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Damselfish and their Effect on the Biodiversity of Algal Species: A Continuation of Research in the Galápagos Islands

Ian DeVaan, Brian Koch, Paige Goodman, Claire Madden

Abstract:

Algal diversity is important in the Galápagos Islands' littoral ecosystems because it is part of the photosynthetic role in the food web. Male damselfish (*Stegastes* spp.) may play a key role in the maintenance of algal diversity due to their territorial behavior; they actively clean territories and thereby, open up niches for algal growth. We investigated the damselfish role in algal coverage and diversity and predicted that there will be greater mean coverage and number of species within territories. Results from this study will contribute to the knowledge base concerning natural diversity maintenance. Data collection occurred during low tide between 20 and 26 July, 2015 at two beaches on Isla San Cristóbal. Using 50cm x 50cm PVC quadrants, we compared algal coverage and species diversity on damselfish territories and on randomly selected areas ("non-territories") within 7 meters of the focal territory (N = 50 for each category at each beach). Using a chi-square goodness of fit analysis protocol, we found a significant difference between the mean number of algal species within a territory as compared to non-territories at both beaches (Playa Mann: 2.5 vs. 2.0, respectively and La Lobería: 3.0 and 2.5, respectively). At La Lobería, there was significantly less algal coverage in non-territories ($P < 0.001$). There was no difference in mean algal coverage at Playa Mann ($P = 0.94$). Reduced algal coverage within non-territories at La Lobería may be a function of a generally shallower area and high snorkeling activities. Lower algal coverage may be

explained by daily abrasion of the bottom by the public. In terms of mean algal diversity, results are in agreement with our prediction and damselfish appear to play an important role in the maintenance of higher algal diversity. This research provides valuable insight into the biodiversity of algal species in marine ecosystems, as well as further supports the importance of Damselfish in regards to upkeep of these marine ecosystems.

Introduction:

There are several distinct ecosystems present in the Galápagos Islands that demand maintenance by certain keystone species in order to maintain their vigor and longevity. A keystone species is a population of organisms on which other species in an ecosystem largely depend, such that if it were removed the ecosystem would change drastically (Wagner, 2010). An example of one of these ecosystems would be the marine ecosystems in which the keystone species are the White-Tailed Damselfish (*Stegastes leucurus beebei*) and Yellow-Tailed Damselfish (*Stegastes arcifrons*) (Hixon and Brostoff 1983). These species are closely related and share many of the same behaviors

with each other. All males exhibit constant upkeep of their territories. Specifically, during the mating period, males continuously remove foreign matter from their territories. This behavior results in keeping more competitive species of algae in check. The removal of more competitive algae allows for less competitive algae to begin growth within the Damselfish territories. The importance of allowing the less successful algae to grow lies in the development of more complex ecosystems. Without the growth of these less competitive algal species there would be a very low probability of an ecologically viable marine ecosystem developing that could sustain the Damselfish and many other marine species (Jones et al. 2006). Without the constant maintenance by the Damselfish species there would be less variation of algal species, which may influence overall diversity of the marine ecosystem. Algae, in a marine ecosystem, provides the foundation for all of the food webs that exist in the sea. Algae acts as a producer and utilizes photosynthesis to convert sunlight into usable energy. Larger organisms then consume the algae, thus moving the stored energy within the food web. The importance of the variation of algal species cannot be understated. The keystone role of the Damselfish is to increase the algal biodiversity and as a result support their ecosystem. If the Damselfish were to be removed from this ecosystem the degree of biodiversity would decrease dramatically thus altering the ecosystem dramatically. The algae, regardless of species, acts as the cornerstone of the marine ecosystem because of its role as a primary producer. If the algae were to be removed from the ecosystem then the species which rely on the algal growth for sustenance would be forced to use another, far less abundant food source, or die off. Seeing as all marine species rely, in some way or another, on the algal growth in the ocean; the removal of algae from the marine ecosystem would be catastrophic.

Research that has already been done on this topic has concluded that damselfish reduce grazing on the algae in their respective territories whilst simultaneously acting as predators and aggressors that preserve various algal densities. (Irving and Witman 2009). By farming the algal populations within their territories the Damselfish prevent the various populations of algae from becoming too dense (Sammarco, 1983). If these algal populations were left unchecked some species would outcompete other species. If this were allowed to happen, then the overall biodiversity will be less because some species will be excluded. These consequences are only compounded in higher levels of the food web. This is because there are some species that utilize the less abundant algae species as a food source and if they cannot find food, they would be forced to either find a new food source, which may prove quite difficult, or die out causing the species that rely on them for food to experience the same problem.

This study was conducted to determine whether or not the White and Yellow-Tailed Damselfish are a legitimate keystone species that play a role in promoting the biodiversity of algae within their respective territories, specifically the study areas of Playa Mann and La Loberia on the island of San Cristóbal in the Galapagos Islands. This study is a continuation of research done in previous years (July of 2013 in the bay of La Loberia & July of 2014 in the bay of Playa Mann) on the same topic. This continuation of research is necessary to determine whether or not there is a significant difference in algal biodiversity near different beaches on the same island and at the same time. One of the key reasons this research is being done is to see if, during the same year, the results are the same as the results from the two previous year's studies on the two different beaches. The continuation of research also will help determine whether or not there is a significant

difference in algal biodiversity over a span of three years. We hypothesize that there will be an increase in algal biodiversity within Damselfish territories, due to the fact that their farming behavior will not only allow for a larger number of algae species to grow but also that they actively reduce predation on the algae within their territories.

Methods:

This study was conducted on the Galapagos Islands, which are 600 miles off the coast of Ecuador. Data was collected from two different beaches on San Cristobal (La Loberia and La Playa Mann) at the same time each day. La Loberia is located in the southeast corner of the island approximately four miles from Puerto Baquerizo Moreno. Playa Mann is located on the southwest corner of Puerto Baquerizo Moreno, across the street from University of San Francisco - Quito, San Cristobal.

Low tide was selected as the most appropriate time of day to collect data due to the presence of strong under currents at high tide that could be potentially dangerous to swimmers. Data was collected between July 20, 2015 and July 26th 2015. Over this span of time, low tide varied between 9:00am and 4:00pm.

Each day, ten separate data entries were made for both Damselfish territories and non-Damselfish territories. Data points were collected between 10 and 30 meters away from the shoreline and data was collected by alternating between Damselfish territories and non-Damselfish territories. The non-Damselfish areas were determined by moving at least five meters away from each respective Damselfish territory in a random direction. The random direction was obtained with a random number generator to select a set of numbers between one and four prior to the data collection period. Each number

corresponded to a direction with one being towards the shoreline and three being away from the shoreline.

Each Damselfish territory or non-Damselfish area was measured using a 50cm by 50cm 'quad' that was divided into 25 smaller squares using high visibility string. Photo of quad is shown below.



This allowed us to estimate the percentage of algae coverage within the quad by making the assumption that each smaller square is equivalent to 4% of the total area. A photo was taken of each Damselfish territory and each non-Damselfish area so that analysis could be done after the each day's data was collected. A Nikon Coolpix AW120 underwater camera with a 16-megapixel-image sensor was used on both beaches. Each photo was analyzed to determine the percentage of algae coverage and the number of types of algae

present in each quad. By physical description, we identified four potential species. For the best analysis of each photo the images were enhanced using the stock photo application found in Apple's OSX Yosemite Version 10.10.3. The collected data was then analyzed using Microsoft Excel to determine averages, standard deviations, chi squared values, and Z-Tests

Results:

Analysis of the collected data revealed that at Playa Mann there was an average of 2.5 species of algae per plot in damselfish territories where as the non-damsel territories had an average of 2 species per plot. The average percent algal coverage in damselfish territories at Playa Mann was 59 percent. The average percent algal coverage in non-damselfish territories was 55 percent. These results can be seen in the data collection tables labeled Table 1.

Table 1. Playa Mann. Algal biodiversity and percent coverage of algal species observed at Playa Mann for Damselfish and non-Damselfish territories.

Playa Mann Trial	Damselfish Territories		Non-Damselfish Areas		
	# Of Species	% Coverage	# Of Species	% Coverage	
7/20/15	1	2	48	2	80
	2	3	56	1	62
	3	3	58	3	40
	4	2	33	2	32
	5	3	45	1	16
	6	4	63	3	35
	7	3	46	1	24
	8	3	35	1	12
	9	3	55	2	9
	10	4	60	2	30
7/21/15	11	2	70	1	9
	12	3	55	1	6

	13	3	45	2	23
	14	2	73	2	28
	15	3	50	1	23
	16	2	57	2	30
	17	1	40	1	18
	18	2	60	2	8
	19	3	63	1	15
	20	1	43	1	5
7/23/15	21	2	80	1	16
	22	3	83	1	25
	23	2	75	1	30
	24	3	90	2	60
	25	3	95	1	65
	26	2	90	1	20
	27	2	92	1	10
	28	2	75	1	25
	29	2	84	2	28
	30	3	88	2	30
7/24/15	31	2	65	1	30
	32	3	70	2	60
	33	3	90	2	50
	34	3	85	1	65
	35	3	90	2	100
	36	2	65	2	90
	37	2	95	1	40
	38	2	70	1	10
	39	2	85	1	25
	40	3	60	1	70
7/25/15	41	3	70	1	40
	42	3	85	1	35
	43	2	94	2	44
	44	3	60	1	20
	45	2	70	2	16
	46	2	75	2	25
	47	1	65	3	45
	48	3	55	1	50
	49	2	80	1	20
	50	3	70	2	30
		Average: 2.5	Average: 59%	Average: 2.0	Average: 55%

At La Loberia the average number of algal species in damselfish territories was 3. In non-damselfish territories the average number of species was 2.5. In damselfish territories, the average percent algal coverage was 57.5 percent. Non-damsel fish territories had an average percent algal coverage of 28.5 percent. These results can be seen in the data collection tables labeled Table 2.

Table 2. La Loberia. Algal biodiversity and percent coverage of algal species observed at La Loberia for Damselfish and non-Damselfish territories.

La Loberia	Damselfish Territories		Non-Damselfish Areas		
	Trial	# Of Species	% Coverage	# Of Species	% Coverage
7/20/15	1	3	56	2	32
	2	3	65	1	16
	3	3	40	1	20
	4	4	56	1	4
	5	3	80	1	3
	6	2	20	2	10
	7	2	47	1	8
	8	3	30	2	10
	9	4	80	2	30
	10	4	95	1	8
7/21/15	11	3	85	1	15
	12	3	68	1	12
	13	2	60	1	18
	14	1	50	2	20
	15	3	48	1	32
	16	4	75	3	50
	17	3	42	2	50
	18	4	90	1	30
	19	3	70	1	60
	20	2	75	1	50
7/23/15	21	3	68	1	30
	22	3	56	1	24
	23	2	72	1	16
	24	4	58	2	26
	25	3	40	1	9
	26	2	39	1	12

	27	3	32	1	25
	28	4	78	2	31
	29	2	52	3	42
	30	3	46	1	60
7/24/15	31	2	60	1	20
	32	3	71	2	34
	33	3	82	2	28
	34	3	56	1	42
	35	2	44	2	36
	36	3	64	1	15
	37	4	89	3	39
	38	4	73	2	27
	39	2	41	3	56
	40	3	68	2	38
7/25/15	41	3	75	1	39
	42	3	63	1	42
	43	4	46	2	37
	44	4	69	2	47
	45	3	72	1	16
	46	4	87	2	37
	47	3	58	2	28
	48	3	60	1	16
	49	2	41	2	52
	50	3	59	3	25
		Average: 3.0	Average: 57.5%	Average: 2.5	Average: 28.5%

Chi squared tests were conducted to compare algal biodiversity and z-tests for two population means were used to compare algal coverage within damselfish territories and non-damselfish territories on each beach. We found the differences between algal diversity in damselfish and non-damselfish areas on Playa Mann to be significant ($p \leq .001$). We found the differences between percent coverage in damselfish and non-damselfish areas on Playa Mann to be insignificant ($p = 0.94$). We found the differences between algal diversity in damselfish and non-damselfish areas on La Loberia to be significant ($p \leq .001$). We found the differences between percent coverage in damselfish

and non-damselish areas on La Loberia to be significant ($p \leq .001$). The beaches were also compared to one another with a t-test using the data collected for algal diversity in damsselfish territories on the two beaches. We found the difference to be significant ($p \leq .001$). This p-value is below the 0.05 critical value signifying that these results are highly statistically significant and that there is a significant difference between the number of algal species on La Loberia and Playa Mann. A t-test comparing the percent algal coverage between beaches was conducted. We found our results to be statistically insignificant ($p = .0502$). This p-value signifies that there is no significant difference between algal percent coverage between beaches. This data was processed into two graphs labeled Figure 1 & Figure 2.

Figure 1: The Average Number of Species on La Loberia vs. Playa Mann

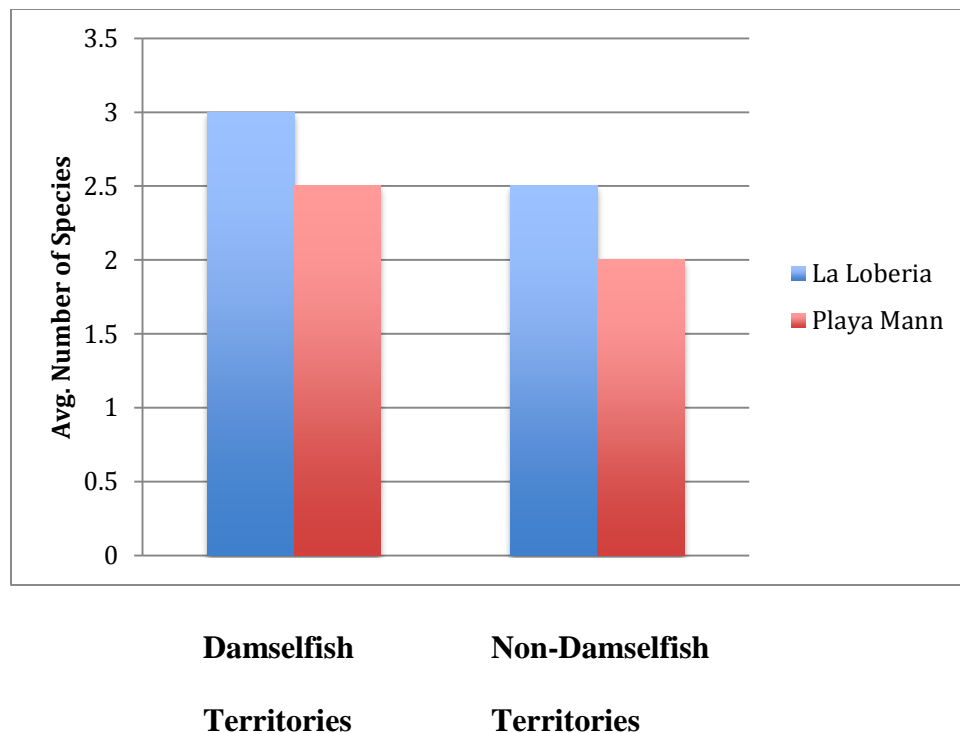
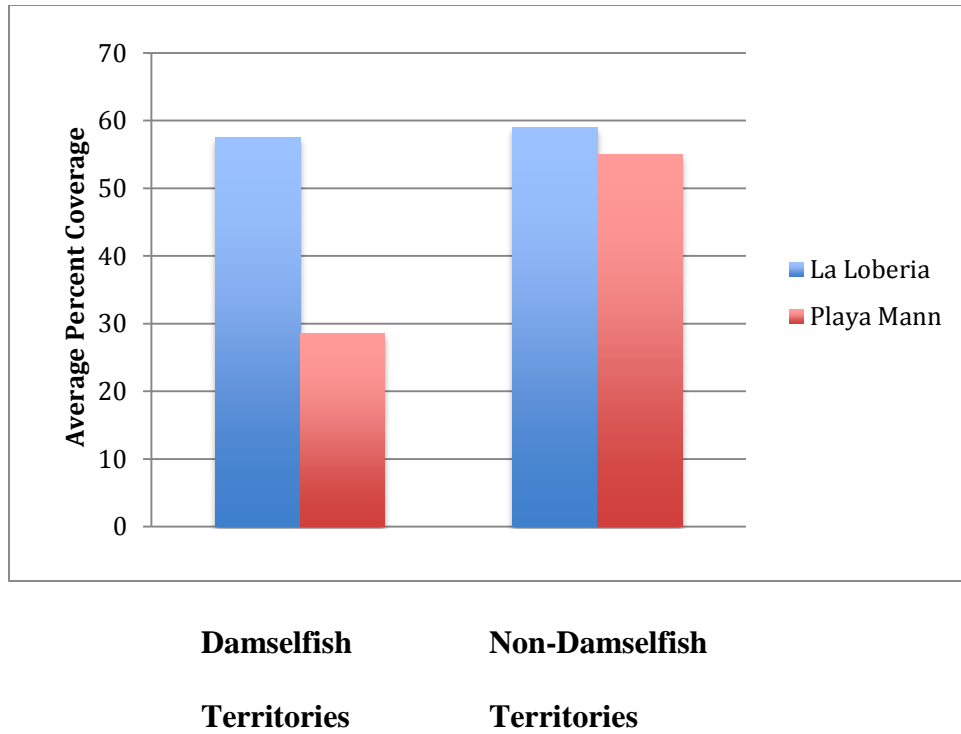


Figure 2: The Average Amount of Algal Coverage on La Loberia vs. Playa Mann



Discussion:

After the data was analyzed from La Loberia and Playa Mann it was determined that there were significant differences between the number of algal species between the two beaches ($p \leq .001$). In addition to that, there was a significant difference in percent algal coverage in Damsel fish territories between the two beaches, favoring La Loberia ($p = 0.0502$). The data also showed that there was no significant difference between the percent algae coverage in Damsel fish territories between beaches.

This allows us to conclude that there is significantly more algae growth and algal biodiversity in Damsel fish territories than in non-Damsel fish areas. It also allows us to conclude that, in addition to Damsel fish territories having greater algal biodiversity

and coverage than non-Damselfish areas, the Damselfish at La Loberia are more successful at farming algae than their counterparts at Playa Mann. On average, at Playa Mann, Damselfish territories had .5 more species of algae than the non-Damselfish areas. There was also an average difference of 4% algal coverage, favoring Damselfish territories. At La Loberia, though, the Damselfish territories averaged .5 more algal species than the non-Damselfish areas, and they averaged 29% greater algal coverage than the non-Damselfish areas.

The differences between Damselfish territories and non-Damselfish areas can be attributed to the fact that Damselfish are territorial and are known as a ‘farming’ species of fish (Irving and Witman 2009). The males will aggressively defend their territories from predators and debris. This behavior has been shown to have a positive effect on algal biodiversity within their territories.

The differences between the two beaches though are more difficult to explain. One hypothesis is that due to the rockier seafloor at Playa Mann there are greater opportunities for sea urchins to grow. Sea urchins are antagonistic to the Damselfish in that they consume algae without creating a space for more algae to grow. Another hypothesis could be that due to the much stronger tidal effect at La Loberia the Damselfish have less difficulty when farming their territories. Both of these hypotheses provide opportunities for more research to be conducted.

In 2014, the research conducted at Playa Mann was conducted from July 12 through July 17. The averages collected from Playa Mann in 2014 are significantly different than the averages of the data collected for this study in 2015. In the 2014 study, the average number of species in Damselfish territories was 2.9 species, where as in 2015

that average was only 2.5 species. The average percent of algal coverage in Damsel fish territories decreased from an average of 65.9 percent in 2014 to an average 59 percent in 2015. In non-Damsel fish territories, the average species of algae increased from 1.6 species in 2014 to 2 species in 2015. The average percent of algal coverage also increased from 2014 to 2015. In 2014, the average percent coverage in non-Damsel fish territories at Playa Mann was 27 percent, compared to a 55 percent average algal coverage in non-Damsel fish territories in 2015. One hypothesis that could explain the significant differences in averages between these two years is the beginning of an El Niño event (NOAA, 2015). If the water is beginning to warm due to an incipient El Niño, this could explain why the biodiversity and percent coverage averages have decreased in the past year. Either certain types of algae are not able to thrive in the warmer water, or possibly the Damsel fish have become less productive as an effect of the El Niño. The results of this study are also consistent with the 2013 study conducted at La Loberia.

If this study were to be conducted again, there are a few variables that could be addressed in order to improve the research. In this particular study, the data collected was collected on July 20 through July 25. On July 22 data was not collected for reasons unrelated to the study. To ensure the most consistent study, it would be ideal to have collected data consecutively over the course of a week. The data collected in this study was collected within 1.5 to 2 hours before/after low tide. If this margin was decreased to ensure that all data was collected as close to the same time relative to low tide as possible, the results could be more precise. Another variable, that would be harder to control, is the number of human beings that are present in the water while data is being collected. When there are more individuals in the water, more sediment is kicked up. The

extra sediment circulating may reduce visibility and may have an impact on the data collections. Ideally, data would be collected when there are few people around to disturb the area. The sea lions that occupy the area can also cause interruptions when collecting data for much the same reason as there being more people there. In addition to that, the sea lions also will patrol their beaches and may perceive a researcher as a threat. This could cause the data collection process to be skewed because some areas of the beach may be inaccessible.

Conclusion:

On both beaches, La Loberia and Playa Mann, damselfish territories showed to have a significantly larger amount of biodiversity and amount of coverage compared to non-damselfish territories. On La Loberia, the algal biodiversity was significantly higher than on Playa Mann. However, there was no significant difference of percent of algal coverage between the two beaches. This supports that damselfish and their 'farming' techniques help support algal biodiversity and amount of coverage. Damselfish are known for their aggressive behavior towards objects in their environments, due to this they protect the algae from predators and debris, which helps the algae prosper.

Previous studies performed during the same month on the same beaches last year and the year before had significantly different data than the study performed this year. A reason for this could be due to the fact that at the time period of the 2015 study, an El Nino event was in action and had been affecting the area for about 7 months. The El Nino could have warmed the waters enough to either impact the algal species or the El Nino could have affected the productivity of the damselfish. This would explain why the 2015 study had different outcomes than the 2014 study.

The hypothesis, that there would be an increase in algal biodiversity within Damselfish territories, was supported by the data collected. The null hypothesis was rejected from the study performed. Due to the fact that damselfish protect their territories from predators and debris, algal species are more productive and healthy.

Certain studies can be performed to further enhance the data already collected. If studies were performed annually during the same month, the data would be useful to compare to previous years to continue to keep track of damselfish and algal health. Also, more data points could be collected each year to show accuracy in the study.

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