# Eco-conscious resort construction reduces living coral coverage, species richness, species abundance, and increases algae coverage

**Ryan DN Mullen** Corresp. [1]

[1] Department of Environmental Science, Policy, and Management, University of California, Berkeley, Berkeley, California, United States

Corresponding Author: Ryan DN Mullen
Email address: rmullen@berkeley.edu

Tourism today is moving towards sustainable approaches because the industry poses significant threats to the environment. This includes a shift in construction type: to building structures that aim to coexist with their surroundings. One example of this is the overwater resort bungalow. Although there is a substantial amount of research on the effects of coastal development on the environment, there is little research on the effects of sustainable approaches. This study aimed to quantify the effects of oceanic overwater resort bungalows on coral reef ecosystems. Two overwater bungalow resort sites were investigated on the island of Mo'orea in French Polynesia to see whether or not they impacted their environment. The percentage of living coral coverage, percentage of algae coverage, species abundance, and richness, were examined by surveying different areas of the lagoon that all varied in distance away from the bungalow chain. The resort sites were ultimately compared to two control sites, both without bungalows and slightly removed from the resort sites, in order to account for other factors influencing the response variables. Living coral coverage, species abundance, and species richness, were all positively correlated with distance away from the bungalow chain. Algae coverage was negatively correlated with an increase in distance. The data collected provides evidence that bungalows are impacting the environment they are situated in. Increased algae presence near the bungalow chain may be due to shade coverage produced by the bungalows. Decreased living coral coverage, species richness, and species abundance, in close proximity to the chain, may be due to the impacts of initial construction, tourists, and competition. Regulations need to be imposed on future construction of bungalows in order to avoid prolonged and greater effects on reef ecosystems. It also needs to be considered that all ecofriendly structures may be inherently affecting the environments they surround.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

# Eco-conscious Resort Construction Reduces Living Coral Coverage, Species Richness, Species Abundance, and Increases Algae Coverage

Ryan D. N. Mullen
Department of Environmental Science, Policy, and Management
University of California, Berkeley
Berkeley, California, USA

rmullen@berkeley.edu

**Abstract**

Tourism today is moving towards sustainable approaches because the industry poses significant threats to the environment. This includes a shift in construction type: to building structures that aim to coexist with their surroundings. One example of this is the overwater resort bungalow. Although there is a substantial amount of research on the effects of coastal development on the environment, there is little research on the effects of sustainable approaches. This study aimed to quantify the effects of oceanic overwater resort bungalows on coral reef ecosystems. Two overwater bungalow resort sites were investigated on the island of Mo'orea in French Polynesia to see whether or not they impacted their environment. The percentage of living coral coverage, percentage of algae coverage, species abundance, and richness, were examined by surveying different areas of the lagoon that all varied in distance away from the bungalow chain. The resort sites were ultimately compared to two control sites, both without bungalows and slightly removed from the resort sites, in order to account for other factors influencing the response variables. Living coral coverage, species abundance, and species richness, were all positively correlated with distance away from the bungalow chain. Algae coverage was negatively correlated with an increase in distance. The data collected provides evidence that bungalows are impacting the environment they are situated in. Increased algae presence near the bungalow chain may be due to shade coverage produced by the bungalows. Decreased living coral coverage, species richness, and species abundance, in close proximity to the chain, may be due to the impacts of initial construction, tourists, and competition. Regulations need to be imposed on future construction of bungalows in order to avoid prolonged and greater effects on reef ecosystems. It also needs to be considered that all ecofriendly structures may be inherently affecting the environments they surround.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

## Introduction

Anthropogenic disturbances alter ecosystems and affect biodiversity. Consequently, extensive research has been conducted on assessing the overall effects of human development and intentional land-use change on the environment, especially in regions with rich biodiversity (Ceballos-Lascurain, 1993). During the urbanization of rural areas, for example, species lose their habitats and ecological interactions among individuals are altered (Kühn & Klotz, 2006). The effects of intentional land-use change can also be seen in the case of water diversion, with subsequent droughts, and in some cases, extirpation of species (Anderson, Freeman, & Pringle, 2006). As a result, there has been a transition in development towards eco-conscious construction.

Sustainable development aims to coexist with, and minimize alteration of, its environment (Ayala, 1995). Unlike traditional construction, the ecofriendly structures are seemingly a step removed from the ecological interactions they surround due to some aspect of their construction (Yusof & Jamaludin, 2013). In the case of construction in rural areas, the structures may be elevated from the ground or make use of trees as support beams in order to minimize impacts on the surroundings. Crop rotation, another form of sustainable development, ensures the cycling of nutrients among different areas within an ecosystem, aiming to reduce the impact on its surroundings (Balota et al., 2004). Although sustainable development intends to have minimal influence on its environment, little research has been completed to see whether or not it inherently affects its surroundings.

In the tropics, overwater oceanic bungalows are built as a form of ecofriendly resort construction that enables tourists to closely interact with the marine ecosystem. The structures are raised above the reef, supported by pilings, and many bungalows offer direct access to the reef via swim platforms (Bromberek, 2009). Like all types of sustainable development, the bungalows seem to be removed from the reef environment without affecting the organisms below. The effects overwater bungalows have on ecosystems are not well studied. This is not because coral reefs are unimportant; however, as coral reefs, though only estimated to cover about 0.1-0.5% of the ocean floor on Earth (Roberts et al., 2002) are one of the most productive and biologically diverse ecosystems on Earth (Sale, 2002), and house more species per unit area than any other marine ecosystem (Glynn, 1993).

The small total percentage of coral coverage worldwide is due to their very specific set of environmental conditions needed for growth (Hughes, 2003). Most corals need clear water in order for their mutualistic algae (zooxanthellae) to photosynthesize (De'ath et al., 2012). Detrimental effects associated with cloudy water as a result of sedimentation, agriculture runoff, and algal dominance is documented (De'ath et al., 2012). Reef-building corals also require temperatures that are generally between 20-32 degrees Celsius and a pH between 8.2 and 8.4 (Bruno et al., 2007). Coral bleaching events, the whitening in color and ultimate death of the coral, have been attributed to conditions outside of these ranges (Lesser, 1997). Additionally, a number of studies have been conducted to investigate the effects of change in depth on coral coverage (Bak, 1977). Under ideal conditions, coral is able to grow and reproduce, and so are the associated organisms, including species of fish and invertebrates, that feed and live in it.

Due to their specific conditions needed for growth, coral could be greatly influenced by the presence of the bungalows. The structures of the overwater bungalows present the possibility of either enabling or inhibiting the survival of different organisms in the associated coral reef ecosystem. The pilings of the bungalows, large concrete cylindrical poles drilled into the ocean floor, have a big surface area and may provide a new substrate for marine organisms to establish on. Alternatively, the placement of the pilings during initial construction may have lasting impacts on coral growth and species survivorship. The large surface areas of the bungalow platforms, which generate large amounts of shade (Bromberek, 2009), may promote the dominance of marine algae by protecting the algae from prolonged and direct amounts of sun. The combination of algae dominance and blockage of sunlight could potentially have an effect on the photosynthetic activity and fitness of the corals. Contrarily, the large surface area of the bungalows could provide an ideal temperature for marine species to gather, promoting diversity in close proximity to the bungalows. Another important factor to consider in the effect the bungalows may have on the environment is runoff water from the watering of planter boxes and rainwater. The runoff water, containing nutrients, may promote the growth of algae near the bungalow chain. The runoff water could also pose strong hindrance on the growth of coral due to being cloudy and ultimately blocking sunlight.

The island of Mo'orea in French Polynesia, with five overwater bungalows resorts, presents the opportunity to investigate the exact impact the bungalows impart on the environment. There has been one research project that examined the effects of bungalows on reef health (Cossey, 1998) and focused on the area directly below the structures and their pilings. There is opportunity to research species diversity and abundance around the bungalow areas, specifically in response to distance away from the bungalow chains. Using the Hilton Moorea Lagoon & Spa and the Sofitel Ia Ora Beach Resort, along with associated control sites, this study aims to quantify the exclusive relationship between distance away from the overwater bungalow chains and species diversity, abundance, and percentage coverage of living coral and algae. It is hypothesized that with an increase in distance from the hotel bungalow chain, there will be an increase in living coral coverage, along with an associated increase in fish and invertebrate species and abundance and a subsequent decrease in algae coverage.

## Materials and Methods

### *Study Sites*

Mo'orea (17°30'S, 149°50'W), a volcanic island approximately 1.4 million years in age, is located 18 km northwest of Tahiti within the Society Archipelago of French Polynesia in the central South Pacific Ocean (Lecchini & Poignonec, 2009). The island is surrounded by a barrier reef that creates a lagoon, 800 - 1300 m in width, between the reef and Island's seashore (Dufour, Riclet, & Lo-Yat, 1996). The lagoon is associated with smaller waves and less intense currents than the open ocean due to the reef crest's ability to break large waves. This study focused on the overwater bungalows at two resorts, along with two associated control areas in the lagoon.

### *Opunohu Hotel Site*

Opunohu Hotel Site, the Hilton Mo'orea Lagoon Resort & Spa, is located just west of Cook's Bay and east of Opunohu Bay on the north shore of Mo'orea (Figure 1). The hotel was built in 2000 and consists of 54 overwater bungalows that are all 62 $m^2$ in area. The first bungalow on the bungalow chain is approximately 40 m from shore. Each bungalow is accessible by one main wooden boardwalk that splits twice and ultimately forms three forks (Figure 2). Bungalows are erected on either side of each fork. The bungalows and pilings are made of concrete and have thatched roofing. Coral was displaced during the drilling of the pilings. Potable water, wastewater, and electricity are all transported to and from the bungalows in pipes that run directly under the boardwalk. The pipes do not penetrate the sea. The main reef runs openly under all three major forks of the bungalow chain.

*Opunohu Control Site*

Opunohu Control Site, the public beach 800 m to the east of Opunohu Hotel Site, is the control site that corresponds to Opunohu Hotel Site. There are neither overwater bungalows nor additional human development in the lagoon or on the shore. No boats moor in the vicinity. Opunohu Hotel Site, together with Opunohu Control Site, will be referred collectively as Opunohu Site (Figure 1). The same main reef occupies the lagoon at both the Opunohu Hotel Site and the Opunohu Control Site.

*Temae Hotel Site*

Temae Hotel Site, the Sofitel Mo'orea Ia Ora Beach Resort, is adjacent to Temae Public Beach and located approximately 1 km to the southwest of Mo'orea Temae Airport. It is situated on the northeast corner of Mo'orea. The hotel was originally constructed in 1976 and contains 39 overwater bungalows, 19 of which are 52 $m^2$ and the remaining 20 are 31$m^2$ in area. The first bungalow is approximately 25 m from shore. Like at the Opunohu Hotel Site, each bungalow is accessible by a wooden boardwalk. The boardwalk splits into two and bungalows are on either side of each boardwalk (Figure 3). The construction materials, including the piping that runs under the boardwalk, are the same as those described at the Opunohu Hotel Site. Coral was displaced during the construction of the resort.

*Temae Control Site*

Temae Control Site, a section of Temae Public Beach, is the control site used in conjunction with Temae Hotel Site. Temae Control Site is a section of Temae Beach approximately 400 m northwest of the property line shared by the Sofitel and Temae Beach. The control site has no overwater bungalows, no moorage of boats, and no structures built on the shore of the beach. Temae Hotel Site with Temae Control Site will be referred together as Temae Site (Figure 1). Due to their close proximity, the control site and associated hotel site contained similar reef bommies and encompassed parts of the same main reef.

*Sampling*

Individual meetings with the general managers of each resort were initially arranged in September 2016 in order to gain permission to survey under the bungalows and to note historical information on the construction and upkeep of the resorts. Field sampling occurred in October and November 2016 and was restricted to mornings to eliminate any potential biases associated with change in sunlight and tide.

*Sampling Method at Opunohu Site and Temae Site*

Sampling at Opunohu Site began by surveying Opunohu Hotel Site. A transect tape was placed starting at the first bungalow and continuing for 100 m westward parallel to shore and sampling was conducted every 10 m along this line. The first point of sampling was at the base of the bungalow—recorded as distance zero.

Sampling consisted of two separate procedures: a timed survey followed by a coverage survey. The timed survey took place in three-minute intervals (by use of a stopwatch) during which species richness and abundance, including that of all fish and all invertebrates, were observed and recorded. Fish were identified to the species level and invertebrates were identified to the family level. After the timed survey, a $4m^2$ quadrat was centered on the survey point at that particular distance away from the bungalow chain and values of percentage living coral coverage and percentage algae coverage were noted. After the entirety of the 100 m transect line was surveyed, additional 100 m transect lines, each 10 m further from shore, and parallel to, the previous, were created (Figure 2). The starting point of each new transect line, distance zero, was always at the base of the bungalow chain at the given distance from shore. This methodology was repeated until 50 m past the last bungalow on the chain of bungalows was reached. After the entire western chain of bungalows was surveyed, the same methodology was completed for the eastern chain. The eastern transect lines, however, ran east and started at the base of the east-facing bungalows on the easternmost chain (Figure 2).

Once sampling was finished at Opunohu Hotel Site, sampling at Opunohu Control Site took place. The first transect at Opunohu Control Site took place at the same distance from shore as the first transect at Opunohu Hotel Site. Therefore, the same total area of ocean that was surveyed at Opunohu Hotel Site was surveyed at Opunohu Control Site. Due to its relatively close proximity to the resort site (800 m), the control site accounts for variables affecting the response variables other than the presence of bungalows.

Sampling at Temae Site occurred in the same way as that described for Opunohu Site (Figure 3). The transects ran parallel to shore but due to Temae Site's positioning on the island, the transects ran northeast and southwest accordingly (Figure 3). The distance from shore of the first bungalow, and therefore the distances away from shore of every transect line, however, were different than those of Site Opunohu.

### *Statistical Analyses*

First, a matrix of Pearson correlation coefficients was calculated among all of the response variables, including combined fish and invertebrate richness, combined fish and invertebrate abundance, living coral coverage, and algae coverage, to assess correlations between response variables. Next, a factorial ANCOVA was applied with site (Site Opunohu or Site Temae, respectively) and treatment (the existence or absence of hotel) as predictor variables and combined fish and invertebrate species richness as the response variable. Three additional factorial ANCOVA's were applied to test for differences among sites in three other response variables: living coral coverage, algae coverage, and combined invertebrate and fish abundance.

## Results

### *Correlation Matrix of Response Variables*

Four independent correlations were found among different response variables. A relationship existed between algae coverage and living coral coverage, $r(1364) = -.36$, $p < .001$ (Figure 4). In areas with greater algae coverage, there was, on average, a lesser amount of coral coverage. Further, it was found that with an increase in living coral coverage, there was an associated increase in species richness $r(1364) = .27$, $p < .001$ (Figure 5), and species abundance $r(1364) = .30$, $p < .001$ (Figure 6). A significant positive correlation was also seen between species richness and species abundance $r(1364) = .67$, $p < .001$ (Figure 7). No significant correlation was apparent between algae coverage and species richness, $r(1364) = -.02$, $p = .44$ ( Figure 8) and between algae coverage and species abundance $r(1364) = -.06$, $p < .001$ (Figure 9).

*Algae Coverage*

A factorial ANCOVA was conducted to test for differences between site and treatment on algae coverage controlling for distance away from the bungalow chain. It was found that the site significantly affects the mean algae coverage. The mean algae coverage per survey at Opunohu Site was 24% while at Temae Site was 17%, $F(1, 1359) = 57.82$, $p < .001$ (Figure 10). The treatment, the presence or absence of the hotels' bungalow chains, was seen to affect algae coverage. At Opunohu Site, the hotel survey had a mean of 18% algae coverage per survey and the control site had a mean of 28% per survey. Temae Site's hotel site had 14% mean algae coverage per survey, while the control site had 19% mean coverage. The effect of treatment was significant, $F(1, 1359) = 76.89$, $p < .001$ (Figure 10). There was also a significant combined effect of site and treatment, $F(1, 1359) = 8.01$, $p = .01$. Opunohu Hotel Site, Opunohu Control Site, Temae Hotel Site, and Temae Control Site had the greatest mean algae coverage per survey area at distances 0, 80, 0, and 20 m, respectively, and least mean algae coverage per survey at distances 100, 30, 80, and 70 m from the bungalow chain, respectively (Figure 11). It was observed that with an increase in distance from the bungalow chains, there was an associated decrease in mean algae coverage per survey, $F(1, 1359) = 97.91$, $p < .001$ (Figure 11).

*Living Coral Coverage*

An additional factorial ANCOVA was completed to determine statistical difference between site and treatment on living coral coverage while controlling for distance away from the bungalow chain. Total living coral coverage was 11% greater at Opunohu Site than Temae Site (80% mean coverage versus 72% mean coverage, respectively). There was a statistically significant effect of site on living coral coverage, $F(1, 1359) = 12.86$, $p < .001$ (Figure 12). Further, it was found that treatment also significantly affected living coral coverage $F(1, 1359) = 53.88$, $p < .001$ (Figure 12). There was a combined effect of site and treatment, $F(1, 1359) = 44.72$, $p < .001$. Opunohu Hotel Site, Opunohu Control Site, Temae Hotel Site, Temae Control Site had the greatest mean living coral coverage per survey area at distances 100, 90, 100, and 30 m, respectively, and least average algae coverage at distances 0, 30, 0, and 10 m from the bungalow chain, respectively (Figure 13). It was found that with an increase in distance from the bungalow chain there was a coupled increase in living coral coverage, $F(1, 1359) = 229.08$, $p < .001$ (Figure 13).

*Species Richness*

The effect the distance from the bungalow chains has on species richness was quantified through use of an additional factorial ANCOVA. The mean number of species per survey at Site Opunohu was 3.95, while the mean number of species per survey at Site Temae was 3.21. This represents 23% greater average species richness per survey at Site Opunohu than Site Temae (Figure 14). The effect of site on species richness was significant, $F(1, 1359) = 60.70$, $p < .001$. The effect of treatment on species richness was insignificant, $F(1, 1359) = .02$, $p = .88$ (Figure 14). There was no combined effect of site and treatment on species richness, $F(1, 1359) = 1.65$, $p = .20$. A significant relationship between distance away from the resort sites' bungalow chains and number of species was found, $F(1, 1359) = 30.74$, $p < .001$ (Figure 15).

*Species Abundance*

By use of a factorial ANCOVA, the effects of the distance away from the bungalow chains on species abundance were found. The total number of individuals at Site Opunohu was 7015, while at Site Temae the total was 4384. The mean number of individuals at Site Opunohu per survey area was 18.76, and the mean number of individuals at Site Temae per survey area was 14.23. On average, there were 4.53 more species at any given survey spot at Site Opunohu than Site Temae. This effect of site was significant, $F(1, 1359) = 44.08$, $p < .001$ (Figure 16). Treatment was also found to be significant in determining the species abundance, $F(1, 1359) = 6.05$, $p = .01$ (Figure 16). There was a combined effect of site and treatment on species abundance, $F(1, 1359) = 5.68$, $p = .02$. Opunohu Hotel Site, Opunohu Control Site, Temae Hotel Site, and Temae Control Site had the greatest average number of total individuals at distances 90, 0, 100, and 70 m, respectively, and least average number of total individuals at distances 0, 20, 10, and 100 m from the bungalow chain, respectively (Figure 17). After quantifying the effects of the distance away from bungalow chain against species abundance, it was found that with an increase in distance from the bungalow chains there was an associated increase in mean number of individuals present, $F(1, 1359) = 53.26$, $p < .001$ (Figure 18).

## Discussion

The significant relationship between an increase in distance from the bungalow chain and an increase in living coral coverage, species richness, species abundance, and associated decrease in algae coverage indicate a major effect on the coral reef environment at Opunohu Hotel Site and Temae Hotel Site due to the existence of the bungalow chains (Figures 11, 13, 15 and 17). Many possible factors may be affecting the coral reefs' health including: the bungalows' initial construction, their existence in the ecosystem over time, human-induced physical damage by resort guests, pollution, and noise. It is important to note, however, that this study compares the effects of green development with no development. The effects overwater bungalows have on their surrounding environment may be less when compared to the effects of a traditional construction type.

*Construction*

The original construction of the bungalows at both sites may have lasting impacts on the surrounding coral's health. Initially, coral was displaced and/or removed altogether around the construction site. There are areas in which the pilings of the bungalows were drilled immediately

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

adjacent to coral bommies during initial construction. This may have not only directly killed and hindered future growth of the coral by destroying habitats and certain niches, but it also may have caused an indirect uplift of sediments on the seafloor. Coral reef species, being stenotypic, have a very narrow set of environmental conditions that they can live in (Hughes et al., 2003). Any change in the set of conditions would potentially affect their survivorship (Hoegh-Guldberg et al., 2007). The uplift of sedimentation would therefore present the possibility of blocking sunlight. Without sunlight, the coral species are unable to photosynthesize.

There have also been disturbances subsequent to the original construction at both sites. At the Opunohu Site and the Temae Site, the bungalows and their boardwalk chains have been renovated. The renovation process included an increase in boat traffic, people working in the area around the bungalows for continual amounts of time, and loud noise.

*Bungalows' Existence Over Time*

The bungalows have been in the same place within the lagoon environment since the time they were originally constructed. Therefore their presence alone may have imparted prolonged detriments on the reef environment. The existence of the pilings in the lagoon creates a physical barrier underwater and as a result, the marine species have to navigate the pilings. Further, acting in the same way as rocks, the pilings may limit horizontal coral growth due to their positioning throughout the entire bungalow chains (Johannes et al., 1983). Aside from the pilings, the bungalows' large floor plans generate a large amount of shade above the lagoon at all times of day. Photosynthesizing species, such as the zooxanthellae found in coral that are needed for coral growth, are affected by this. Additionally, in past studies, marine algae have been seen to thrive in areas of sea with moderate shade coverage (Tamburic et al., 2011). The large percentage coverage of algae and lower percentage coverage of coral closer to the bungalow chains may be due to the greater amount of shade. The algae's favorable environmental conditions may further hinder coral growth as it limits available nutrients and space. The creation of constant shade above parts of the lagoon at distances far from shore is distinctive to the overwater bungalow construction type.

*Physical Damage*

Snorkelers were observed breaking, touching, and holding onto the coral around the data collection areas at both sites. Swimmers were also observed standing on the coral. Accidental breakage and collection of coral pieces was noted at both hotel sites. Coral has the ability to regrow into new colonies via fragmentation if excessive stress was not imparted during the initial breakage (Wallace, 1985). Although this act would occur at all types of coastal developments, the overwater bungalow chains present the opportunity for snorkelers to enter the water at any distance away from shore. This may therefore increase the frequency of swimmers in the water and may also position tourists in places within the lagoon that would be otherwise inaccessible at traditional coastal development sites.

Garbage in the lagoon that falls from the bungalow chain is routinely collected at both resorts and only a minimal amount of garbage was noted at the control sites. A large surface layer of sunscreen that followed the entire bungalow chain at both sites was noted. This is probably insignificant, as it is greatly diluted in the ocean. Runoff water after the watering of the garden baskets on the overwater bungalow chain was observed. This could potentially be a source of nutrients for algae growth. Runoff from storms and rain was observed falling on the bungalow chain and eventually emptying into the ocean, taking all of the micronutrients present on the bungalow surface with it into the ocean. The effects of runoff water have not been thoroughly studied on Mo'orea but runoff from fields and resorts have been observed to harm coral in Hawaii (Royer, Tester & Stewart, 2014). Further small eutrophication events, overcrowding and competition for resources as a result of mass algae bloom, may have occurred in response to the nutrient-rich runoff water entering the lagoon in proximity to the bungalows. At traditional construction sites, such as beachfront hotels, the agriculture runoff collects near the shoreline. The bungalow chains, due to their construction outwards over the lagoon, allow runoff to reach areas far removed from the shoreline.

Music constantly plays along parts of the bungalow chain. There is also a large amount of noise from golf carts repeatedly going down the planks of the boardwalks. Noise from the people staying in the bungalows was also heard at all times throughout the day. In addition, there was noise due to boat engines around the sites. Anthropogenic ocean noise has been observed previously to negatively affect marine species and needs to be considered in this study as a factor affecting the observed data (Weilgart, 2007). Although this occurs at beachfront hotel sites, the existence of the overwater bungalows allow for the music source to occur hundreds of meters removed from the beach, ultimately reaching distances at all different depths throughout the lagoon.

**Conclusion**

In addition to accounting for differences in the response variables as a result of depth change, distance from shore, ocean acidification and agriculture runoff, the control sites accounted for pollution and physical damage as there was about the same amount of each between the control sites and resort sites. The exclusive effect of the bungalow chain itself and its effects on the environment overtime, however, were not accounted for in the control sites and therefore should be quantified in the results of the resort site.

An increase in coral coverage, species richness, and species abundance as the distance away from the bungalow chains increases suggests two possibilities: the initial construction of the bungalows impacted the reef dynamic and had lasting effects, or the bungalow chains' continual existence regularly impacts the surrounding environment. The combined effect of these two possibilities allows for the rapid expansion of algae and decrease in coral coverage in closer proximity to the bungalows at the resorts on Mo'orea.

In French Polynesia, the economy is greatly dependent on the health of the marine reef environment, not only for tourism purposes but also for food, protection, and medicinal uses (Cesar et al., 1997). The predicted increase in construction of overwater resort bungalows in the tropics will possibly impose strong hindrances on all of the previously listed aspects that healthy coral reefs provide. The increase in construction may ultimately inflict a detrimental effect on the local economy and living conditions in the country.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

The conservation of the reef environment in tropical destinations is necessary due to the large quantity of ecological relationships that are facilitated there. Disruption in trophic cascades occurs without the better management of the overwater bungalows. Further, the tourists' demand for, and the very existence and construction of, future overwater resort bungalows depend on the surrounding natural beauty of the marine ecosystem. It is therefore very important to prevent the destruction of the lagoon reef ecosystems because without them, local economies will be hindered.

Currently, the combined effects of the overwater bungalow resorts around the world are minimal due to the small number of them that exist in relation to the vastness of the ocean. But, the demand for tourism in the tropics has been significantly increasing and therefore demand for the overwater bungalow resort type will continue to grow.

It is important to make clear any misconceptions about the sustainability and eco-consciousness of ecofriendly construction types, including the overwater resort bungalow. In this study the bungalows were seen to negatively impact the reef environment by promoting dominant algae coverage and decreasing living coral coverage, species richness, and abundance. Guests need to be aware that their resort is inherently affecting the surrounding environment. Hotel managers also need to be aware of how the bungalows are affecting the reef, as the future of the hotel and profits depend on the survivorship of the reef organisms. The results of this study should be brought to the attention of local environmental protection agencies and governments in hopes of creating a set of regulations in the construction of future overwater resort bungalows.

**Acknowledgements**

Thank you to the professors on the trip, Patrick O'Grady, Cindy Looy, Justin Brashares and Jonathon Stillman, for their continual support in all aspects of this research project. Gratitude would also like to be expressed to the Graduate Student Instructors of the course: Eric Armstrong, Ignacio Escalante Meza, and Natalie Stauffer-Olsen, for their help with statistics, transportation, and overall round-the-clock support. Finally, thank-you to the staff at the Richard B. Gump Research Station on Mo'orea along with the hotel staff at the Hilton and Sofitel.

**References**

Anderson, Elizabeth P., Mary C. Freeman, and Catherine M. Pringle. "Ecological consequences of hydropower development in Central America: impacts of small dams and water diversion on neotropical stream fish assemblages." *River Research and Applications* 22.4 (2006): 397-411.

Ayala, Hana. "Ecoresort: a 'green' masterplan for the international resort industry." *International Journal of Hospitality Management* 14.3 (1995): 351-374.

Bak, Rolf PM. "Coral Reefs and Their Zonation in Netherlands Antilles: Modern and Ancient Reefs." (1977): 3-16.

Balota, Elcio L., et al. "Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol." *Soil and Tillage Research* 77.2 (2004): 137-145.

Bromberek, Zbigniew. *Eco-resorts: Planning and Design for the Tropics*. Routledge, 2009.

Bruno, John F., and Elizabeth R. Selig. "Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons." *PLoS one* 2.8 (2007): e711.

Ceballos-Lascurain, Hector, K. Lindberg, and D. E. Hawkins. "Ecotourism as a worldwide phenomenon." *Ecotourism: a guide for planners and managers.* (1993): 12-14.

Cesar, Herman, et al. "Indonesian coral reefs-An economic analysis of a precious but threatened resource." *Ambio (Sweden)* (1997).

Cossey, Laura. “The effects of overwater hotel bungalows on coral health and diversity on the island of Moorea, French Polynesia.” (1998).

De’ath, Glenn, et al. "The 27–year decline of coral cover on the Great Barrier Reef and its causes." *Proceedings of the National Academy of Sciences* 109.44 (2012): 17995-17999.

Dufour, Vincent, Emmanuel Riclet, and Alain Lo-Yat. "Colonization of reef fishes at Moorea Island, French Polynesia: temporal and spatial variation of the larval flux." *Marine and Freshwater Research* 47.2 (1996): 413-422.

Glynn, P. W. "Coral reef bleaching: ecological perspectives." *Coral reefs* 12.1 (1993): 1-17.

Hoegh-Guldberg, Ove, et al. "Coral reefs under rapid climate change and ocean acidification." *science* 318.5857 (2007): 1737-1742.

Hughes, Terry P., et al. "Climate change, human impacts, and the resilience of coral reefs."

*science* 301.5635 (2003): 929-933.

Johannes, R. E., et al. "Latitudinal limits of coral reef growth." *Marine ecology progress series. Oldendorf* 11.2 (1983): 105-111.

Kühn, Ingolf, and Stefan Klotz. "Urbanization and homogenization–comparing the floras of urban and rural areas in Germany." *Biological conservation* 127.3 (2006): 292-300.

Lecchini, David, and Denis Poignonec. "Spatial variability of ontogenetic patterns in habitat associations by coral reef fishes (Moorea lagoon–French Polynesia)." *Estuarine, Coastal and Shelf Science* 82.3 (2009): 553-556.

Lesser, M. P. "Oxidative stress causes coral bleaching during exposure to elevated temperatures." *Coral reefs* 16.3 (1997): 187-192.

Moberg, Fredrik, and Carl Folke. "Ecological goods and services of coral reef ecosystems." *Ecological economics* 29.2 (1999): 215-233.

Roberts, Callum M., et al. "Marine biodiversity hotspots and conservation priorities for tropical reefs." *Science* 295.5558 (2002): 1280-1284.

Royer, Thomas C., Patricia A. Tester, and Thomas N. Stewart. "DIURON FROM MAUI SUGARCANE FIELD RUNOFF IS POTENTIALLY HARMFUL TO LOCAL CORAL REEFS." *Atoll Research Bulletin* 8.605 (2014).

Sale, Peter F. *Coral reef fishes: dynamics and diversity in a complex ecosystem*. Academic Press, 2002.

Tamburic, Bojan, et al. "Parameters affecting the growth and hydrogen production of the green alga Chlamydomonas reinhardtii." *international journal of hydrogen energy* 36.13 (2011): 7872-7876.

Wallace, Carden C. "Reproduction, recruitment and fragmentation in nine sympatric species of the coral genus Acropora." *Marine Biology* 88.3 (1985): 217-233.

Weilgart, Lindy S. "The impacts of anthropogenic ocean noise on cetaceans and implications for management." *Canadian journal of zoology* 85.11 (2007): 1091-1116.

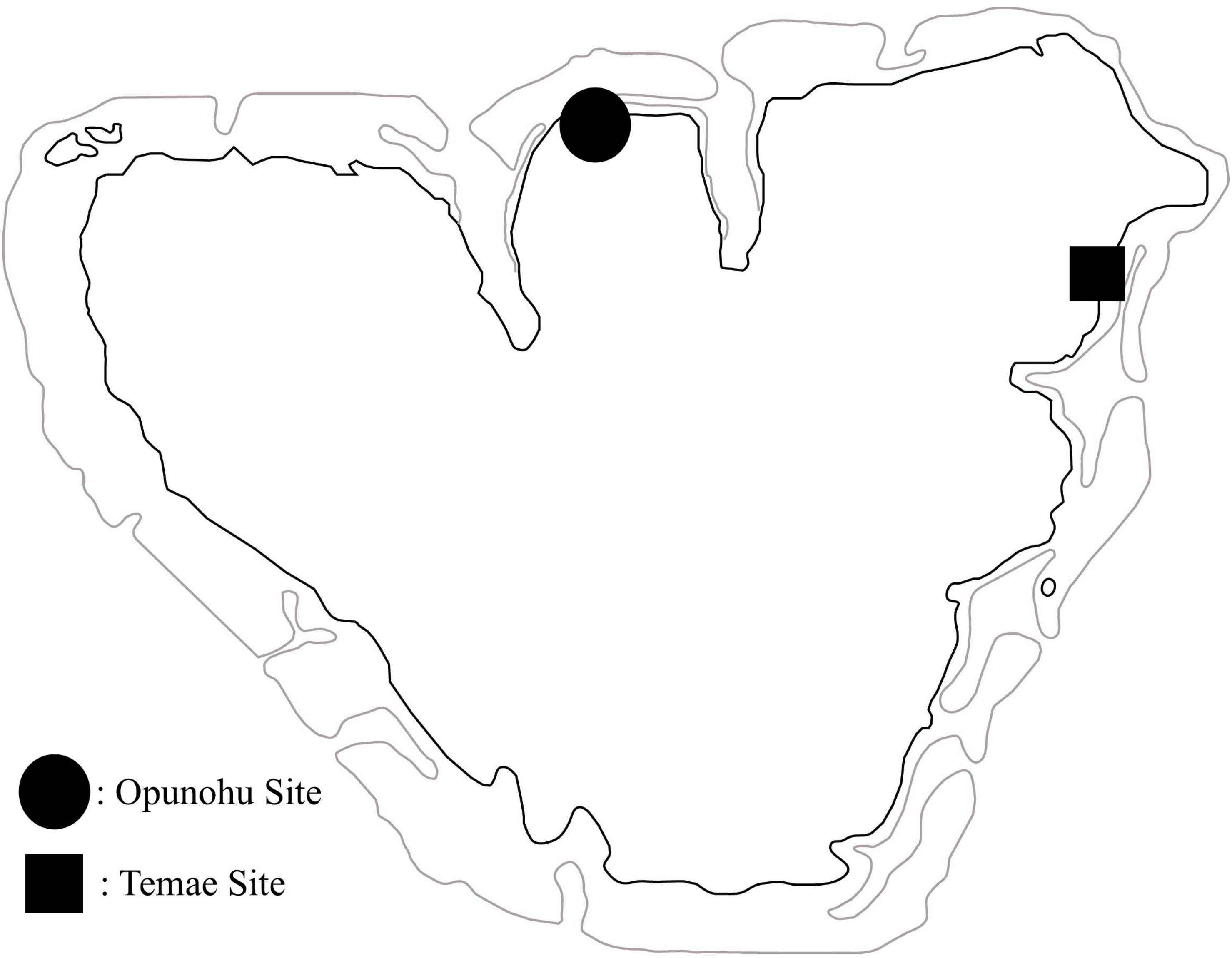
Yusof, Zeenat Begam, and Mariam Jamaludin. "Green approaches of Malaysian green hotels and resorts." *Procedia-Social and Behavioral Sciences* 85 (2013): 421-431.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

## Figure 1 (on next page)

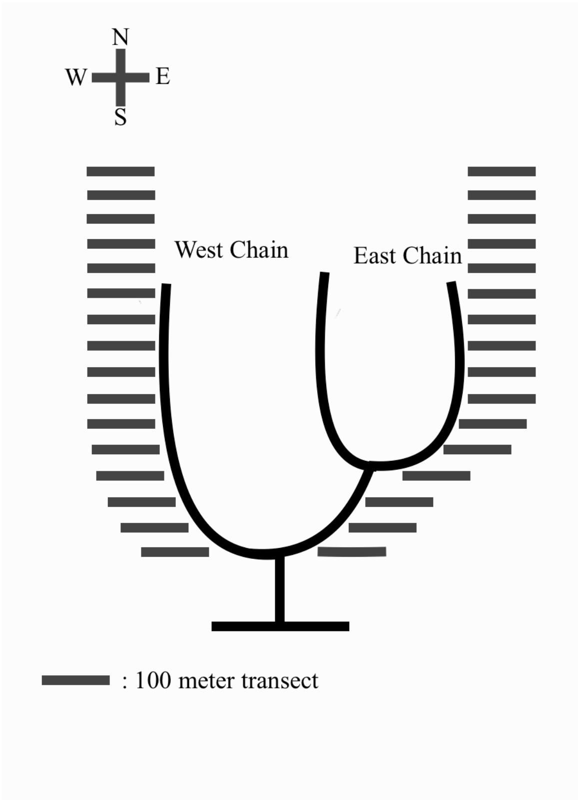
Locations of Sites Opunohu and Temae on Mo’orea Island, French Polynesia

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017


: Opunohu Site
: Temae Site

## Figure 2(on next page)

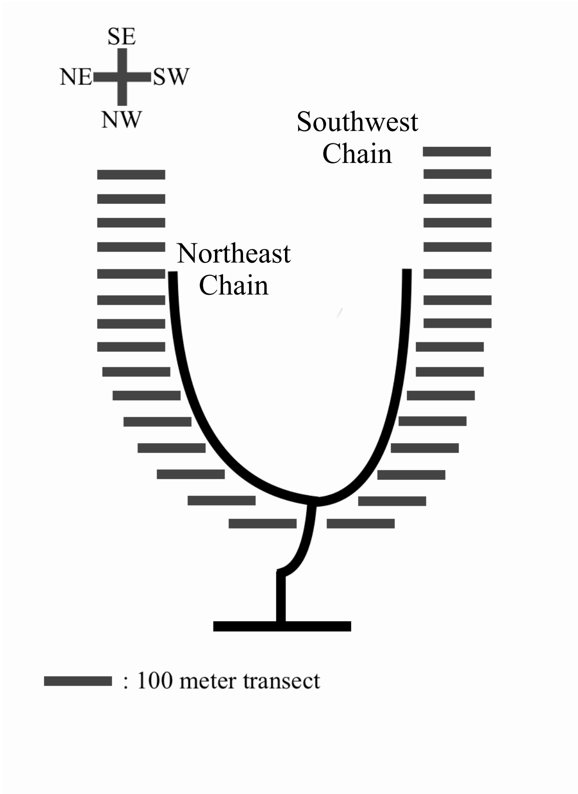
Overwater bungalow layout and survey map of Opunohu Site: black lines indicate wooden boardwalks and grey lines show configuration of survey transects




PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

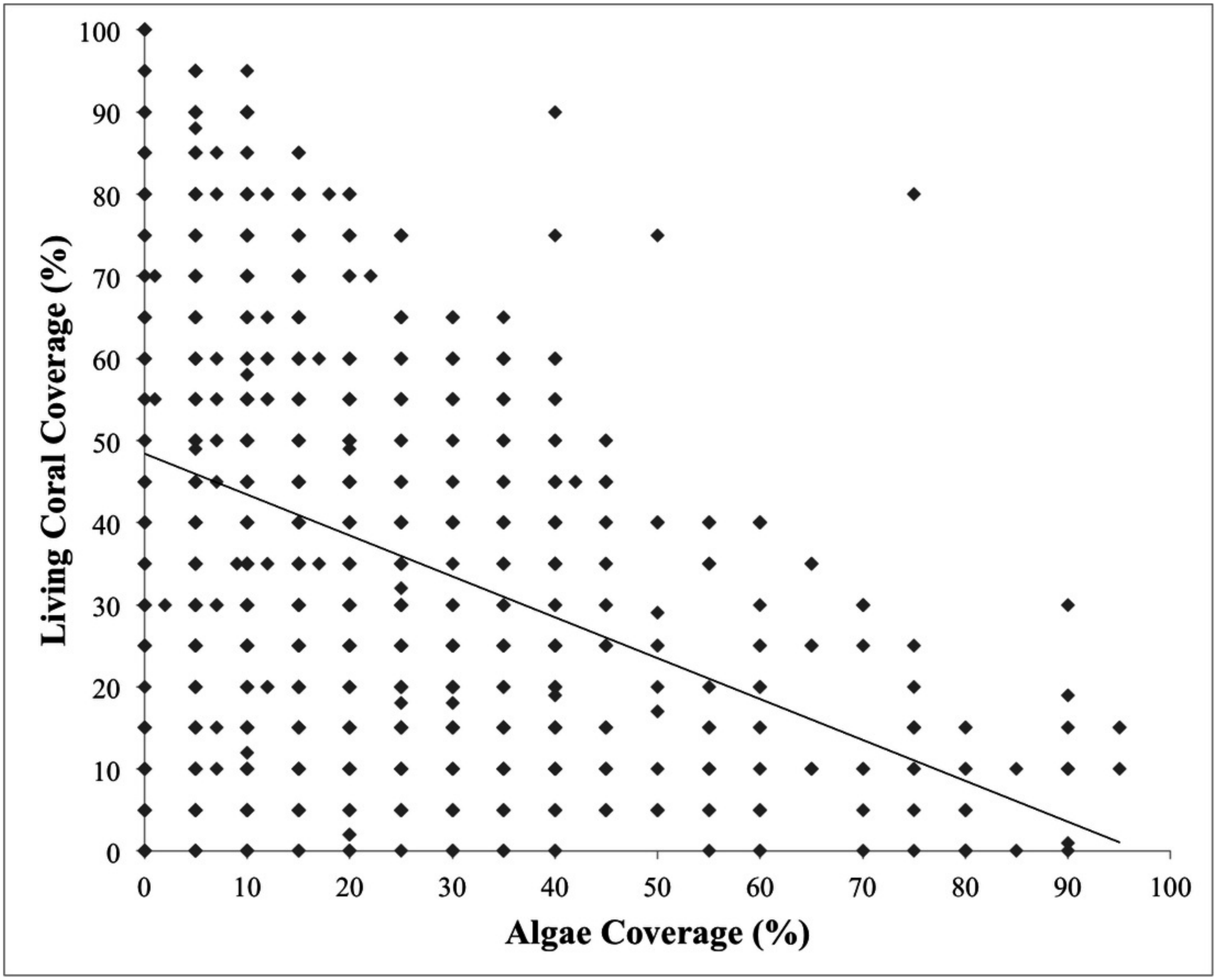
## Figure 3(on next page)

Overwater bungalow layout and survey map of Temae Site: black lines indicate wooden boardwalks and grey lines show configuration of survey transects


SE
NE
SW
NW
Southwest Chain
Northeast Chain
: 100 meter transect

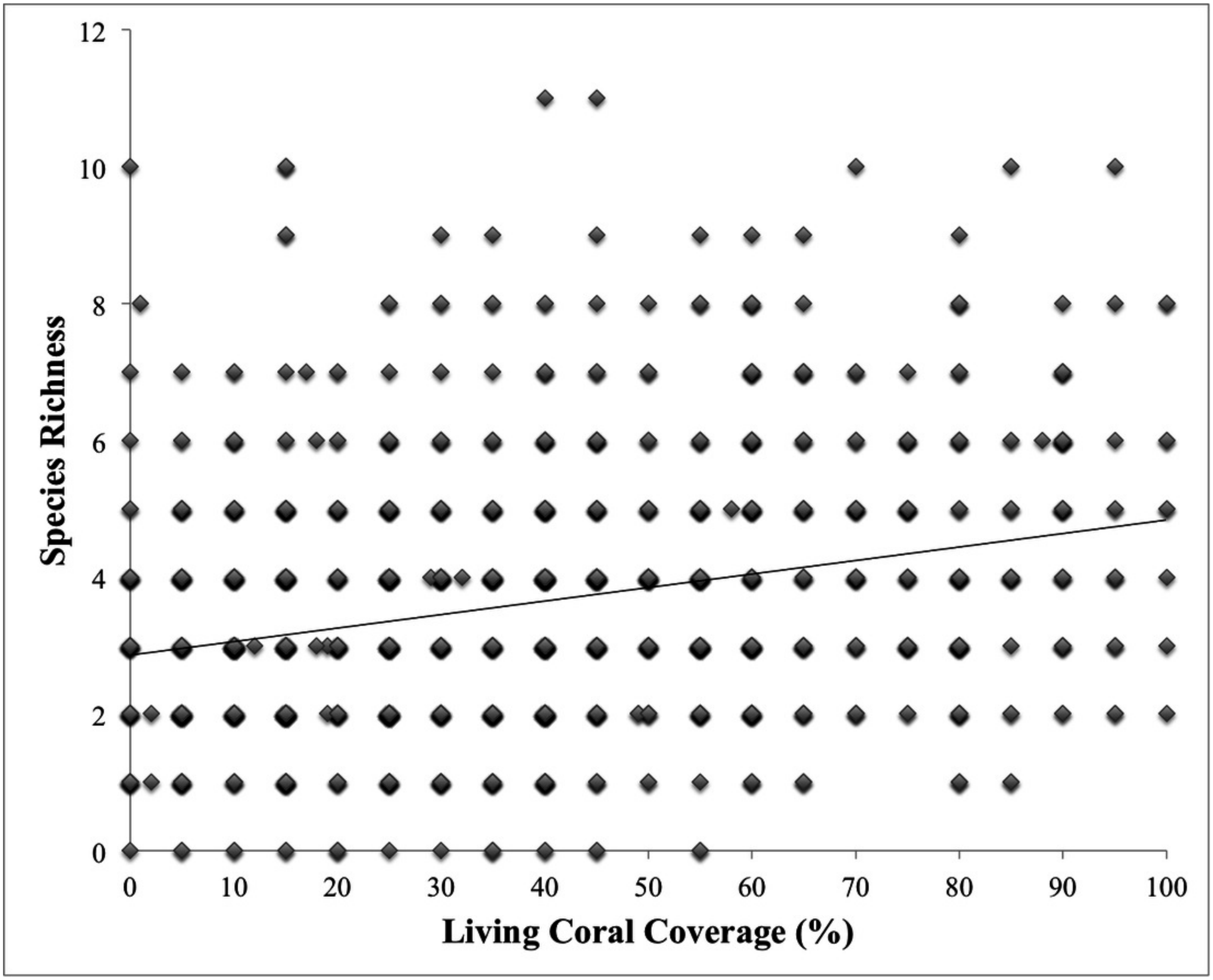
# Figure 4

Correlation between percentage algae coverage and percentage living coral coverage, $r(1364) = -.36$, $p < .001$



# Figure 5

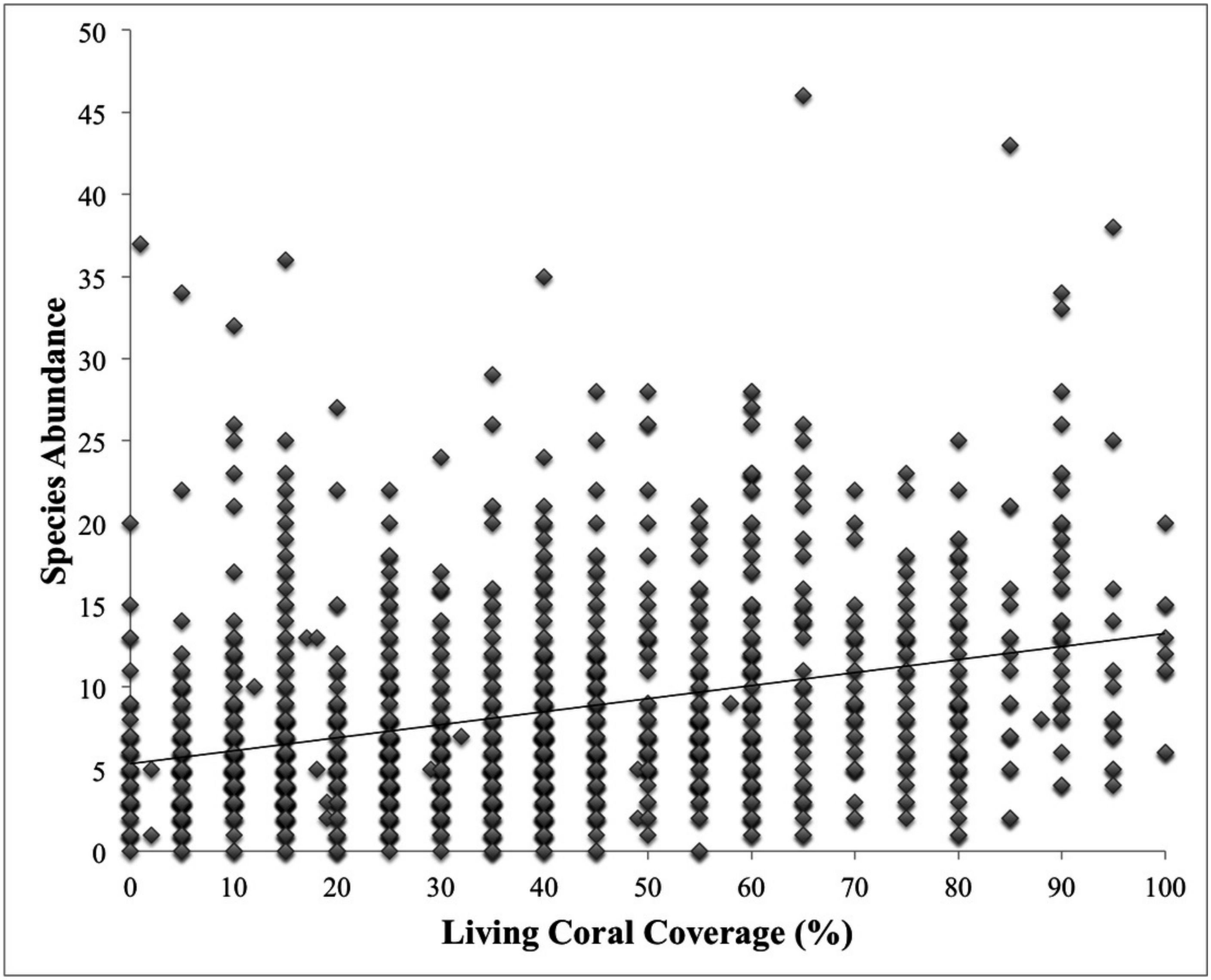
Correlation between percentage living coral coverage and species richness, *r*(1364) = .27, *p* < .001




PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

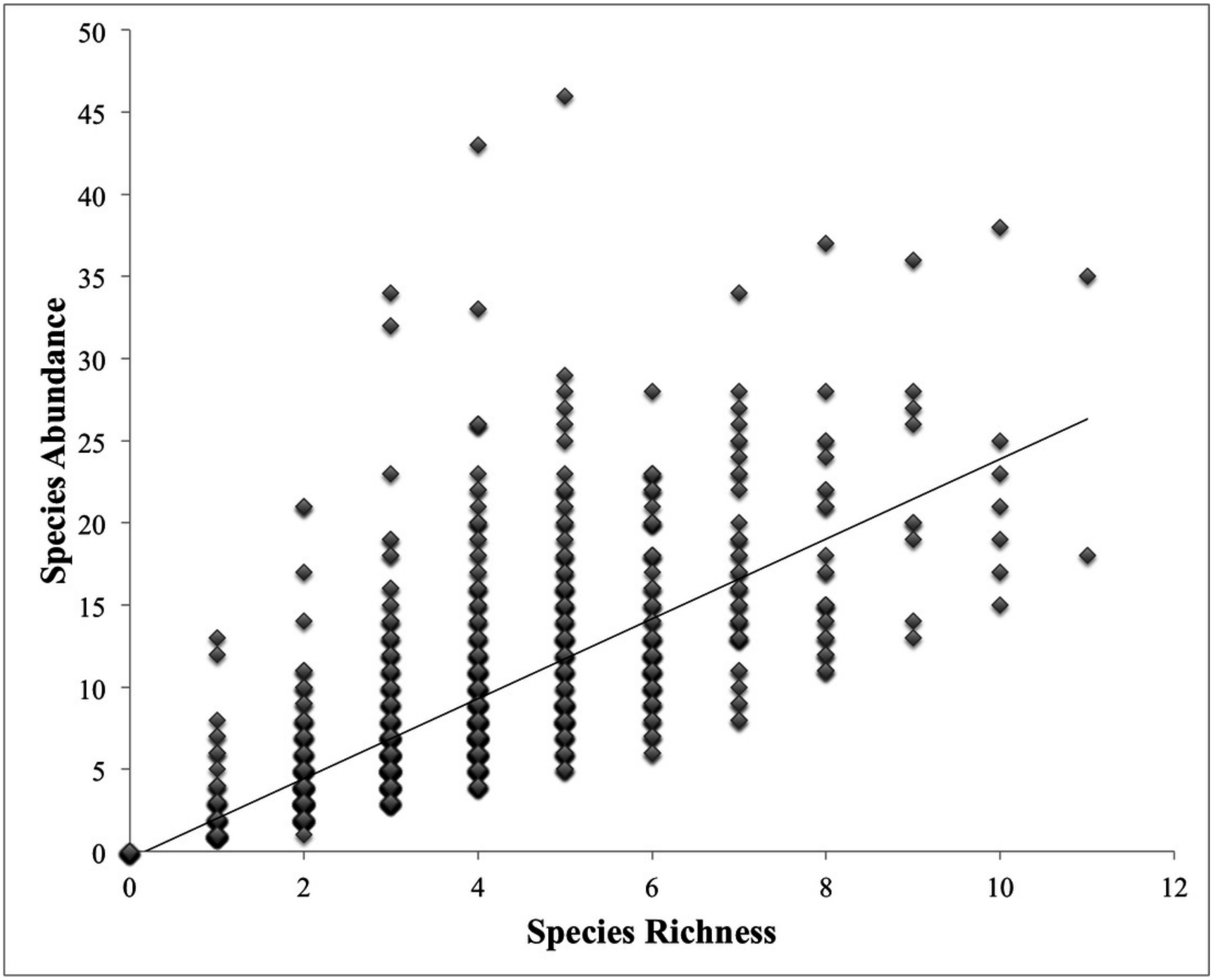
# Figure 6

Correlation between percentage living coral coverage and species abundance, $r(1364) = .30$, $p < .001$



# Figure 7

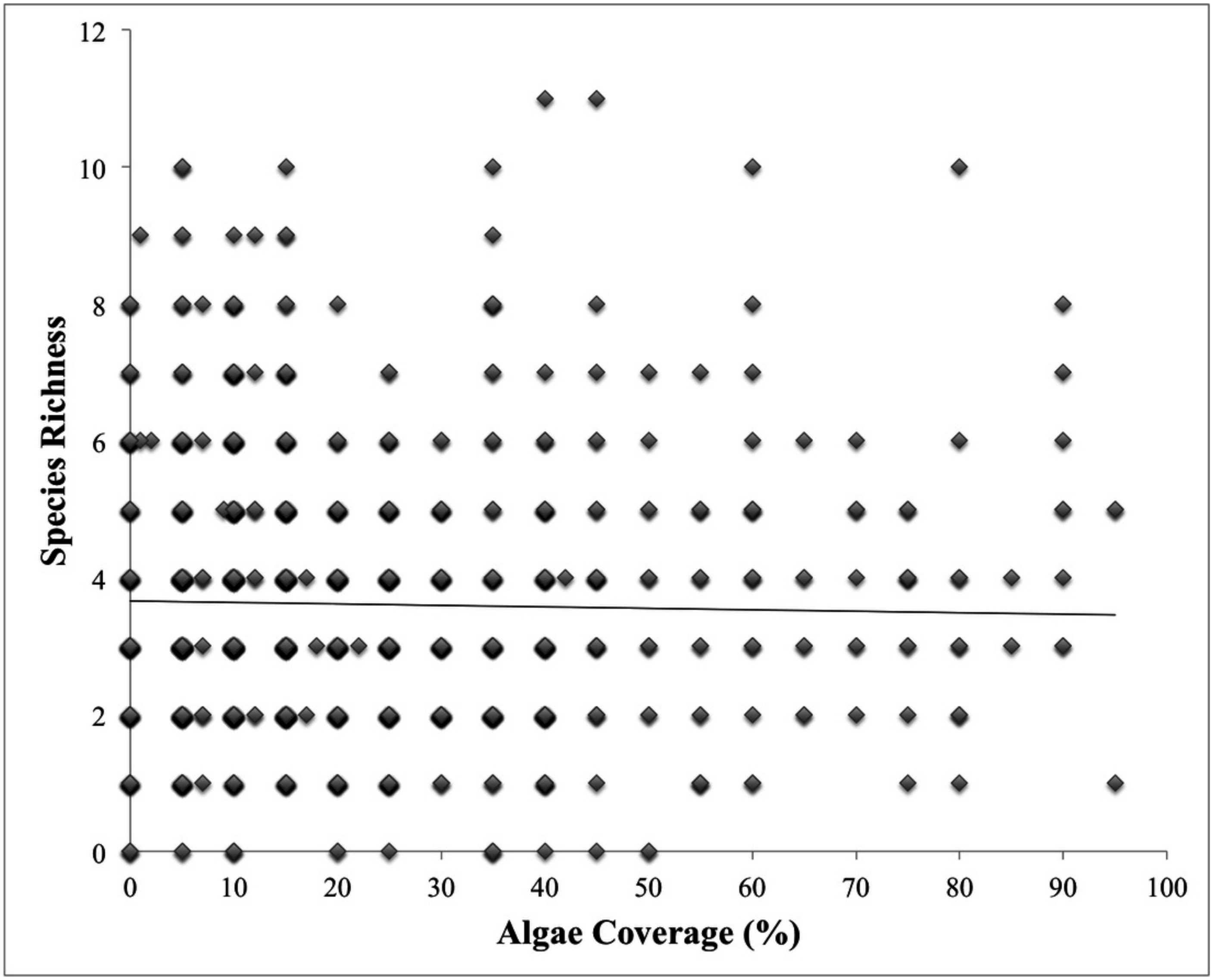
Correlation between species richness and species abundance, $r(1364) = .67$, $p < .001$




PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

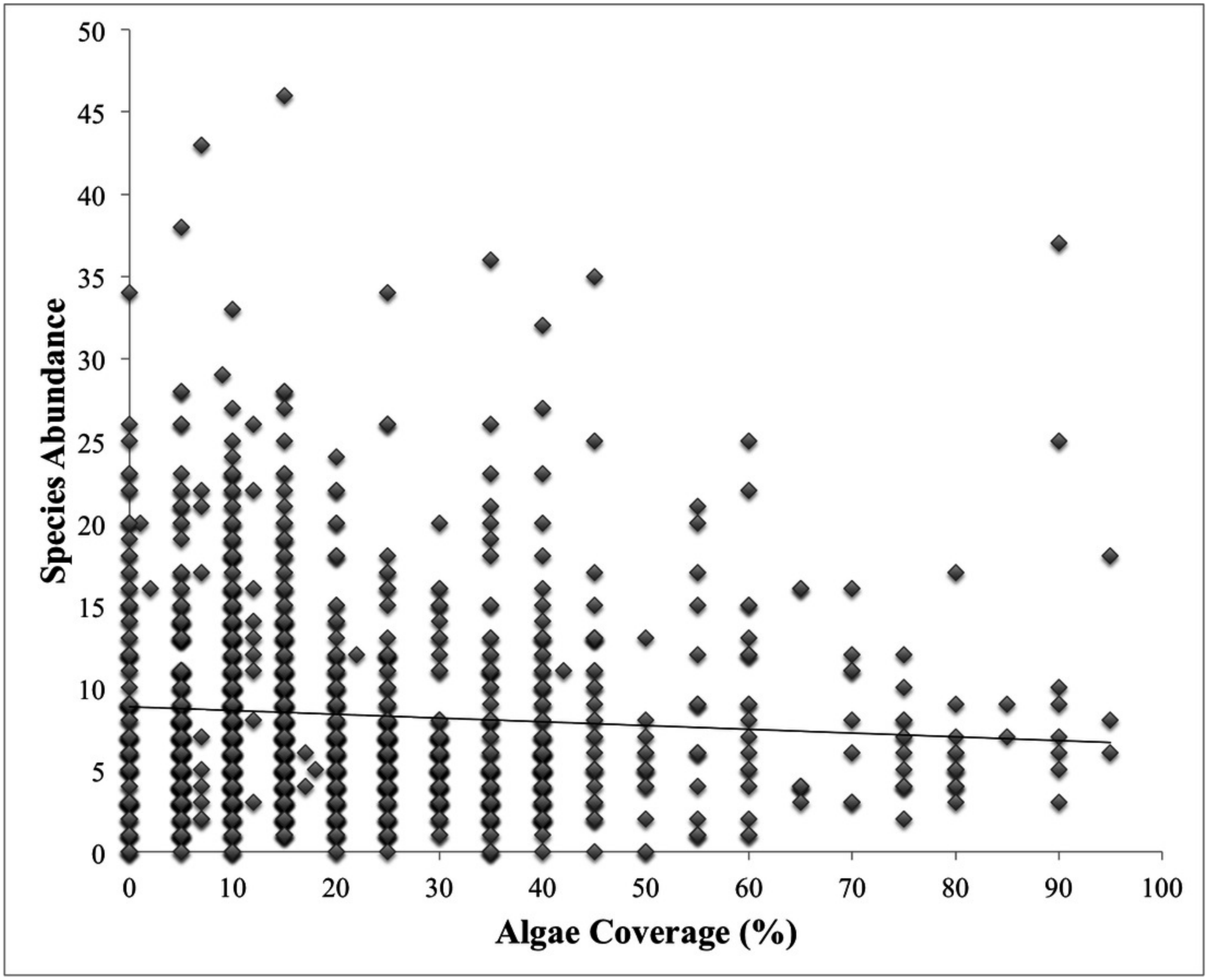
# Figure 8

Correlation between percentage algae coverage and species richness, $r(1364) = -.02$, $p = .44$



# Figure 9

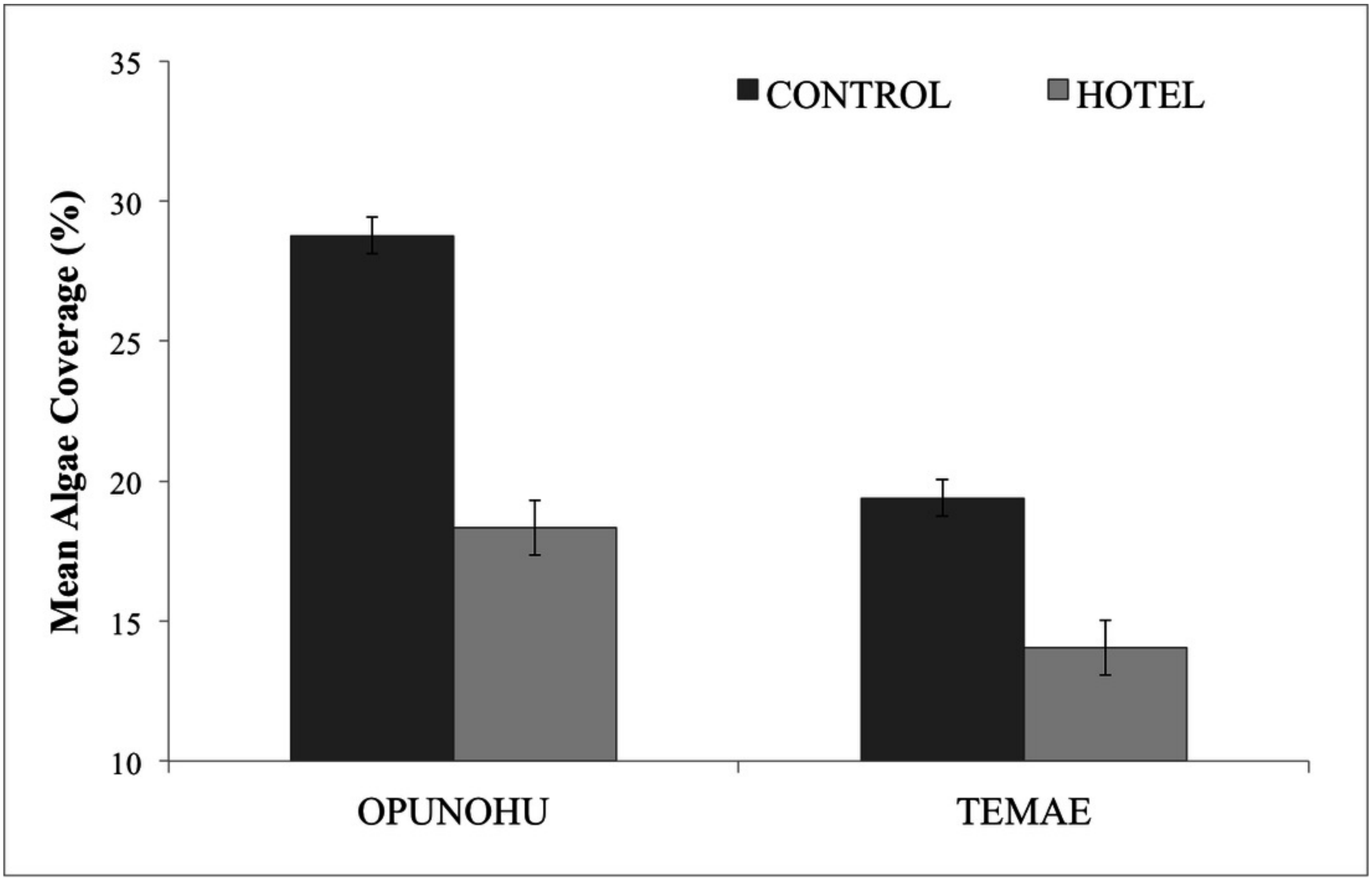
Correlation between algae coverage and species abundance, $r(1364) = -.06$, $p < .001$




PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2750v1 | CC BY 4.0 Open Access | rec: 25 Jan 2017, publ: 25 Jan 2017

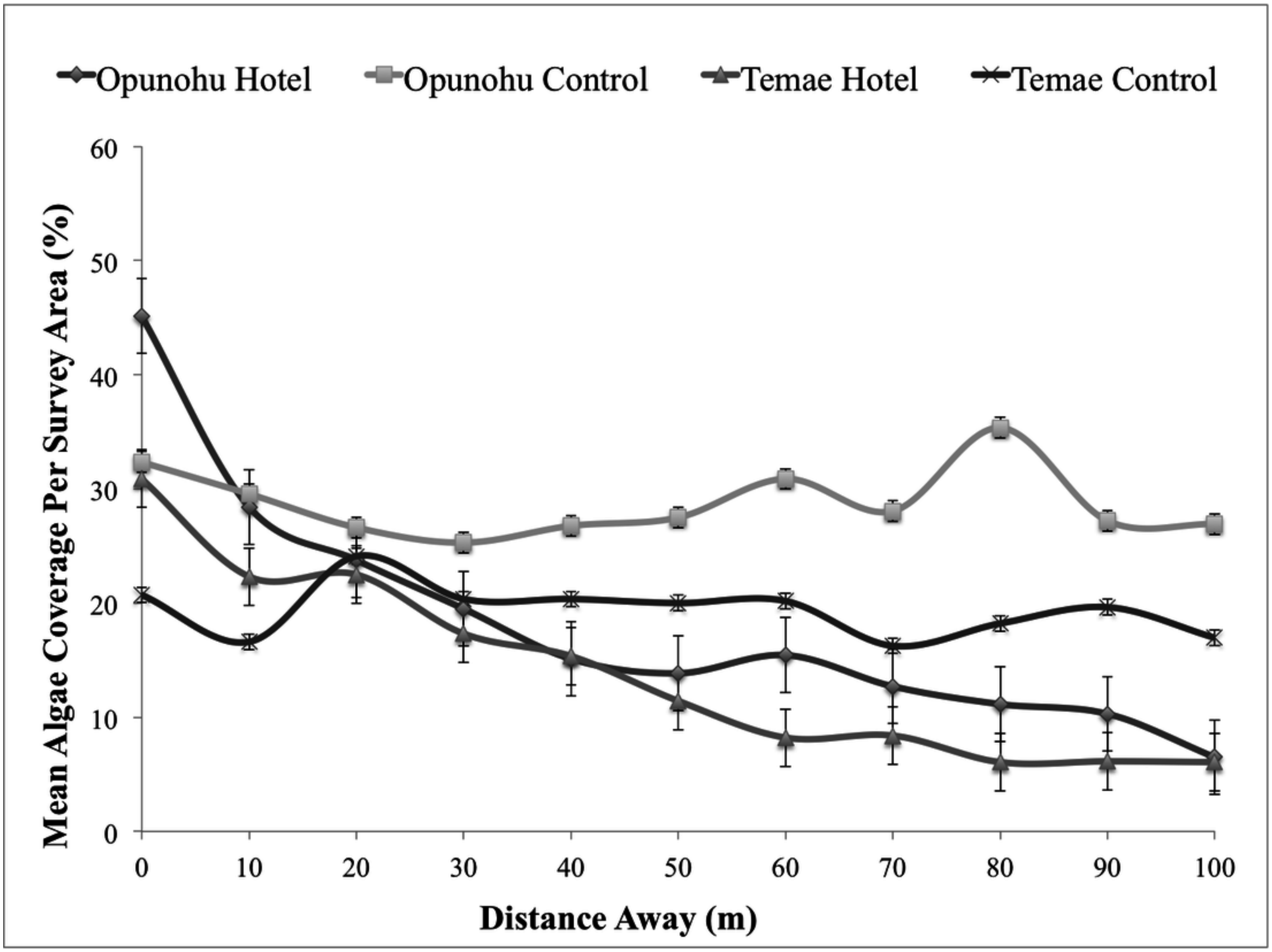
# Figure 10

Site and treatment versus mean algae coverage, $F(1, 1359) = 8.01$, $p = .01$



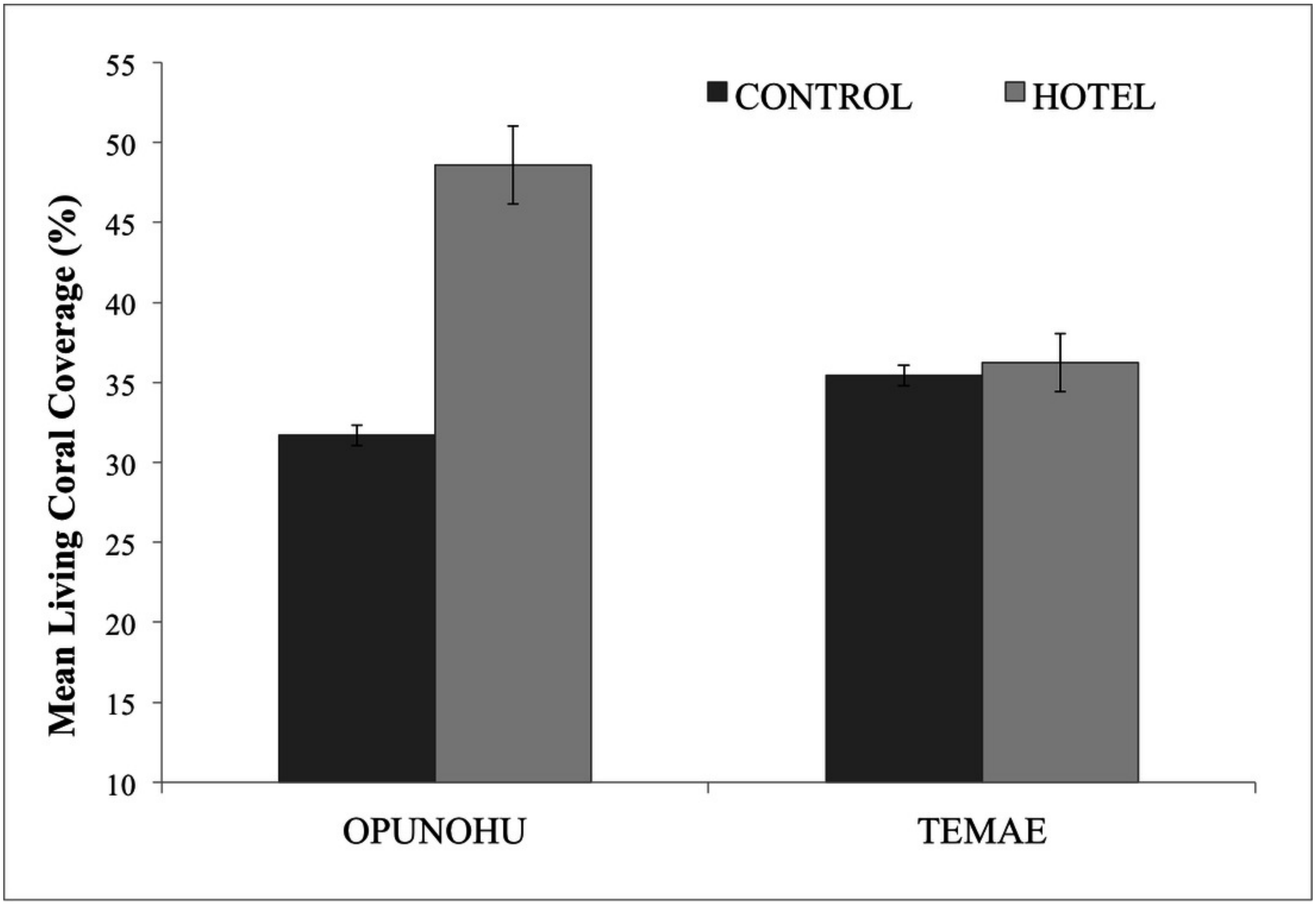
# Figure 11

Distance away from bungalow chain versus mean algae coverage, $F(1, 1359) = 97.91$, $p < .001$



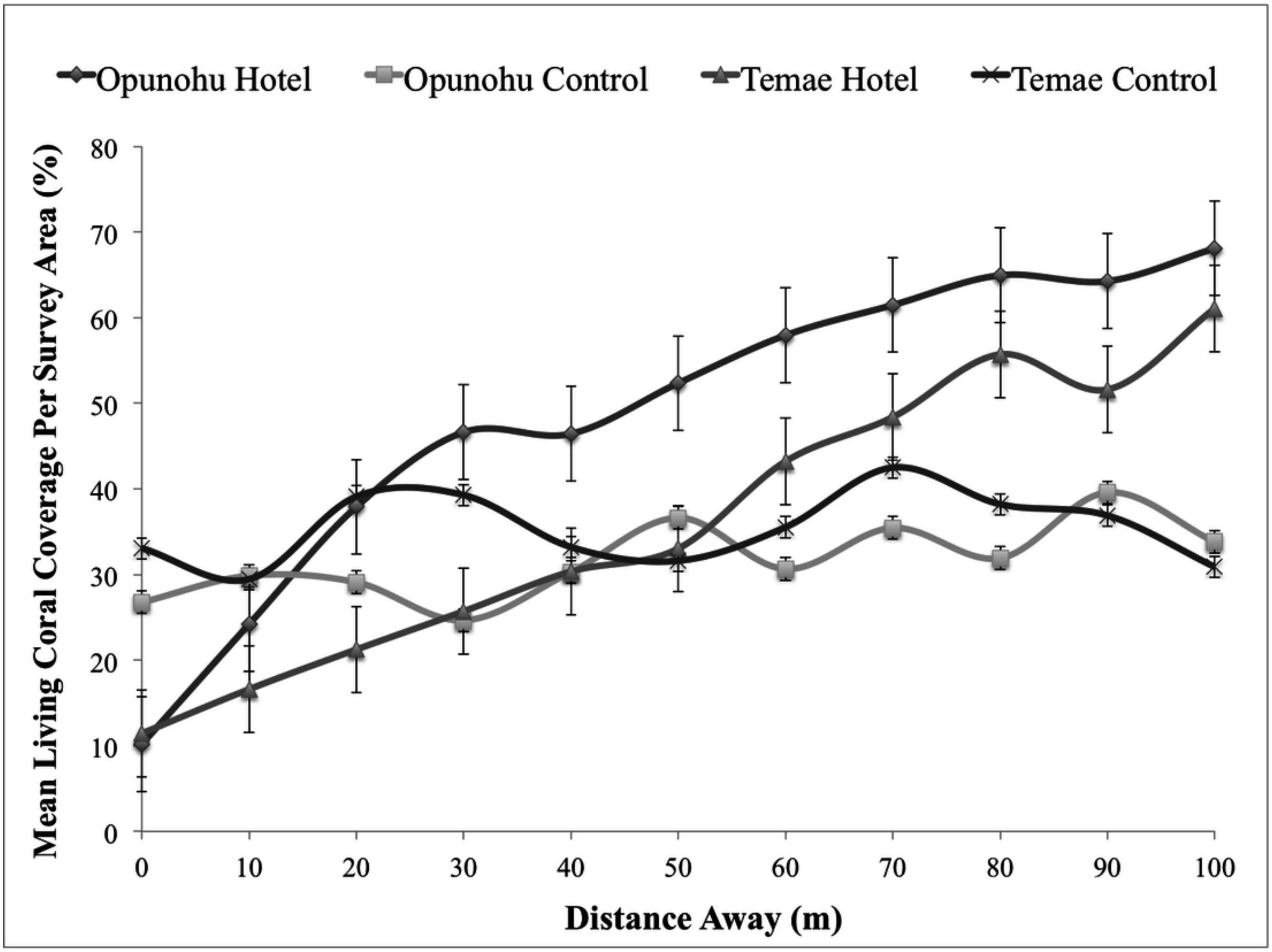
# Figure 12

Site and treatment versus mean living coral coverage, $F(1, 1359) = 44.72$, $p < .001$



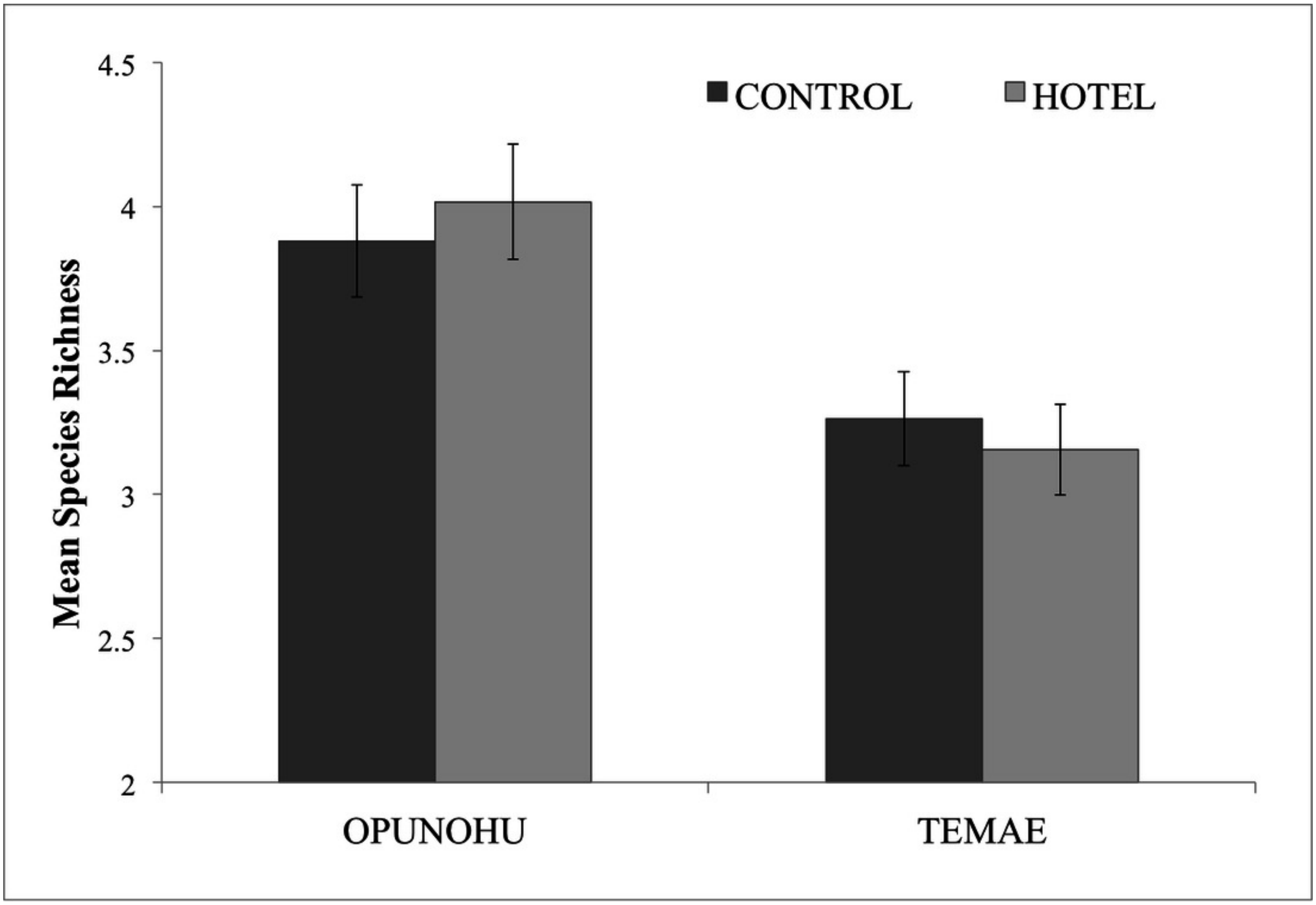
# Figure 13

Distance away from bungalow chain versus mean living coral coverage, $F(1, 1359) = 229.08$, $p < .001$



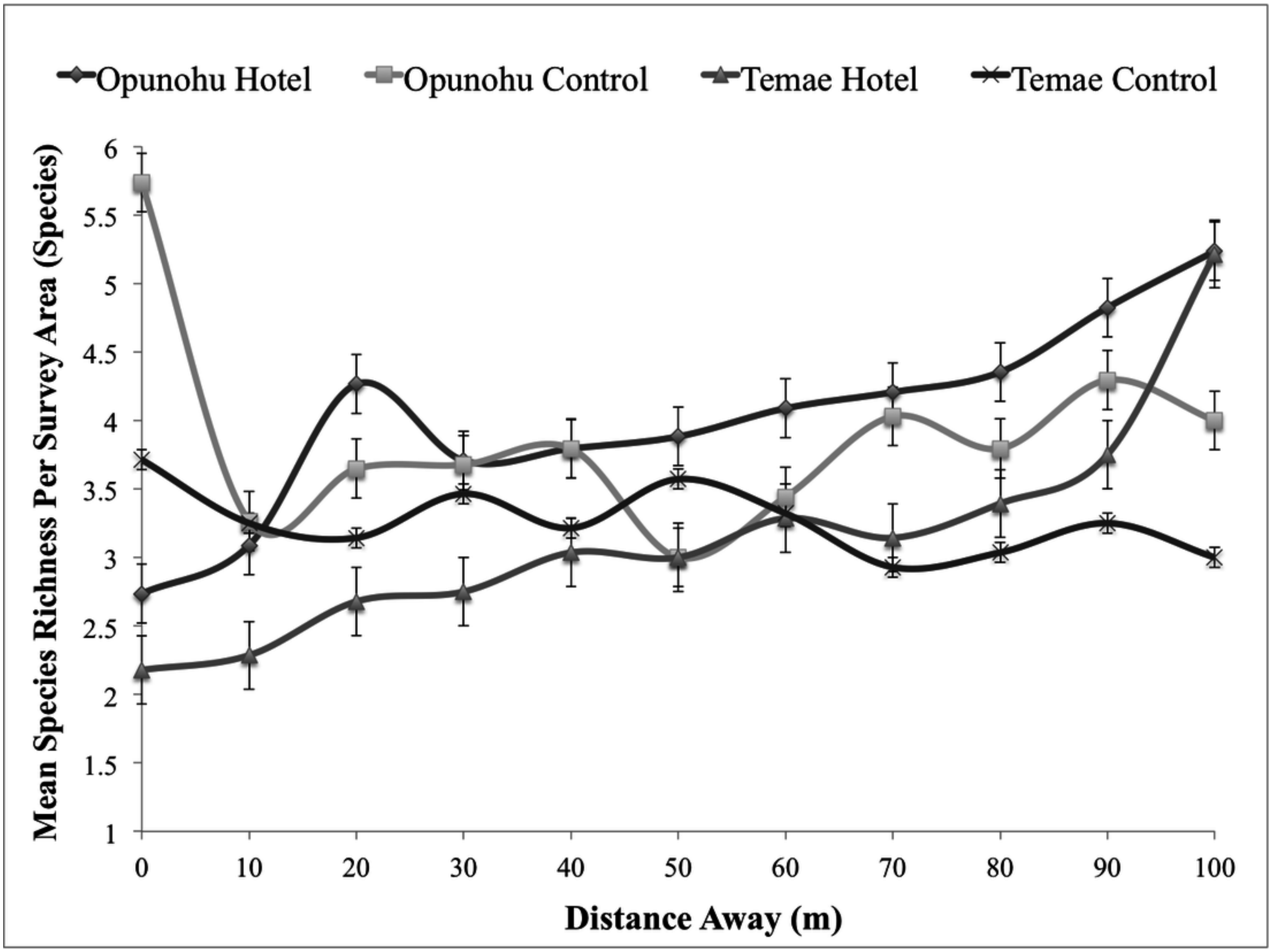
# Figure 14

Site and treatment versus mean species richness, *F*(1, 1359) = 1.65, *p* = .20



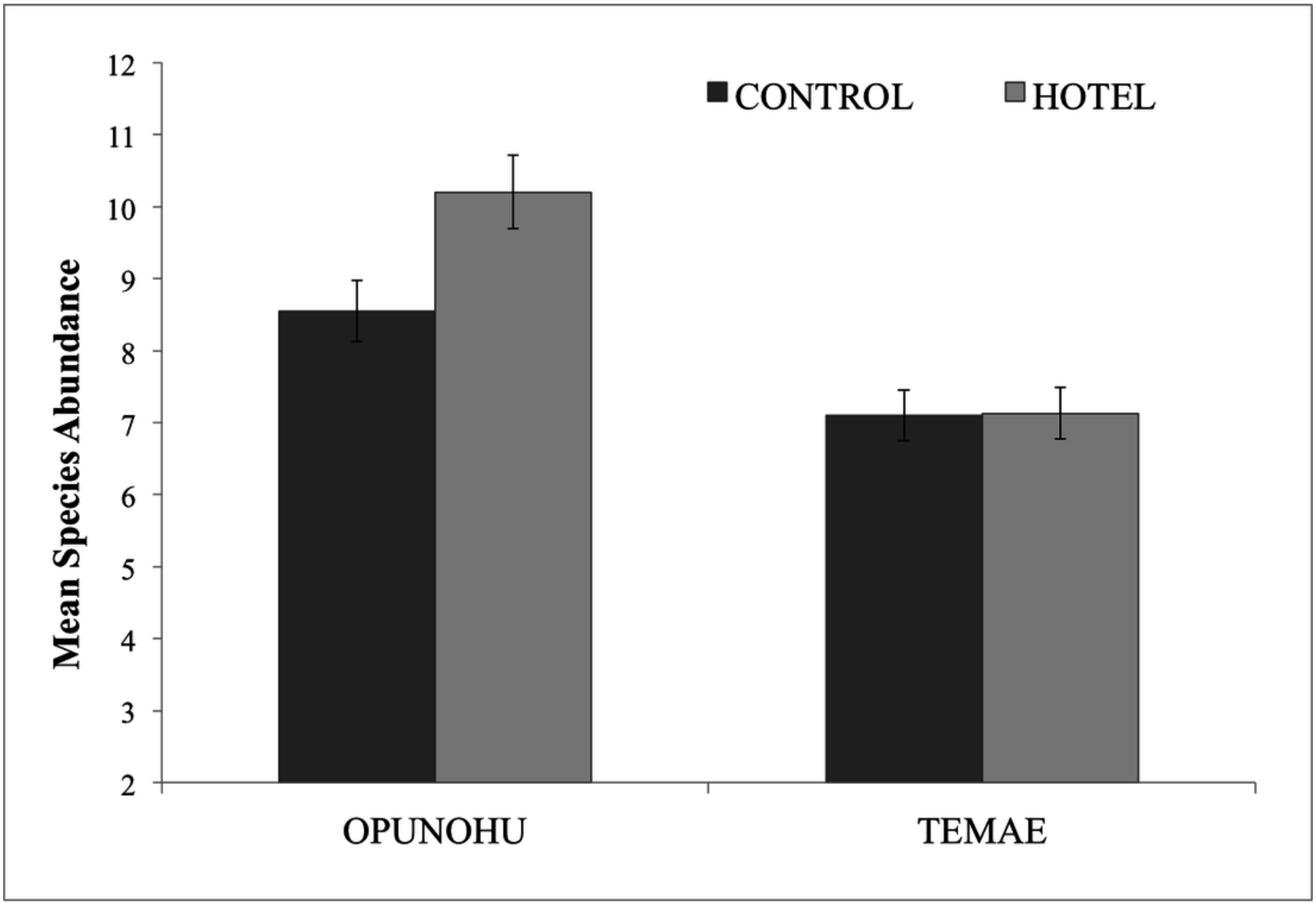
# Figure 15

Distance away from bungalow chain versus mean species richness, $F(1, 1359) = 30.74$, $p < .001$



# Figure 16

Site and treatment versus mean species abundance, $F(1, 1359) = 5.68$, $p = .02$



# Figure 17

Distance away from bungalow chain versus mean species abundance, $F(1, 1359) = 53.26$, $p < .001$