Winter 2017

Coral Bleaching and the Effect of Disturbances on the Damselfish Community on Lizard Island, Australia

Alejandra Munoz
SIT Study Abroad

Coral Bleaching and the Effect of Disturbances on the Damselfish Community on Lizard Island, Australia

By Alejandra Munoz
Project Advisor: Vanessa Messmer, Research Fellow
Lizard Island Research Station
Queensland, Australia

Academic Director: Tony Cummings
Home Institution: Tufts University
Major: Biology and Environmental Studies

Submitted in partial fulfillment of the requirements for Australia: Rainforest, Reef, and Cultural Ecology, SIT Study Abroad, Spring 2017

SIT Study Abroad
School for International Training

ISP Ethics Review

(Note: Each AD must complete, sign, and submit this form for every student's ISP.)

The ISP paper by Alejandra Munoz (student) does/does not* conform to the Human Subjects Review approval from the Local Review Board, the ethical standards of the local community, and the ethical and academic standards outlined in the SIT student and faculty handbooks.

*This paper does not conform to standards for the following reasons:

Completed by: Tony Cummings

Academic Director: Tony Cummings

Signature: J. A. Cummings

Program: ASE- Australia: Rainforest, Reef, and Cultural Ecology

Date: 12th May 2017

Abstract

Coral reefs are characterized by their dynamic ecological processes that supports a high diversity through the recruitment of marine species and temporal disturbances that can have positive effects on the system. In the face of global climate change however, coral reefs face intense coral bleaching and increased degradation as they may begin to have less time to recover between bleaching events in the near future. Little is known on the long term effects of coral bleaching and habitat degradation on reef fish communities and much less is known about the mechanisms that bring about changes to reef fish assemblages.

This study used adult and juvenile populations as before and after snapshots, respectively, to study the effects of coral bleaching on a Damselfish community one year after a major bleaching event. This project aimed to use juvenile community dynamics to detect a phase shift in the Damselfish community assuming the underlying mechanism for a reef fish phase shift is habitat-limited recruitment and to predict the impact of disturbance on this biological community.

The current Damselfish community on Casuarina Reef, one year after a major bleaching event, is an ideal reef fish community for such a degraded habitat characterized by diet and habitat generalists that are able to take advantage of the phase shift following the bleaching event. The Damselfish community may have therefore already gone through a phase-shift in response to the degraded state of the reef. Based on the data between juvenile and adult Damselfish populations, and if juveniles are to be used as a representative of the next Damselfish community, the community does not seem to be changing one year after the bleaching event.

The lack of changes between the adult and juvenile damselfish communities and abundance may lead me to conclude that, currently, any changes happening in the damselfish community is not occurring through habitat-limiting recruitment of juveniles. This highlights the need to better understand the long term effects of coral bleaching and its mechanisms on reef fish communities and understanding the future of coral reef systems in the face of global climate change.

Keywords: **Coral reefs, coral bleaching, juvenile recruitment, reef fish communities, Damselfish.**

Table of Contents

Acknowledgements

I would like to thank my advisor Vanessa Messmer for all her help in setting up this project and her wonderful advice during the project. I would also like to extend my gratitude towards all those on the Lizard Island Research Station, especially Lyle Vail who made our project safe and possible. Thank you to Tony Cummings, Jack Grant, and SIT for making this experience possible. Last, but not least, I'd like to thank Kailey Bissell for being my snorkel buddy through thick and thin.

List of Figures

1.0 Introduction

Coral reefs are characterized by their dynamic ecological processes that supports a high diversity through the recruitment of marine species and temporal disturbances that can have positive effects on the system (Bellwood et al. 2006). Many reef fish species fully depend on live coral for their survival during at least one stage of their life cycles (Jones et al. 2004, McCormick et al. 2010). However, coral reef systems have entered a new era of large-scale coral loss (Wilkinson, 2004) and are facing the disastrous effects of global climate change such as coral bleaching, ocean acidification, and an increase in tropical storms. The effects of global climate change are expected to negatively impact most ecosystems on earth and coral reefs are considered to be one of the most susceptible systems (Walther et al. 2002). In a review done by Wilkinson (2004), 19% of coral reefs have been lost and by the year 2050, this figure will grow to 35%. Projections of annual thermal anomalies (Hoegh-Guldberg 1999) imply that by 2050, corals may not have time to recover between massive bleaching events (Donner et al. 2005). Without sufficient time to recover, coral reef systems may be permanently locked in the degraded state of a highly disturbed system and enter what is known as a phase shift. Phase shifts can be characterized by the breakdown of branching coral into rubble (Sheppard et al 2002, Graham et al. 2006) and the colonization of algae onto dead coral skeletons that can take up small gaps within coral structures (Pratchett et al. 2009).

According to a study by Jones et al. (2004), when coral loss is combined with the degradation of reef habitat there can be a nearly 65% drop in fish abundance. A shift in fish abundance is a crucial indication of a phase shift in a coral reef system and its corresponding fish community in response to the degradation of live and habitat providing coral (Jones et al. 2004). Studies on the effects of coral loss and habitat degradation on reef fish communities have also found that there is a shift from coral specialists to generalists (Bellwood et al. 2006). However, even if a species is not directly dependent on live coral, they may be dependent on the structural complexity provided by coral which has been found to sustain a high fish diversity (Pratchett et al. 2012). In a long term study, Bellwood et al. (2006), found there to be distinct pre-bleaching and post-bleaching fish communities after the 1998 coral bleaching event in the central Great Barrier Reef, bringing attention to the potential effects bleaching may have on community composition. However, the underlying mechanisms for these changes are not well understood (Bellwood et al. 2006).

One possible explanation for this shift in reef fish community is habitat-limited recruitment that may later affect the dynamics of the adult population. Recruitment is known as the life stage that proceeds settlement to the benthos and is marked by the replenishment of the adult population by a juvenile (Biagi et al. 1998). Fish abundance has been found to be inversely correlated with juvenile recruitment (Jones et al. 2004) and numerous studies have shown that there are clear preferences between species regarding where they settle and specific habitats that are successful recruiters of juveniles, depending on the species. Settlement and recruitment can depend on live coral cover (McCormick et al. 2010), substrate type (bare rock, turf algae, etc.) (Macpherson & Zika 1999), and visual and olfactory cues that may be emitted from coral reef systems to planktonic larvae (McCormick et al. 2010). Significant disturbances and a phase shift affecting coral and the substrate complexity of a coral reef system can limit, augment, or change the settlement and recruitment of juvenile fish and thus shift the adult reef fish community. Therefore, a shift in the juvenile community could potentially serve as an indication or a proxy of the future adult reef fish community. Understanding the future of reef fish communities in response to rapid habitat degradation is integral in understanding the future of coral reef communities in the face of global climate change and how its effects may be mitigated or prevented. This study uses adult and juvenile populations as before and after snapshots, respectively, to study the effects of coral bleaching on a Damselfish community one year after a major bleaching event. This is a possible way to continue studying the long term effects of coral bleaching and disturbances when studies are limited to data collection only after a high disturbance with no "before" data to compare to.

In this project, juvenile and adult damselfish have been surveyed off of the Lizard Island Research Station in Queensland, Australia, a site that has been heavily affected by coral bleaching, tropical cyclones, and Crown of Thorns starfish outbreaks. These disturbances happened within two years of each other leading to a devastatingly degraded coral reef system that has undergone a phase shift. Damselfish species composition and their relative abundance will be used as measures of changes in the Damselfish community nearly one year after the 2016 bleaching event on the Great Barrier Reef in an effort to better understand the long term effects of coral bleaching on reef fish. Juvenile Damselfish composition, in this case, is used as a proxy for the future Damselfish community that may be shifting or changing through habitat-limited recruitment. Damselfishes are an ideal study group because of their high abundance and they are very diverse in terms of habitat and/or diet requirements and preferences (McCormick et al. 2010). This project aims to use juvenile community dynamics to detect a phase shift in the Damselfish community assuming the underlying mechanism for a reef fish phase shift is habitat-limited recruitment and to predict the impact of disturbance on this biological community.

2.0 Methods

2.1 Study Site

The Lizard Island Group is a mid-shelf reef located on the northern Great Barrier Reef in Queensland, Australia (14.6645˚S, 145.4651˚E). The selected reef is a continuous patch reef located approximately 100 meters from the beach on the west side of the island in relatively shallow waters (maximum 5m depth). Casuarina Reef, suffered in the 2016 bleaching event on the Great Barrier Reef as well as two category four cyclones that hit the island in 2014 and 2015. This reef was selected for its proximity to the beach that did not require a boat to access.

2.2 Substrate Data Collection

Data was collected in early April 2017 off of Lizard Island Research Station in Queensland, Australia. The substrate was analyzed using a point intersect transect method. A 20 meter transect tape was stretched north-to-south from the edge of the reef every five meters. This was repeated stretching a 20 meter transect tape north-to-south 21 meters from the edge of the reef. Along each transect, the substrate located directly underneath every 50cm was recorded and tallied for a total of 40 data points on each transect. 30 transects were done resulting in a total of 1200 substrate data points. The substrate was differentiated between coral and non-coral, living or dead, and hard or soft. The following categories were used: turf hard dead substrate, coral rubble, macro algae, soft coral, hard coral, and other. Hard coral was identified to the following family groups: Acroporidae, Pocilloporidae, Poritidae, and Fungiidae.

2.3 Damselfish Surveys

Fish surveys were done by a 20mx2m visual belt transect, this size was chosen to account for the relatively small size and abundance of Damselfish. A 20 meter transect tape was stretched north-to-south from the edge of the reef every five meters and then repeated 21 meters from the edge of the reef outward to cover most of the reef. Fish survey transects were done on the same or as near as possible to the substrate transects done previously. Within each transect belt, Damselfish were identified to the species level and the amount of individuals seen was recorded. Within each species, juveniles were distinguished from adults and counted separately. Any sub-adult forms seen were counted as adults. Only Damselfish that fell within the 20mx2m were counted and individuals seen on the edge of the transect or those that swam into the transect behind me were not counted. 30 transects were done resulting in a total area of 600mx60m that was surveyed for Damselfish.

3.0 Results

3.1 Substrate Data

On average, algal turf substrate dominated nearly half of the surveyed reef representing 43.5% (SE ± 2.66) of substrate cover (Figure 1). There was nearly a 20% difference between algal turf cover and the next abundant substrate type, sand (20.25%, SE ±2.81). All other substrates were therefore present in very low percentages (<20%). The remaining cover is made up, on average, of hard coral (16.75%, SE ± 2.06), rubble (8.0%, SE ± 1.12), soft coral (7.9%, SE ± 1.34), macro algae (3.6%, SE ± 0.97) (Figure 1). Nearly 80% of hard coral was made up of massive porites coral with pocilloporidae and fungiidae each making up less than one percent of the average cover of the reef. No acroporidae, columnar, or foliaceous corals were found on the reef. Therefore, the remaining live coral cover after two cyclones, a bleaching event, and a COTS outbreak, is represented nearly solely by massive porites and soft coral.

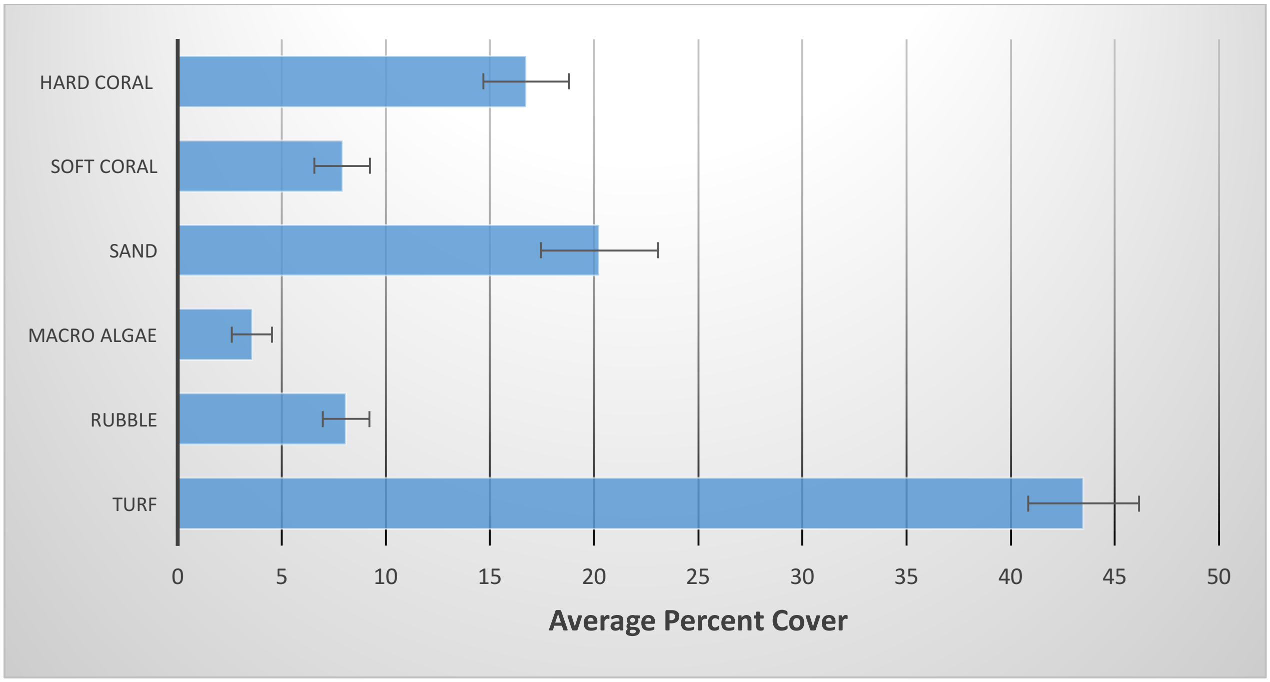

Figure 1. Average Percent Cover of Dominant Substrates. Average percent of substrate types per 20m transect at Casuarina Reef, Lizard Island. Error bars represent standard errors. Substrates that were not found have been excluded and all hard coral has been grouped together.

3.2 Damselfish Community

Fifteen species of Damselfish were found on Casuarina Reef: *Acanthochromis polyacanthus, Amblyglyphidodon curacao, Chrysiptera caesifrons, Chrysiptera rollandi, Hemiglyphidodon plagiometopon, Neoglyphidodon melas, Neopomacentrus azysron, Neopomacentrus cyanomos, Plectroglyphidodon lacrymatus, Pomacentrus adelus, Pomacentrus amboinensis, Pomacentrus chrysurus, Pomacentrus grammorhynchus, Pomacentrus moluccensis,* and *Stegastes apicalis.* All species found have a preferred diet of either plankton, algae or a mixture of the two (Table 1), with the exception of *H. plagiometopon*, a detritivore, and *C. caesifrons*, whose diet is not found in the primary literature.

All of these species were found in both the juvenile and adult Damselfish populations. The adult and juvenile Damselfish community have very similar community compositions. They have similar dominant species such as *N. azysron, P. adelus, P. chrysurus, P. moluccensis,* and *P. grammorhynchus* (Figure 2). In the adult community, these species make up nearly 87% of the Damselfish individuals surveyed on Casuarina Reef. In the juvenile community, these same species make up 55% of the damselfish individuals surveyed. This difference is due to three other dominant species that appeared in the juvenile community but were not dominant in the adult community: *A. curacao* (16%), *A. polyacanthus* (13%) and *C. rollandi* (7%). Other species such as *N. melas, P. lacrymatus, S. apicalis, N. cyanomos, C. caesifrons, P. amboinensis, and H. plagiometopon* are all present in both the adult and juvenile community in very small proportions (0-4%) (Figure 2). The adult and juvenile populations therefore seem to have very similar compositions (Figure 2).

Table 1. Diet and Habitat preferences of Damselfish species found on Casuarina Reef, Lizard Island, Australia. Damselfish species found on thirty 20mx2m visual transect belts on Casuarina Reef, Lizard island. Diets are based on current literature, although little is known about most of these species. *C. caesifrons* in particular is a newly identified species (2015) with no diet preferences described in literature. *These species have a change in diet in their recruit and adult life stages, generally shifting towards algae in their adult stage.

Species	Diet	Reference
A. curacao	Plankton and algae	Australian Museum
A. polyacanthus	Plankton and algae	Australian Museum
C. caesifrons	/	/
C. rollandi	Plankton and algae	Lieske & Myers 1994
H. plagiometopon	Detritivore,	Wilson & Bellwood 1997
N. azysron	Plankton	Australian Museum
N. cyanomos	Plankton	Allen 1991
N. melas	Plankton, algae, and soft coral*	Australian Museum
P. adelus	Algae	Ceccarelli 2007
P. amboinensis	Plankton and algae	Australian Museum
P. chrysurus	Algae	Australian Museum
P. grammorhynchus	Plankton and algae*	Australian Museum
P. lacrymatus	Algae	Allen 1991
P. moluccensis	Plankton and algae	Australian Museum
S. apicalis	Algae	Allen & Emery 1985

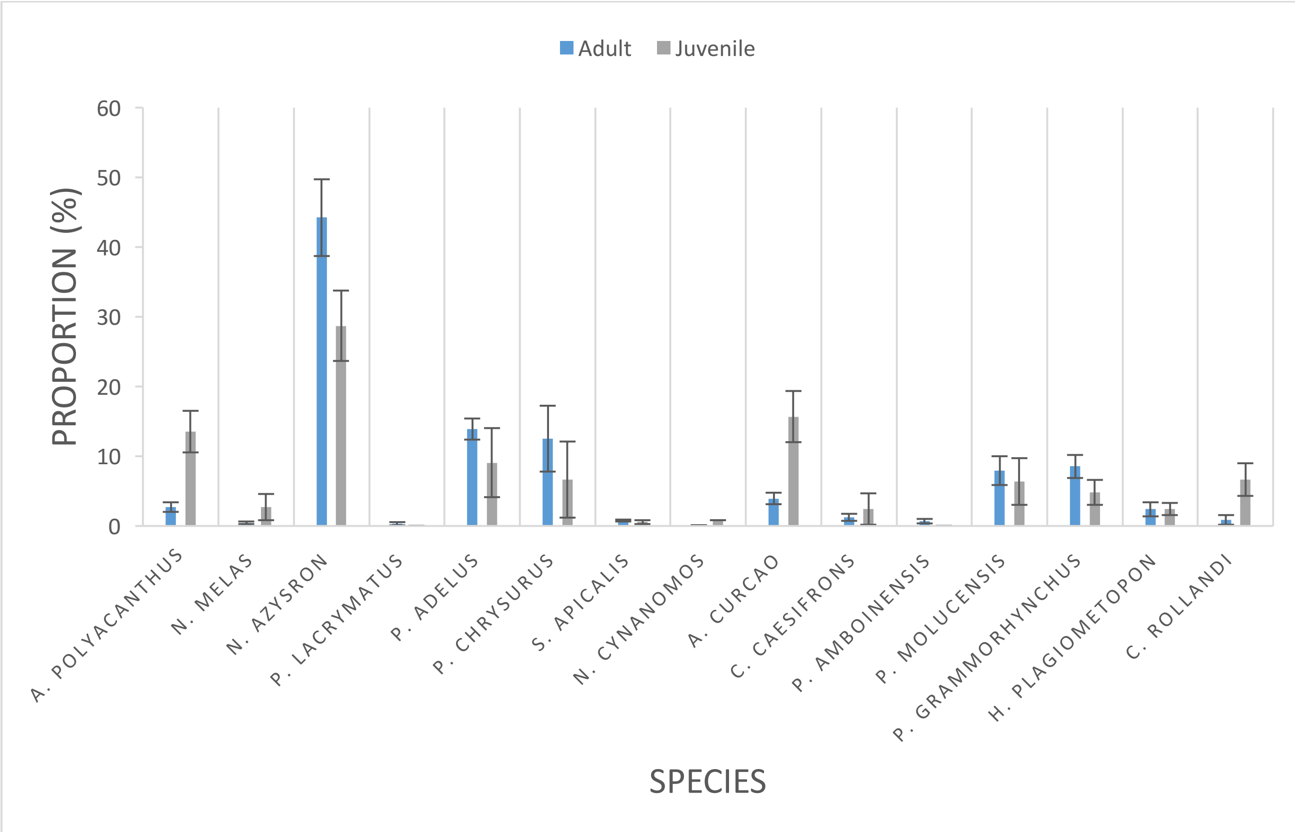

Figure 2. Proportion of Adult and Juvenile Damselfish. Proportions are showed as the percentage of each Damselfish species out of all Damselfish species surveyed from thirty 20mx2m visual transect belts on Casuarina Reef, Lizard Island. Juvenile and adult community composition are compared with these proportions. Error bars represent standard error.

3.3 Damselfish abundance

On average, most damselfish species had similar abundances in the adult and juvenile community (Figure 3). Interestingly, the five dominant damselfish species (*N. azysron, P. adelus, P. chrysurus, P. moluccensis,* and *P. grammorhynchus*) all had differences in average abundance between their adults and juveniles (Figure 3) with at least, on average, three times more adults than juveniles. The highest difference being between in the species *N. azysron* which had on average six times more adults than juveniles. Therefore, these species, on average, had a 20% decline in abundance from adults to juveniles. No species had an increase in average abundance in their juvenile populations (Figure 3).

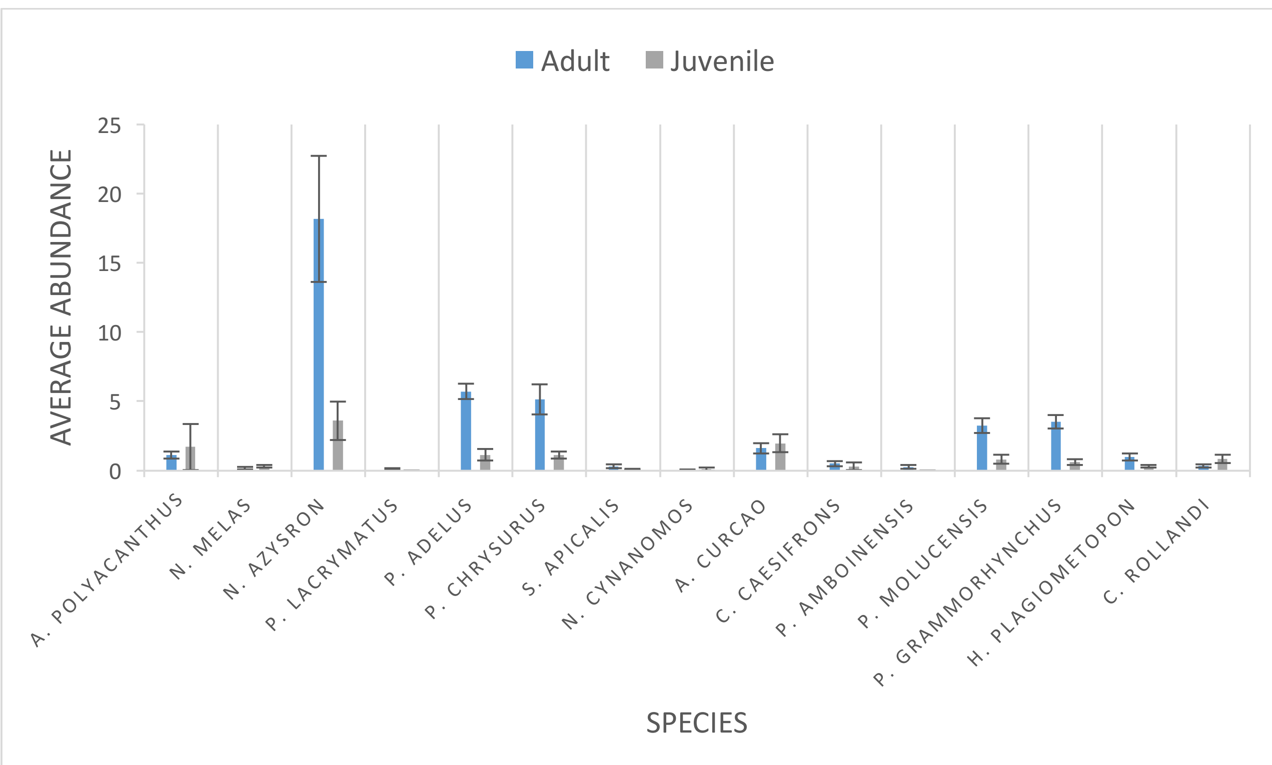

Figure 3. Average Abundance of Adult and Juvenile Damselfish. Abundance is shown as an average abundance per transect from thirty 20mx2m visual transect belts along Casuarina Reef, Lizard Island. Average abundance of adult and juvenile Damselfish are compared. Error bars represent standard error.

3.4 Substrate Preferences by Damselfish

N. azysron

Nearly 60% of *N. azysron* were found on transects with low to medium (>20%) amounts of massive porites coral and nearly 80% were found on transects with very low (<10%) amounts of algal turf (Figure 4). These trends suggest that *N. azysron* prefers areas with a higher cover of massive porites and stays away from areas of high algal turf.

P. adelus

Nearly 60% of *P. adelus* were found on transects with low to medium (>20%) amounts of sand and 84% percent were found on transects with very low (<10%) amounts of soft coral (Figure 4). This result suggests that *P. adelus* prefers areas with a higher cover of sand and and is less abundant in areas with higher amounts of soft corals.

P. chrysurus

P. chrysurus followed the same pattern as *P. adelus* with 60% of its individuals found on transects with low to medium (>20%) amounts of sand and 84% percent found on transects with very low (<10%) amounts of soft coral (Figure 4). *P. chrysurus* therefore exhibited the same substrate preferences as *P. adelus.*

P. grammorhynchus

Less than half (46%) of the individuals of *P. grammorhynchus* were found on transects with low to medium (>20%) amounts of turf and 60% of individuals were found on transects with very low (<10%) amounts of soft coral (Figure 4). This suggests that *P. grammorhynchus* prefers areas with higher amounts of turf and avoids areas with high amounts of soft coral.

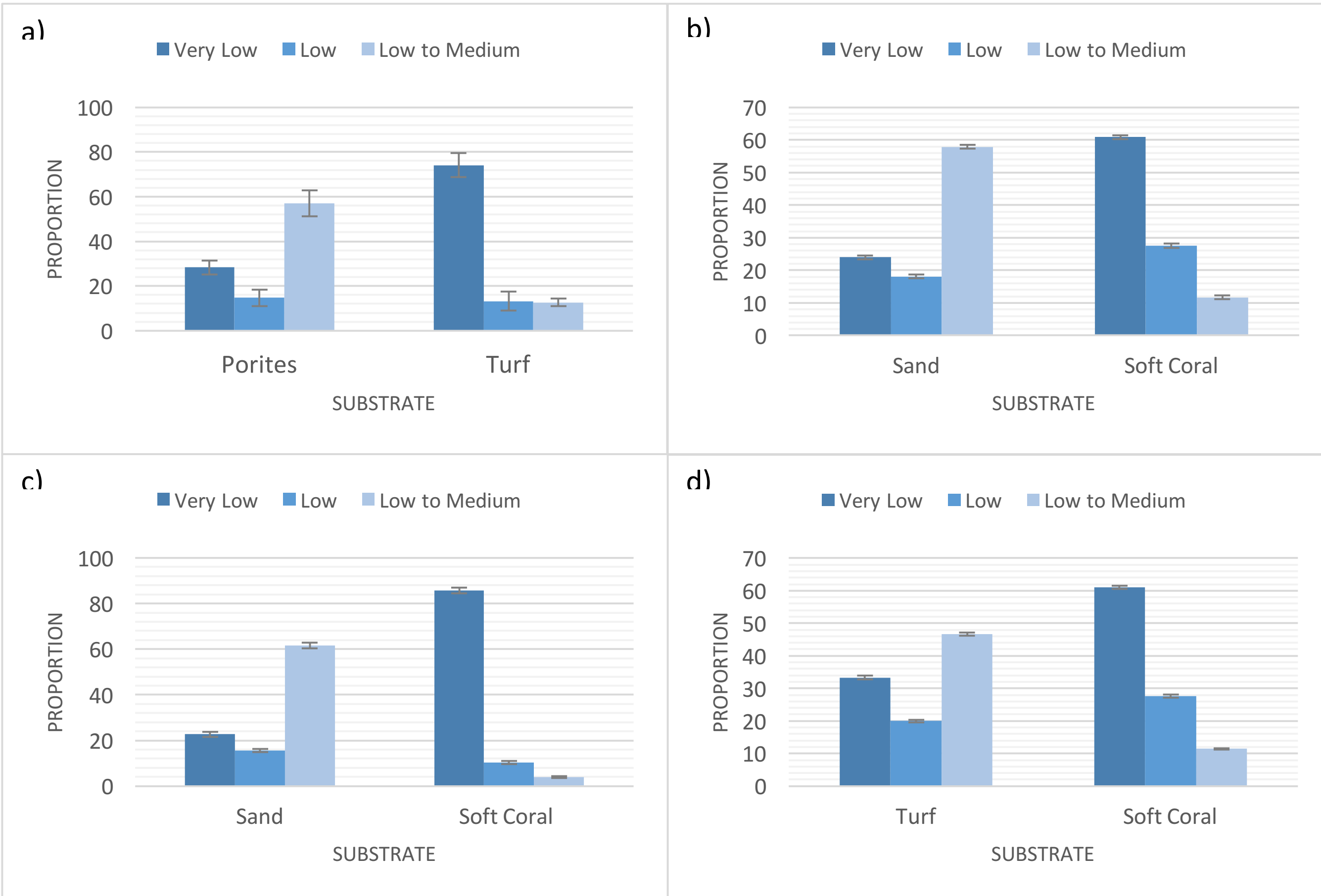

Figure 4. The effect of 3 densities of substrates on 4 adult damselfish species: a) ***N. azysron*** **b)** ***P. adelus,*** **c)** ***P. chrysurus, and*** **d)** ***P. grammorhynchus.*** For each transect, three low densities of particular substrates were chosen: Very low (<10%), Low (10-20%), and Low to Medium (≥ 20%). Low densities were chosen because all substrates, except for algal turf, were present in small percentages. The percentage of individuals found on transects with very low, low, or low to medium of each substrate was calculated for species who had over 100 individuals surveyed in total. Plotted here are the extremes of the results, both the substrate most preferred and least preferred by each Damselfish species. For example, nearly 60% of *N. azysron* were found on transects with low to medium percentages of Porites and nearly 80% of *N. azysron* were found on transects with very low percentages of algal turf. This suggests that *N. azysron* prefers areas with a higher cover of porites and stays away from areas of high algal turf. ± SE is shown.

4.0 Discussion

The bleaching event of 2016 affected most reefs found on Lizard Island, including a patch reef found 100 meters from the shore: Casuarina Reef. According to personal accounts, the reef has little resemblance to the reef it once was before a major bleaching event and two major cyclones hit the island. Nearly half of this reef is dead hard coral overridden with algal turf and nearly eighty percent of the hard coral that's left was massive poritids. A high representation of massive porites coral is similar to the results of the 1998 bleaching in Okinawa, Japan, where Loya et al. (2001) found a "community-structural shift" towards coral with higher tissue-thickness such as massive and encrusting corals. "Community-structural shift", as they describe it, is the result of differential coral survival from a disturbance that causes a shift in not only species composition, but the structure of the reef (Loya et al. 2001) resulting in a large representation of massive corals. Reef fish communities have shown, in the past, a vulnerability to such changes in the coral community and therefore to coral bleaching (Bellwood et al. 2006).

The current Damselfish community on Casuarina Reef, one year after a major bleaching event, is an ideal reef fish community for such a degraded habitat characterized by diet and habitat generalists that are able to take advantage of the phase shift following the bleaching event. The Damselfish community is made up entirely of either planktivores, herbivores, or a mixture of the two (Table 1). This result is unsurprising as live coral cover only made up an average of 25% of the substrate cover (Figure 1), likely leading to the decline and possible local extinction of any obligate corallivores in the Damselfish family. Reef degradation is known to have an affect on reef fish communities such as increasing the abundance of herbivores and/or decreasing the abundance of coral specialists (Booth & Beretta 2002). For example, Pratchett et al (2008) concluded that fish that increased after disturbances were normally diet generalists. The

Damselfish community may have therefore already gone through a phase-shift in response to the degraded state of the reef. Many of the damselfish species present on this reef are omnivores consuming both plankton and algae. Those that specialize in either can thrive because plankton may not be directly affected by bleaching and increased algal turf is a product of a shifting post-bleaching coral reef (Pratchett et al. 2009).

In addition to ideal diets for this disturbed reef, the current Damselfish community has very few species that depend on live coral for habitat. Most are known generalists that can live in dead or live coral such as *P. lacrymatus* (Allen 1991) and *P. amboinensis* (Syms & Jones 2001). Others even specialize in dead coral and rubble such as *P. adelus* (Kuiter & Tonozuka 2001), *P. chrysurus* (Allen 1991), *S. apicalis* (Allen & Emery 1985). Since rubble, on average, made up only 8% of the substrate cover on Casuarina reef (Figure 1), most of the reef has kept its structural integrity which has been hypothesized to be critical for fish diversity (Pratchett 2012) and may still be continuing to provide a structural habitat for these Damselfish species despite the loss of live coral cover.

Habitat preferences for four Damselfish species (*N. azysron, P. adelus, P. chrysurus,* and *P. grammorhynchus)* was able to be analyzed since substrate and fish transects were done in nearly the same locations and I could therefore tie the substrates found on each transect with the abundance of each Damselfish species. Both *P. adelus* and *P. chrysurus* tended to prefer areas with higher amounts of sand, *N. azysron* preferred porites coral, and *P. grammorhynchus* preferred areas with algal turf (Figure 4). Their preferred substrates were the most dominant substrates on the reef possibly explaining why these four species were the dominant species in the community. It is these same substrates that are typically dominant in a post-bleaching coral community suggesting that the Damselfish community may be structured in response to the phase shift caused by the 2016 bleaching event. This is supported by findings by Booth & Beretta (2002) who saw a significant decrease in juvenile and adult damselfish diversity as a result from the 1998 bleaching event and the resulting large loss in coral cover in Okinawa, Japan.

Currently there have been very few long term studies on the effects of bleaching and disturbances on reef fish assemblages (Bellwood et al. 2006) and determining whether or not this damselfish community is temporary or changing is critical towards understand the long term impacts of phase shifts in coral reef systems. Based on the data between juvenile and adult Damselfish populations, and if juveniles are to be used as a representative of the next Damselfish community, the community does not seem to be changing one year after the bleaching event. The juvenile and adult populations have very few differences in community composition, with similar dominant species except for three new species that are appearing to be more abundant in the juvenile population. Neither diet nor habitat preferences, however, seem to explain why *A. curacao*, *A. polyacanthus,* and *C. rollandi* were dominant juvenile species but not dominant adult species since all three are diet and habitat generalists. It is also worth to note that some species are naturally more abundant than others such as *N. azysron* that tends to be present in large groups (personal obs.).

It is also unclear why the dominant damselfish species (*N. azysron, P. adelus, P. chrysurus, P. moluccensis,* and *P. grammorhynchus)* all drop in abundance between their adult and juvenile populations. Diet could explain the difference in abundance between the adult and juvenile populations of *P. grammorhynchus*. *P. grammorhynchus* changes diet through its life cycle eating plankton as a juvenile recruit then moving on to grazing benthic algae (Australian Museum). Therefore, it is possible that juvenile *P. grammorhynchus* were not limited by food during their settlement and were able to move into the reef in large numbers as recruits. Being that most of the damselfish species are herbivorous there may be intense competition for territory and space that may have driven down abundance levels of the adult *P. grammorhynchus.* It is more likely, however, that these changes in abundances are due to something other than diet and habitat preferences of the damselfish. For example, Almany (2004) found the absence and presence of different kinds of predators to explain the difference in abundance between juvenile recruits and adults. Although more fish surveys would need to be done to test this, there may be more predators present in Casuarina reef that prey on recruits than those that prey on adults. The differences in abundance may also be due to sampling errors such as missing juvenile recruits due to their small size and shyness and estimating the numbers of large aggregations of damselfish such as *N. azysron* that typically tend to be in large groups.

The lack of changes between the adult and juvenile damselfish communities and abundance may lead me to conclude that, currently, any changes happening in the damselfish community is not occurring through habitat-limiting recruitment of juveniles. Booth & Beretta (2002) also found a decrease in damselfish density after a bleaching event but no significant decline in juvenile recruitment. A change in recruitment could have been the case soon after the bleaching that could have driven coral specialists out, but it may no longer be occurring now one year after the bleaching event. The limitations of this study must be acknowledged, however. This study was done on only one patch reef, there is no data on the Damselfish community before the bleaching event, and many factors could have affected Damselfish counts such as tides, identification mistakes, and miscounting. Based on the results of this study, one year after a major bleaching event, the Damselfish community is showing no significant signs of changes or shifts indicating that the shift from specialists to generalists after major disturbances

(Bellwood et al. 2006) may be the immediate short term effect but the long term effects of coral bleaching on reef fish communities still need to be better understood. Studies need to be continued on the long term effects of bleaching on reef fish communities and the mechanisms in which they change need to be further investigated. If this Damselfish community is changing it may not be through habitat-limited recruitment but through other means. If this Damselfish community is not changing it begs the question, is a shift from specialists to generalists and a drop in abundance the only effect of coral bleaching on reef fish? Understanding the long term effects of coral bleaching on reef fish communities is critical towards understanding the future of coral reef systems in the face of global climate change.

5.0 Literature Cited

Allen, G. R. (1991). *Damselfishes of the world*. Mergus Publishers, Melle, Germany.

Allen, G. R., Emery, A. R., & Museum, B. P. B. (1985). *A review of the pomacentrid fishes of the genus Stegastes from the Indo-Pacific with descriptions of two new species*. Honolulu, Hawaii : Bernice Pauahi Bishop Museum. Retrieved from http://trove.nla.gov.au/version/46508528

Almany, G. R. (2004). Differential Effects of Habitat Complexity, Predators and Competitors on Abundance of Juvenile and Adult Coral Reef Fishes. *Oecologia*, *141*(1), 105–113.

Australian Museum. (n.d.). Lizard Island Field Guide: description of Damselfishes (family: Pomacentridae). Retrieved May 10, 2017, from http://lifg.australianmuseum.net.au/Group.html?hierarchyId=PVWrQCLG&groupId=Kpc65SEV

Bellwood, D. R., Hoey, A. S., Ackerman, J. L., & Depczynski, M. (2006). Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. *Global Change Biology*, *12*(9), 1587–1594. https://doi.org/10.1111/j.1365-2486.2006.01204.x

Biagi, F., Gambaccini, S., & Zazzetta, M. (1998). Settlement and recruitment in fishes: The role of coastal areas. *Italian Journal of Zoology*, *65*(sup1), 269–274. https://doi.org/10.1080/11250009809386831

Booth, D. J., & Beretta, G. A. (2002). Changes in a fish assemblage after a coral bleaching event. *Marine Ecology Progress Series*, *245*, 205–212. https://doi.org/10.3354/meps245205

Ceccarelli, D. M. (2007). Modification of benthic communities by territorial damselfish: a multi-species comparison. *Coral Reefs*, *26*(4), 853–866. https://doi.org/10.1007/s00338-007-0275-1

Donner, S. D., Skirving, W. J., Little, C. M., Oppenheimer, M., & Hoegh-Guldberg, O. (2005). Global assessment of coral bleaching and required rates of adaptation under climate change. *Global Change Biology*, *11*(12), 2251–2265. https://doi.org/10.1111/j.1365-2486.2005.01073.x

Graham, N. A. J., Wilson, S. K., Jennings, S., Polunin, N. V. C., Robinson, J., Bijoux, J. P., & Daw, T. M. (2007). Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. *Conservation Biology: The Journal of the Society for Conservation Biology*, *21*(5), 1291–1300. https://doi.org/10.1111/j.1523-1739.2007.00754.x

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., … Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science (New York, N.Y.)*, *318*(5857), 1737–1742. https://doi.org/10.1126/science.1152509

Jones, G. P., McCormick, M. I., Srinivasan, M., & Eagle, J. V. (2004). Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences*, *101*(10.1073/pnas.0401277101), 8251–8253. https://doi.org/http://dx.doi.org/10.1073/pnas.0401277101

Kuiter, R. H., & Tonozuka, T. (2001). *Pictorial guide to Indonesian reef fishes*. Seaford, Vic. : Zoonetics. Retrieved from http://trove.nla.gov.au/version/26909034

Lieske, E., & Myers, R. (2001). *Coral Reef Fishes: Indo-Pacific and Caribbean*. HarperCollins.

Loya, Y., Sakai, K., Yamazato, K., Nakano, Y., Sambali, H., & van Woesik, R. (2001). Coral bleaching: the winners and the losers. *Ecology Letters*, *4*(2), 122–131. https://doi.org/10.1046/j.1461-0248.2001.00203.x

Macpherson, E., & Zika, U. (1999). Temporal and spatial variability of settlement success and recruitment level in three blennoid fishes in the northwestern Mediterranean. *Marine Ecology Progress Series*, *182*, 269–282. https://doi.org/10.3354/meps182269

McCormick, M. I., Moore, J. a. Y., & Munday, P. L. (2010). Influence of habitat degradation on fish replenishment. *Coral Reefs*, *29*(3), 537–546. https://doi.org/10.1007/s00338-010-0620-7

Pratchett, M., Munday, P., Wilson, S., Graham, N., Cinner, J., Bellwood, D., … Mcclanahan, T. (2008). Effects Of Climate-Induced Coral Bleaching On Coral-Reef Fishes ?Äî Ecological And Economic Consequences. In *Oceanography and Marine Biology* (Vols. 1–0, pp. 251–296). CRC Press. Retrieved from http://www.crcnetbase.com/doi/abs/10.1201/9781420065756.ch6

Pratchett, M. S., Baird, A. H., McCowan, D. M., Coker, D. J., Cole, A. J., & Wilson, S. K. (2009). Protracted declines in coral cover and fish abundance following climate-induced coral bleaching on the Great Barrier Reef. In B. M. Riegel & R. E. Dodge (Eds.), *Proceedings of the 11th International Coral Reef Symposium* (pp. 1042–1046). Florida, USA: 11th International Coral Reef Symposium. Retrieved from http://www.nova.edu/ncri/11icrs/proceedings/files/m25-08.pdf#zoom=100

Pratchett, M. S., Bay, L. K., Coker, D. J., Cole, A. J., & Lawton, R. J. (2012). Effects of coral bleaching on coral habitats and associated fishes. In *Wildlife and Climate Change* (Vols. 1–0, pp. 59–67). Royal Zoological Society of New South Wales. Retrieved from http://publications.rzsnsw.org.au/doi/abs/10.7882/FS.2012.012

Sheppard, C. R. C., Spalding, M., Bradshaw, C., & Wilson, S. (2002). Erosion vs. Recovery of Coral Reefs after 1998 El Niño: Chagos Reefs, Indian Ocean. *AMBIO: A Journal of the Human Environment*, *31*(1), 40–48. https://doi.org/10.1579/0044-7447-31.1.40

Syms, C., & Jones, G. P. (2001). Soft Corals Exert No Direct Effects on Coral Reef Fish Assemblages. *Oecologia*, *127*(4), 560–571.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., … Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, *416*(6879), 389–395. https://doi.org/10.1038/416389a

Wilkinson, C. (2004). Status of coral reefs of the world: 2004. Global Coral Reef Monitoring Network, Australian Institute of Marine Science, Townsville.

Wilson, S., & Bellwood, D.R. (1997). Cryptic dietary components of territorial damselfishes (Pomacentridae, Labroidei). *Marine Ecology Progress Series*, *153*, 299–310. https://doi.org/10.3354/meps153299