadrat location can be difficult. The low percent cover seen in the 2018 dataset at ‘Ewa Beach could be attributed to local community cleanups or an increase in invertebrate abundance. Patterns of low macroalgae cover have been observed in intertidal areas where there is an increase in benthic invertebrate grazers (Underwood and Jernakoff 2006).

Variations among each site could be influenced by biological processes and physical factors (La valle et al. 2020). Wave exposure, ocean transport, and substrate availability can have an effect on the settlement and composition of the algal species (Cox et al. 2013). The increasing abundance of the invasive algae species at intertidal communities has been attributed to low grazing and an increase in anthropogenic nutrients in the surrounding water (Smith et al. 2002). Other factors that can increase invasive species abundance are the differences in substrate availability that can affect the growth and survival of algae species assemblages (Cox et al. 2013). The nonindigenous algae success can be attributed to rapid growth rates and high nutrient concentrations (Smith et al. 2002).

Intertidal community structure is impacted by species distribution and abiotic factors (La Valle et al. 2020; Mcquaid and Branch 1984). Anthropogenic factors such as the introduction of foreign species and threat of climate change are independent causes of ecosystem damage (Stachowicz et al. 2002). When these two factors are combined, the pressure can overwhelm the structure of the ecosystem. As global temperatures increase, ecosystems are experiencing phase shifts. The shift in abundance of indigenous and nonindigenous algae can have a cascading effect on the trophic levels of the intertidal ecosystem (Smith et al. 2002). Thermal stress can have varying effects on native and non-native species (Cox et al. 2017).

Nonindigenous algae species demonstrate faster reproduction strategies, resilience, and adaptability to thermal stress therefore supporting the prediction of their increased presence at intertidal communities (Smith et al 2002, La Valle et al. 2020). Invasive algae can modify biotic and abiotic components of the ecosystem, often out-competing native species (Foster et al. 2019). To protect the diversity of intertidal ecosystems and prevent competition with nonindigenous species, consistent monitoring of these sites is needed. Restoration efforts and algae cleanups can benefit the native species' success and limit the settlement and growth of invasive algae.

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