CORAL REEF COMMUNITY COMPOSITION IN RELATION TO CLEANER WRASSE POPULATION DENSITY IN MOOREA, FRENCH POLYNESIA

NICOLAS S. LOCATELLI

Environmental Science Policy and Management,
University of California, Berkeley, California 94720 USA

Abstract. Identifying species whose presence affects overall ecosystem function is critical to conservation and restoration efforts. The island of Moorea in French Polynesia is a useful system because many of its reef community members are found throughout the Pacific and Indian Oceans. Therefore, the island system can be used as a model for these much larger systems. In this study, populations of cleaner wrasse were analyzed to determine if their densities were correlated with certain natural history traits of reef fish and also if their densities were associated with variations in coral, macroalgae, and reef-altering fish β-diversity. Significant correlations were found between *Labroides bicolor* population densities and the abundances of small-bodied fish ($p<0.0001$), territorial fish ($p<0.0001$), solitary or paired fish ($p<0.01$), large groups of fish ($p<0.0001$), herbivorous fish ($p<0.0001$), and primarily corallivorous fish ($p<0.01$). Significant correlations were also found between *Labroides dimidiatus* population densities and the abundances of medium-bodied fish ($p<0.01$) and sedentary fish ($p<0.01$). Results indicated that there is a strong relationship between cleaner wrasse population density and corals and macroalgae β-diversity at the family level. However, no relationship was found between cleaner population density and reef fish β-diversity at the family level.

Key words: Scleractinia; *beta diversity*; *community composition; Moorea, French Polynesia; mutualism*

INTRODUCTION

Finding species that are strong bioindicators of ecosystem condition is critical in a world undergoing rapid climate change. Species that have a disproportionately large effect on ecosystems can be used as powerful indicators of ecosystem function and change and help justify protection of a given ecosystem that is degraded or threatened. In addition, if a species is found to be a keystone species, there are implications for restoration biology (Mills et al. 1993). If an ecosystem relies on a species, restoration can commence in a given area by reintroducing that organism or bolstering initially small populations (Conway 1989).

By removing ectoparasites off of reef fish, cleaner wrasses keep the fish healthy, which in turn consume the excess alga on corals. In areas with low densities of *Labroides dimidiatus*, reef fish diversity and abundance were drastically lower than in areas with healthy populations of the cleaner (Grutter et al. 2003, Waldie et al. 2011). In addition, areas with low herbivorous fish biodiversity and abundance have been found to have lower coral biodiversity, lower percentages of live coral cover, and higher percentages of turf alga cover (Manikandan et al. 2014).

In Moorea, French Polynesia, three species of cleaner wrasse are present: *Labroides dimidiatus*, *L. bicolor*, and *L. rubrolabiatus* (Randall 1958). *L. bicolor* and *L. dimidiatus* represent the two most commonly observed cleaners in Moorea while *L. rubrolabiatus* is far more elusive and inconspicuous. All cleaner wrasses are similar in their ability to cleanse clients of dead tissue or ectoparasites as well as cheat clients by consuming mucus.

However, *L. dimidiatus* is generally found in very small home ranges known as cleaner stations while *L. bicolor* tends to wander more as adults and have large home ranges. In addition, *L. bicolor* has been found to cheat clients more frequently than *L. dimidiatus*, due to the ability of the species to have more client interactions over the large home range (Oates et al. 2010). *Labroides* lure clients into cleaner interactions primarily by visual cues such as bright coloration and lateral body stripes. In addition, cleaners maintain client interest using behavioral cues such as alluring body movements or tactile stimulation (Stummer et al. 2004).

The goal of the present study was to analyze the differences in coral reef community composition in relation to abundance of *Labroides bicolor* and *Labroides dimidiatus*. It was hypothesized that in Moorea, areas with low abundances of *Labroides* would hold lower corallivorous and herbivorous fish diversity and therefore a lower percentage of live coral coverage and diversity.

METHODS

This study was conducted on the island of Moorea in French Polynesia during the months of October and November in 2014. Moorea is part of the greater Society Island Archipelago in the Pacific Ocean and represents a biologically isolated location in the South Pacific. The approximate study site location in relation to the island is depicted in Fig. 1.

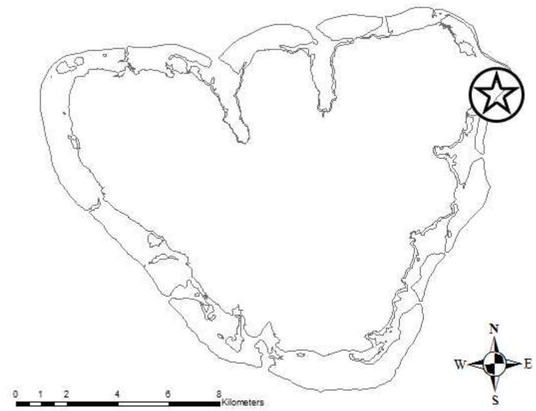

FIG. 1. The approximate location of the field site at the Temae public beach on Moorea indicated by the star. (Base map courtesy of the Geospatial Innovation Facility, University of California, Berkeley.)

Site and Sampling

The public beach at Temae (17°30'0.26"S 149°45'21.72"W) was chosen as a study site due to it containing both *Labroides dimidiatus* and *L. bicolor* and due to its large diversity of coral structures. The Temae site is a barrier reef that transitions in the southeast direction from sand, to sparse coral mounds, to dense coral fields, and finally to rubble fields and the algal crest. Surveys were conducted with the objective of determining the organismal composition of each of these zones and how cleaner wrasse population density relates to community composition and organismal abundance.

This reef survey was largely carried out through intensive sampling at the Temae site. Specifically, a set of four sampling bands was established using ArcMap and ten 10m x 10m quadrats were established in each band to be sampled for fish, coral, and macroalgae diversity (Fig. 2). Each of the bands contained various levels of coral cover and composition. This site selection method resulted in a stratified systematic sample. The sample was still considered random due to the lack of previous knowledge of the organisms or structures present at each site.

Sampling of fish diversity:

In each 100m² quadrat, individuals of *Labroides dimidiatus* and *L. bicolor* were tallied. The FishBase online database (http://www.fishbase.org/ accessed December 15, 2014) was used to obtain information about the generalized natural history traits about each reef-altering fish family. Reef fish were tallied by family if their diets fully or partially incorporate coral or algae. Only wholly or

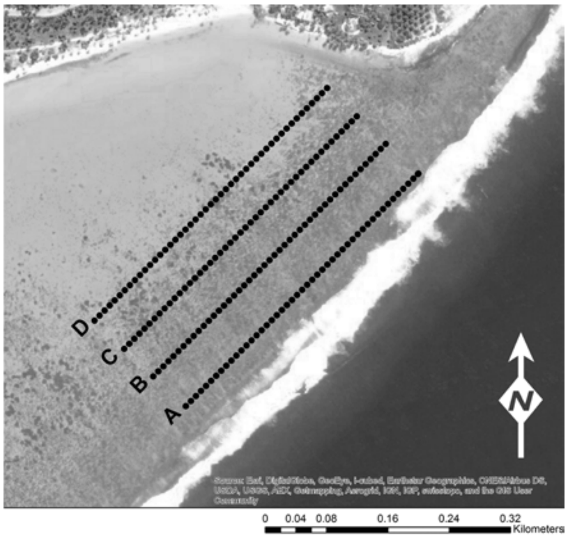

FIG. 2. This map centered at 17°30'0.26"S 149°45'21.72"W shows the approximate locations of sampling bands at the Temae reef.

partially corallivorous and herbivorous fish were tallied due to their large effect on coral reef development and structure. Families were labelled as either herbivorous (Pomacentridae, Pomacanthidae, Acanthuridae, Scaridae), omnivorous (Balistidae), or corallivorous (Chaetodontidae, Zanclidae) based on the diets of their representatives present in the reefs of Moorea. For example, balistids generally feed upon benthic invertebrates and would be classified as primarily carnivorous but the representatives present in Moorea such as *Balistapus undulatus* (Park, 1797) have a more varied diet that includes invertebrates, algae, and coral and therefore Balistidae is labelled as omnivorous.

Families of reef fish were further divided into categories in rough accordance with that of Arnal et al. (1999). In that study, fish were assessed—albeit on an individual or species basis rather than by family—in terms of body size, behavior, and gregariousness. Body size was assessed in Moorea by average adult size of representatives in each family. For example, the most abundant member of Pomacentridae at the Temae reef is *Stegastes nigricans* (Lacepède, 1802) which can exceed 10cm in exceptional individuals but on average does not exceed 10cm in size and therefore falls under the small category. Fish were classified into three size categories: small (<10 cm, Pomacentridae), medium (10-20cm, Pomacanthidae, Acanthuridae, Chaetodontidae), and large (>20 cm, Balistidae, Scaridae, Zanclidae).

Similarly, behavior was assessed based on the general trend of actions across the entirety of the families present in Moorea rather than on a species or individual basis. Families were divided into territorial (Pomacentridae), sedentary (Pomacanthidae, Acanthuridae, Balistidae, Chaetodontidae, Zanclidae), or mobile categories (Scaridae). Families such as Zanclidae which have variations in behavior at different locations were assessed exclusively on their behaviors at the Temae reef. At Temae, zanclids were found to behave similarly to chaetodontids and tended to remain in the vicinity of established areas but did not defend these areas as vigorously as individuals from a territorial family such as Pomacentridae.

Finally, fish families were also categorized based on their gregariousness. As with the previous two categorizations, the families were assigned to categories based on their average behaviors. For example, scarids are classified as small groups due to their schooling behavior when young (schools of 5-25 initial phase individuals) and their smaller group behavior when old (groups of 1-5 terminal phase individuals) which results in an average gregariousness that falls into the 3<n<20 category. Three gregariousness groups were established: solitary or paired (Pomacanthidae, Balistidae, Chaetodontidae, Zanclidae), small groups (3<n<20, Scaridae, Acanthuridae), and large groups (n>20, Pomacentridae).

Sampling of coral and macroalgae diversity:

The coral and macroalgae diversity of the reef at Temae was measured primarily through percent cover of live scleractinian coral and macroalgae. Assessment was done based on visual estimates. The size of the quadrats ($100m^2$) allowed for manageable estimation of percent coverage due to each $1m^2$ representing a percent cover of 1%. Percentage live coral and macroalgae were broken up into coral families (Poritidae, Pocilloporidae, Acroporidae, Fungiidae, Agariciidae) and macroalgae families (Sargassaceae, Dictyotaceae). Non-scleractinian anthozoans such as anemones and non-corals such as *Millepora* spp. were excluded due to their extremely low percent coverage (<0.1%) or their poor ability to host living organisms. The scleractinian family Faviidae was found in approximately half of the quadrats but was found at such low percent coverages (<0.05%) that it was not recorded as a significant contributor to the living structural components of the Temae reef.

Data Analysis

The data were analyzed to deduce the relationship between cleaner wrasse population density and their surrounding mobile and sessile community partners. All statistical analyses were performed using non-parametric tests due to the data not conforming to the requirements of parametric tests. In addition, all statistical analyses were conducted in R (R Core Development Team 2014). The data analyses consisted of three separate community measures: density comparisons of β-diversity, non-metric multidimensional scaling of reef community composition in relation to distance from reef crest, and Spearman rank correlation of cleaner densities versus natural history traits of reef-altering fish.

The β-diversity measure was visualized by comparing population densities of each cleaner species with coral and macroalgae community data and reef fish community data. Each data set was analyzed separately using the Picante package within R and visualized in the form of a series of boxplots (Kembel et al. 2010). Within the Picante package, the function betadiver was used to perform the analysis by calculating the average steepness (z) of the species area curve in the Arrhenius model of each community dataset. The function betadisper was used to further analyze β-diversity by evaluating z in respect to cleaner wrasse densities (Oksanen 2014). Note: the sample sizes of community datasets with high population densities (between 5 and 8 cleaners per $100m^2$) were much smaller than those of lower population densities (between 1 and 5 cleaners per $100m^2$) due to the difficulty in finding such high cleaner densities in the field. In the boxplots shown in Fig. 3 and 4, distance from centroid is defined by distance from the most heterogeneous and therefore most amount β-diverse point in a given geographic area (geographic areas defined in this study by number of cleaners per m^2) relative to the entire dataset being analyzed.

NMDS ordination in the Picante package was used as a tool for visualizing how the reef composition differed with respect to distance from the reef crest. The reef composition analysis consisted of performing two separate ordinations, one for reef fish community data and one for coral and macroalgae community data. Each ordination used Bray-Curtis dissimilarity to determine the differences between the sampling bands (A, B, C, and D). For the coral and macroalgae community data, percent covers were converted to relative abundance for NMDS to reduce stress and to remove non-living elements (i.e. dead coral, bare sand, etc.) that contributed to the total 100% coverage. In each of the analyses, the ordiellipse function was used to create a confidence ellipse around each of the sampling bands (A-D) to visually illustrate how dissimilar each of the bands was in terms of fish, coral, and macroalgae community composition.

Spearman's rank correlation was used to determine the relationship between cleaner population density and the presence of reef fish exhibiting certain natural history behaviors. For example, reef fish community data was sorted by diet and each diet (herbivorous, corallivorous, and omnivorous) was analyzed in relation to cleaner density. This correlational analysis would determine how cleaner wrasse population density is associated with fish at a functional level rather than a taxonomic level. Associations between each cleaner density and natural history behavior were analyzed using $\alpha = 0.01$.

RESULTS

β-diversity in relationship to cleaner wrasse density

No trends in reef fish β-diversity were discovered in relation to *L. dimidiatus* and *L. bicolor* population density. Distance from centroid is the distance away from the most heterogenous point in a given geographic area (geographic areas in this study being defined by number of cleaner wrasses per m²) Nearly all population densities of cleaner wrasse in

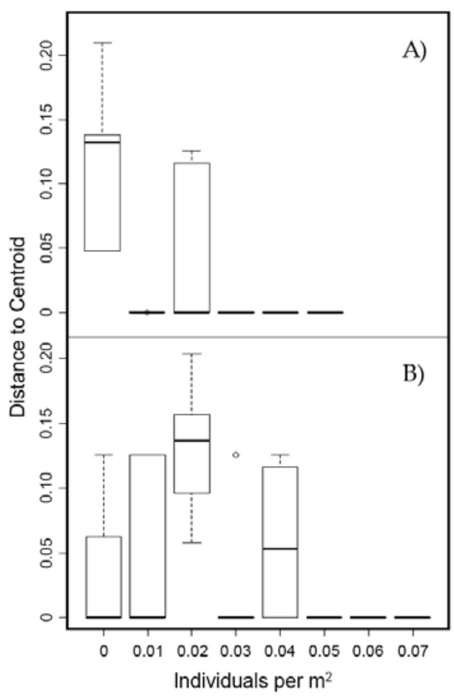

FIG. 3. Distance to the centroid of β-diversity of fish families in relation to *L. bicolor* (A) and *L. dimidiatus* (B) population densities (individuals/m²).

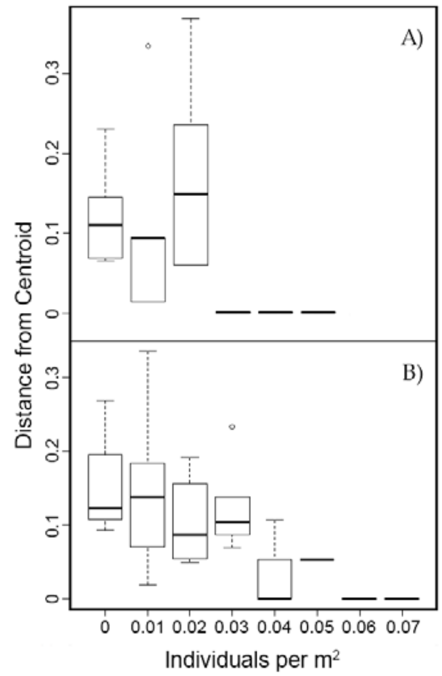

FIG. 4. Distance to the centroid of β-diversity of coral and macroalgae families in relation to *L. bicolor* (A) and *L. dimidiatus* (B) population densities (individuals/m²).

both species showed an average distance to centroid of 0 indicating no definitive trends (Fig. 3).

Similar analyses of coral and macroalgae β-diversity yielded fairly strong trends in which higher densities of both species of cleaner wrasse were associated with higher β-diversity values of coral and macroalgae (Fig. 4).

Non-metric multidimensional scaling (NMDS) *of reef community composition in relation to distance from reef crest*

NMDS analyses of fish community composition (stress≈0.16, 3 runs) showed that sampling bands, A, B, C, and D, were not completely isolated and unique in terms of family composition but rather transitioned gradually in family composition and abundance (Fig. 5B). NMDS analysis of coral and macroalgae community data (stress≈0.05, 1 run) showed a similar but less gradual transition in community composition (Fig. 5A)

TABLE 1. Average ($\bar{x}$), median ($\mu_{1/2}$), and standard deviation (σ) cleaner wrasse population density (individuals per m^2) by zone/distance from reef crest.

Sampling Band	*Labroides dimidiatus*	*Labroides bicolor*
A	$\bar{x} = 0.024$, $\mu_{1/2} = 0.02$, $\sigma = 0.021$	$\bar{x} = 0.003$, $\mu_{1/2} = 0$, $\sigma = 0.0067$
B	$\bar{x} = 0.031$, $\mu_{1/2} = 0.03$, $\sigma = 0.017$	$\bar{x} = 0.004$, $\mu_{1/2} = 0$, $\sigma = 0.0084$
C	$\bar{x} = 0.022$, $\mu_{1/2} = 0.02$, $\sigma = 0.015$	$\bar{x} = 0.012$, $\mu_{1/2} = 0.01$, $\sigma = 0.012$
D	$\bar{x} = 0.013$, $\mu_{1/2} = 0.01$, $\sigma = 0.0067$	$\bar{x} = 0.017$, $\mu_{1/2} = 0.015$, $\sigma = 0.015$

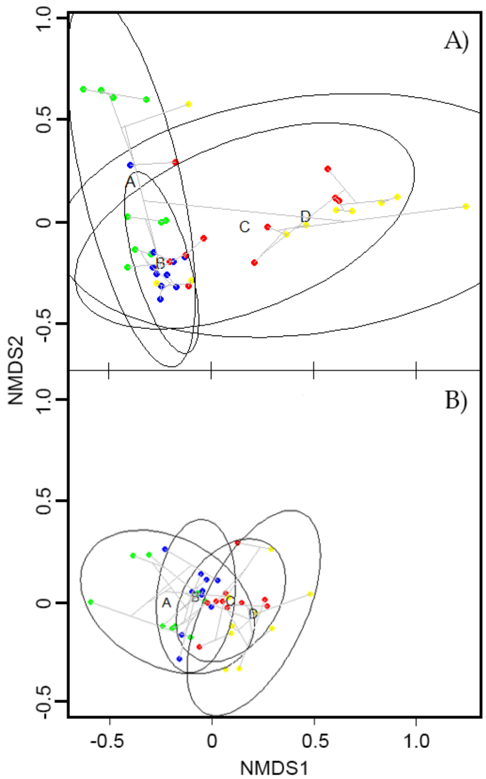

FIG. 5. NMDS analysis of coral and macroalgae (A) and fish (B) community data in relation to sampling bands A, B, C, and D.

These NMDS analyses correspond with the gradual changes in average and median *Labroides* species densities as one moves from bands A to D shown in Table 1. In general, *L. dimidiatus* was found to gradually decrease in population density when increasing in distance from the reef crest (moving from band A to D) while *L. bicolor* was found to increase in population density along the same distance.

Correlational trends between cleaner wrasse density and natural history traits of reef fish

Although no trends were found between cleaner wrasse density and reef fish β-diversity, strong, statistically significant Spearman's rank correlation values were discovered between cleaner wrasse density and reef fish size, behavior, gregariousness, and diet. Strong correlations between *Labroides bicolor* and small-bodied fish ($p<0.0001$), territorial fish ($p<0.0001$), solitary or paired fish ($p<0.01$), large groups of fish ($p<0.0001$), herbivorous fish ($p<0.0001$), and primarily corallivorous fish ($p<0.01$) were found in statistical analyses of natural history traits as shown in Table 2. *Labroides dimidiatus* showed fewer but different strong correlations than did *L. bicolor*. At the Temae reef site, *L. dimidiatus* was found to be strongly correlated with medium-bodied fish ($p<0.01$) and sedentary fish ($p<0.01$) as shown in Table 2. In addition, correlations that were discovered between natural history traits and *L. dimidiatus* density tended to be less strong in r_s value when compared to trends found in *L. bicolor*.

TABLE. 2. Spearman rank correlation values (r_s) between cleaner wrasse densities and natural history traits of reef-altering fish. P-values are shown in parentheses. Asterisks indicate statistically significant correlations.

	Labroides dimidiatus	*Labroides bicolor*
Small	-0.0168 (0.918)	0.699 (<0.0001)*
Medium	0.409 (<0.01) *	0.132 (0.416)
Large	-0.0424 (0.795)	0.0305 (0.852)
Territorial	-0.0168 (0.918)	0.699 (<0.0001) *
Mobile	-0.0102 (0.951)	-0.0102 (0.951)
Sedentary	0.407 (<0.01) *	0.180 (0.267)
Solitary or Paired	0.266 (0.0966)	0.445 (<0.01) *
Small Groups	-0.0978 (0.548)	-0.0624 (0.702)
Large Groups	-0.0168 (0.918)	0.699 (<0.0001) *
Herbivorous	0.0154 (0.925)	0.713 (<0.0001) *
Omnivorous	0.0965 (0.554)	0.261 (0.104)
Corallivorous	0.242 (0.132)	0.435 (<0.01) *

DISCUSSION

Cleaner wrasse population densities did not show a statistically significant relationship with reef fish family β-diversity most likely because the taxonomic level used in data collection was not precise enough. For example, if fish had been tallied at the genus or species level, fish β-diversity would have likely increased with increases in cleaner wrasse density. Several studies have documented such relationships by using species as the taxonomic level for diversity and richness analyses (Grutter et al. 2003, Bshary 2003).

In terms of reef-altering fish, number of families present in each site was fairly consistent but differed in species composition. For example, sites in bands A through D had similar numbers of Pomacentridae but were divided between different species (*Stegastes nigricans* in D, *Chrysiptera brownriggii* in A, both in C and B). This would lead all four sampling bands to have approximately equal β-diversities at the family level despite being different at the species level.

Trends between coral and macroalgae β-diversity and cleaner wrasse population density were strong and fairly consistent with what would be expected from the literature with lower densities of cleaners and reef fish abundance being linked to lower coral β-diversity (Manikandan et al. 2014, Syms & Jones 2000). Larger population densities of cleaner wrasses were correlated with higher β-diversity in corals and macroalgae. Any inconsistencies in the relationship may have potentially been caused by *Stegastes* species chasing away preferred client species as coral composition transitions to more staghorn *Acropora* dominated areas (Johnson et al. 2011).

It is worth noting that coral β-diversity may be higher in areas with larger populations of *L. dimidiatus* because of the species' preference for medium-bodied, sedentary fish (Table. 2) such as Acanthuridae and Chaetodontidae. The presence of *L. dimidiatus* cleaning stations would attract more of the aforementioned reef-altering families and lead to grazing of algae and natural pruning of coral which would decrease algal presence and increase evenness and β-diversity in the vicinity (Adam 2012). In areas where population densities of cleaner wrasses are low, reef-altering fish families would also be less abundant and their effects on coral community composition would be less pronounced.

In addition, natural history behaviors of each of the cleaner species may have caused many of the trends observed in this study. For example, in the β-diversity analysis of reef-altering fish and corals and macroalgae, it was shown that *Labroides bicolor* had no strong trends in either community dataset. This may have been due to the roaming nature of *L. bicolor* leading to its beneficial effects on community composition not being localized exclusively to sample sites. Contrastingly, *L. dimidiatus* was found to have significantly stronger associations with β-diversity of corals and macroalgae—likely due to the sedentary, cleaning station behavior associated with the species.

Similarly, trends in Spearman rank correlation analyses may have also been due to natural history differences between cleaner species. In particular, *L. bicolor* may be closely correlated with more fish behaviors and traits than *L. dimidiatus* due to the ability to be more specific in terms of client-choice due to being a roaming cleaner species. This allows *L. bicolor* to actively seek out preferred client types rather than being limited to clients only in the vicinity of cleaning stations like *L. dimidiatius*.

NMDS analysis of the reef community showed a gradual transition in fish community composition as distance increased away from the reef crest. This corresponds closely with the observed increase in *L. bicolor* population density and decrease in *L. dimidiatus* population density. This is likely the result of the close relationship—as shown in Spearman rank correlation values (Table 2) —between *L. bicolor* and small, territorial, large group, herbivorous fish such as the *Stegastes* farmerfish that also increase with distance from the reef crest. *L. dimidiatus* had fewer strong, significant correlations and may have decreased in population density in the areas furthest from the reef crest due to fish community composition changes that affect their ability to clean preferred clients (Adam and Horii 2012). Differences in behavior between *L. bicolor* and *L. dimidiatus* may allow for these trends to persist. That is, these trends in Spearman rank correlation may be present because *L. bicolor* behaves significantly different from *L. dimidiatus* in that roaming behavior may allow for increased amounts of cheating and specificity of client choice (Oates et al. 2012).

It is possible that during the course of data collection *Aspidontus taeniatus* (Quoy & Gaimard, 1834) may have been recorded as *Labroides dimidiatus*. However, because *A. taeniatus* behave and look slightly different than *L. dimidiatus* it is unlikely that their presence significantly altered recorded cleaner densities, if at all. Therefore, statistically significant trends found at the Temae reef site are likely to be accurate.

If this study was replicated, it would be beneficial to record the presence of all fish—regardless of their effect on coral and macroalgae structure—to the genus or species level. It is likely that the relationship between cleaner population density and family β-diversity was weak due to the lack of taxonomic specificity. If reef fish were tallied to genus or species it is likely that cleaner wrasse density would have been closely correlated with reef fish β-diversity and could be used in the future as a monitor or restoration species for reef fish richness and/or β-diversity in other reefs in the Pacific and Indian Oceans.

ACKNOWLEDGMENTS

Thank you to Matthew Funsten for assistance in the field and the Moorea Class of 2014 for the endless support I received over the course of this study. Thank you to the professors and graduate students for providing multitudes of assistance and advice for data collection, data analyses, and writing in this study.

LITERATURE CITED

Adam, T. C. 2012. Mutualistic cleaner fish initiate trait-mediated indirect interactions by influencing the behaviour of coral predators. Journal of Animal Ecology **81**:692-700.

Adam, T. C., and S. S. Horii 2012. Patterns of resource-use and competition for mutualistic partners between two species of obligate cleaner fish. Coral Reefs **31**:1149-1154.

Arnal, C., S. Morand, and M. Kulbicki 1999. Patterns of cleaner wrasse density among three regions of the Pacific. Marine Ecology Progress Series **177**:213-220.

Bshary, R. 2003. The cleaner wrasse, *Labroides dimidiatus*, is a key organism for reef fish diversity at Ras Mohammed National Park, Egypt. Journal of Animal Ecology **72**:169-176

Conway, W. G. 1989. The prospects for sustaining species and their evolution. Pages 199-209 in D. Western and M. C. Pearl, editors. Conservation for the twenty-first century. Oxford University Press, New York, USA.

Grutter, A., J. Murphy, and J. Choat 2003. Cleaner fish drives local fish diversity on coral reefs. Current Biology **13**:64-67.

Johnson, M. K., S. J. Holbrook, R. J. Schmitt, and A. J. Brooks 2011. Fish communities on staghorn coral: effects of habitat characteristics and resident farmerfishes. Environmental Biology of Fishes **91**:429-448.

Kembel S.W., P.D. Cowan, M.R. Helmus, W.K. Cornwell, H. Morlon, D.D. Ackerly, S.P. Blomberg, and C.O. Webb. 2010. Picante: R tools for integrating phylogenies and ecology. Bioinformatics **26**:1463-1464.

Manikandan, B., J. Ravindran, S. Shrinivaasu, N. Marimuthu, and K. Paramasivam 2014. Community structure and coral status across reef fishing intensity gradients in Palk Bay reef, southeast coast of India. Environmental Monitoring and Assessment **186**:5989-6002.

Mills, L., M. Soulé, and D. Doak. 1993. The keystone-species concept in ecology and conservation. BioScience **43**:219–224.

Oates, J., A. Manica, and R. Bshary 2010. Roving and service quality in the cleaner wrasse Labroides bicolor. Ethology **116**:309-315.

Oksanen J. 2014. Vegan: ecological diversity. The Comprehensive R Archive Network. Retrieved from http://cran.r-project.org/

R Development Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna Austria. Retrieved from http://www.r-project.org/.

Randall, J. E. 1958. A review of the labrid fish genus Labroides, with descriptions of two new species and notes on ecology. Pacific Sci **12**:327-347.

Stummer, L., J. Weller, M. Johnson, and I. Cote 2004. Size and stripes: how fish clients recognize cleaners. Animal Behaviour **68**:145-150.

Syms, C., & G. Jones 2000. Disturbance, habitat structure, and the dynamics of a coral-reef fish community. Ecology, **81**, 2714-2729.

Waldie, P. A., S. P. Blomberg, K. L. Cheney, A. W. Goldizen, and A. S. Grutter 2011. Long-term effects of the cleaner fish Labroides dimidiatus on coral reef fish communities. Plos One **6**.