4-24-2020

The Feeding Patterns of Sally Lightfoot Crabs in Comparison with the Tides in the Galápagos Islands.

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Emily Olson and Alexandra Radotich 2019

Introduction:

The Galápagos Islands made their biological debut with Charles Darwin and his book *On the Origin of Species*. When Darwin visited the archipelago, he observed both plants and animals and realized that they vary greatly from closely related organisms. This variance was due to evolutionary proliferation of life from island to island (Losos and Ricklefs, 2009). This explains why the animals that Darwin observed reminded him of similar species from the mainland but yet possessed many different adaptations. An example of this was seen in the finches. These birds differed greatly from the mainland and within the archipelago itself. These differences arose from evolution by natural selection as Darwin later wrote in his book.

These realizations lead to his theory of evolution via the biological mechanism of natural selection. This theory was revolutionary. Evolution was not going to be accepted during the 1800's because of the majority views at the time. Judeo/Christian beliefs proposed that the earth was young, and that God created everything perfectly. Since everything was created perfectly, there was no need for evolution. Before Darwin, little was published about any form of evolution. This posed as a great challenge for Darwin and caused him to put off publishing his book until he had as much scientific information backing his theory as possible. In 1859 Darwin published his final draft of *On the Origin of Species.* The topic of evolution was accepted; however, the theory of natural selection was rejected due to missing information on how inheritance works. Gregor Mendel and his famous pea plant study allowed the theory of evolution by natural selection to be more widely accepted because he provided a mechanism that explained inheritance (Dr. Chu 2019 Spring Lecture).

Since the publication and acceptance of Charles Darwin's book, the islands have become a biological research haven. Many biologists have been drawn to the islands to conduct research on the unique species found here. Peter and Rosemary Grant from Princeton University are well known biologists who conducted years of evolutionary research on this archipelago beginning in the 1970's. The Grants studied the finches, made famous by Darwin, on Daphne Major. This evolutionary research is still continuing today. They conducted research on the finches for years and the effects that the surrounding environment had on them. Studies like that of the Grants is not the only incentive for researchers to travel to the archipelago. In 1959, 100 years after the publication of *On the Origin of Species,* research became more focused on the island's ecosystem with the opening of the Charles Darwin Research Center on Santa Cruz island. Years later, after the research center on Santa Cruz, the Universidad San Francisco de Quito established a satellite campus on San Cristobal island which includes a scientific research center of its own. The draw to the islands is not a coincidence, the Galápagos Islands are unique to this world.

The Galápagos Islands are different than any other place in the world due to their small size, boundaries, and the proximity in which the native and endemic species are comfortable with human presence. (Losos and Ricklefs, 2009). Unlike the mainland, these islands are isolated from other land masses and due to that have lower rates of colonization which allows them to evolve based on the events happening on the islands, independent of what happens on other land masses. (Losos and Ricklefs, 2009). With this being said, scientists are able to track and research evolutionary diversification here on the Galápagos islands. Evolutionary diversification can be seen during adaptive radiation which includes proliferation of species from an initial ancestor and the adaptation of species to use different parts of the environment (Losos and Ricklefs, 2009). The archipelago lies just south of the equator and experiences three main ocean currents throughout the year. The Cromwell or Countercurrent brings cold and nutrient filled waters that contribute greatly to the unique marine environment of the Galápagos Islands. The Humboldt current provides an upwelling effect on the archipelago bringing cold water and high amounts of nutrients as well. The final main current that the archipelago experiences brings warm water and is known as the Panama current. These conditions provide the islands with a unique ecosystem. This ecosystem is provided with large amounts of nutrient rich ocean waters allowing marine life to flourish which in turn allows those who depend on the marine life to flourish as well. This allows the archipelago to support large amounts of species on and around the islands.

The Galápagos Islands do not only house endemic species of plants and animals but also are a home to native species as well. Endemic species are species not found anywhere else in the world. Native species are species that survive on the islands naturally but can also be found in other places. The islands have a diverse and rich environment for native crustacea. Even though the environment of the Galápagos Islands includes an abundant crustacea presence, there is very little published about them (Peck, 1993). Some of what has been found is that that there are twenty-eight species of crustacea that are native to the Galápagos Islands and twenty-five that are endemic (Peck, 1993). In comparison to coastal regions all over the Pacific, the Galápagos Islands are lacking in abundance and diversity of crustacea due to the isolation from the mainland. Crustaceans arrived at the islands via long distance oceanic dispersal from the Central American and South American mainland. This resulted in mainly native and endemic species on the archipelago of the Galápagos. (Peck, 1993).

One of the twenty-eight species of crustacea native to the islands is the *Grapsus grapsus* or the Sally lightfoot crab. These crabs are present on every island in the archipelago and can be seen throughout the Pacific and Caribbean as well. The agile Sally lightfoot crab lives on the rocky shores of the islands. These organisms are bright red with a blue belly and lighter colored feet. They are also known omnivores. They eat mainly algae but have been known to eat some small fish and even other Sally lightfoot crabs.

We are interested in the Sally lightfoot crabs' abilities to survive in the unique environment that the Galápagos Islands provide. There is very little published on the Sally lightfoot crab especially the eating patterns that they exhibit. The archipelago receives large amounts of nutrients from the Cromwell, Panama, and Humboldt currents. The nutrients these currents provide is brought to shore by the tides which are controlled by the moon. The islands experience both high and low tide about every six hours (Anonymous, 2019). We hypothesize that the tides do affect the feeding patterns of the Sally lightfoot crabs. If our hypothesis is correct, we predict that the Sally lightfoot crabs will be more likely to feed during low tide due to the larger amounts of rocks being exposed and the large amounts of algae left behind from the previous high tide.

Methods:

Our research was done in Puerto Baquerizo Moreno, San Cristóbal, in the Galápagos Islands between June 12, 2019 and June 22, 2019. We selected four different sites that provide roughly the same environment for the crabs along the shoreline and directly in front of the community malecón. We chose rocky intertidal area one (0°54'8"S 89°36'50"W near the Sunrise coffee hut and coastguard building) and two (0°54'6"S 89° 36'44"W on the patio of Nativo restaurant) for high tide since during low tide the rocks are too far out and difficult see whether or not the crabs are eating. Rocky intertidal area three (0°54’3”S 89°36’42”W right of the Hammerhead pier sign when facing the city) and four (0°54’3”S 89°36’41”W on the left of the Hammerhead pier sign) for low tide due to the increased visibility of the rocks and their close proximity to the pier.

Figure 1: Research site one: 0°54’8”S 89°36’50”W near the Sunrise coffee hut and coastguard building

Figure 2: Research site 2: 0°54’6”S 89° 36’44”W on the patio of Nativo restaurant

Figure 3: Research site 3: 0°54’3”S 89°36’42”W right of the Hammerhead pier sign when facing the city

Figure 4: Research site 4: 0°54’3”S 89°36’41”W on the left of the Hammerhead pier sign)

We separated the Sally lightfoot crabs into three age groups: juveniles, intermediates, and adults. These age groups were determined by coloration. The juveniles were all black while intermediates had red feet and black or darker bodies. Adults stood out with bright red bodies that occasionally had yellow hues, lighter feet and bright blue abdomens. We observed that a crab when eating uses its cheliped and dactyl to bring algae up to its mouth after scraping it off the rock, so we used this movement to determine if a crab was eating or not eating.

Data was collected at low tide and three hours either prior or after low tide (depending on available light). We chose these times to ensure we were collecting data with a big enough time interval between samples. At low tide, we went to rocky intertidal areas three and four and at high tide we went to rocky intertidal areas one and two. Observers picked a section of rocks at each of the rocky intertidal areas and counted the amount of crabs seen of each age group and whether or not they were eating. Twenty minutes were spent observing the crabs at each location and data was compiled in an Excel file. This process was repeated for each of the four rocky intertidal areas. Means, standard deviations, and figures were generated.

Results:

We observed 1,119 crabs in total: 382 adults, 441 intermediates, and 296 juveniles. Out of the 1,119 crabs, 606 of them were eating: 219 adults, 267 intermediates, and 120 juveniles. As depicted in Figure 5, there was a trend of adults and intermediates eating more often throughout the day, as compared to juveniles. The proportion of adults eating was 0.57, intermediates was 0.61, and juveniles was 0.41. There was no significance difference in the proportion of SLC eating and their age group ($x^2 = 0.42$, df = 2, $p > 0.05$).

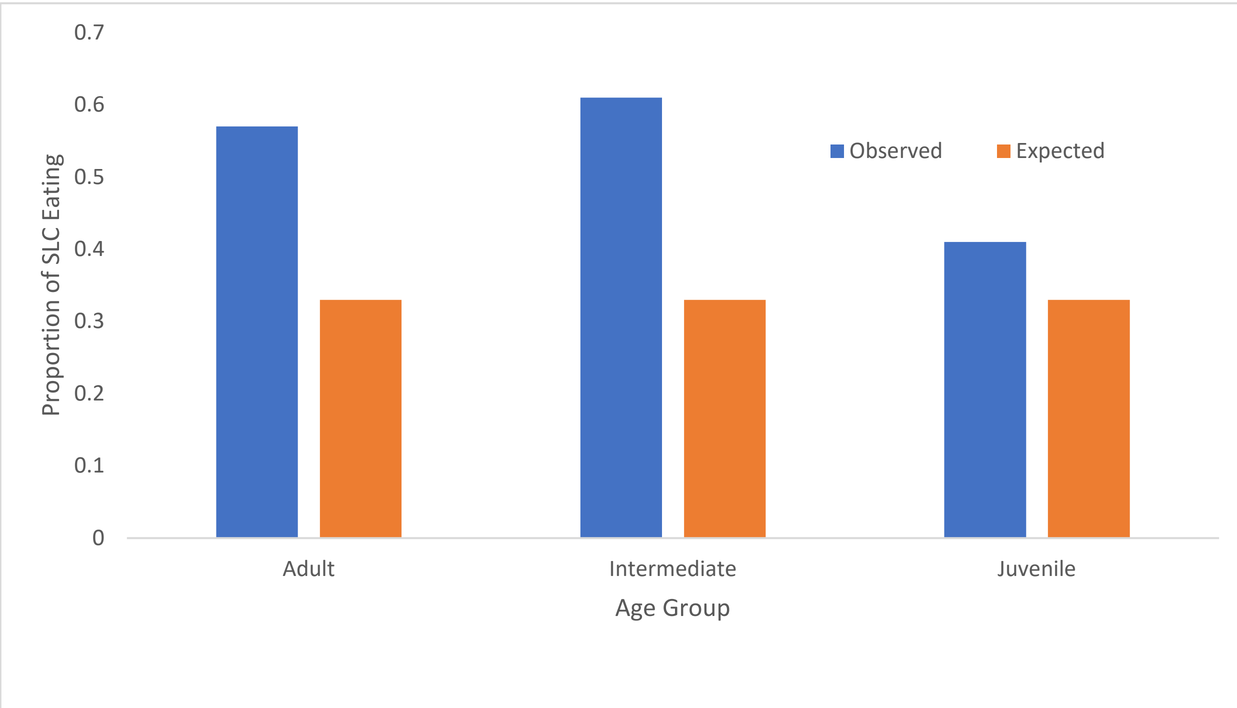

Figure 5. The proportion of SLC eating based on age groups. Puerto Baquerizo Moreno San Cristobal Island, Galápagos Islands $x^2 = 0.42$, df=2, p>0.05

The SLC were more likely to be seen eating during low tide (Figure 6). The proportion of eating during low tide was 0.77 and high tide was 0.37. There was no significant difference in the mean proportion of SLC eating in comparison with the tides ($x^2 = 0.18$, df = 1, $p > 0.05$).

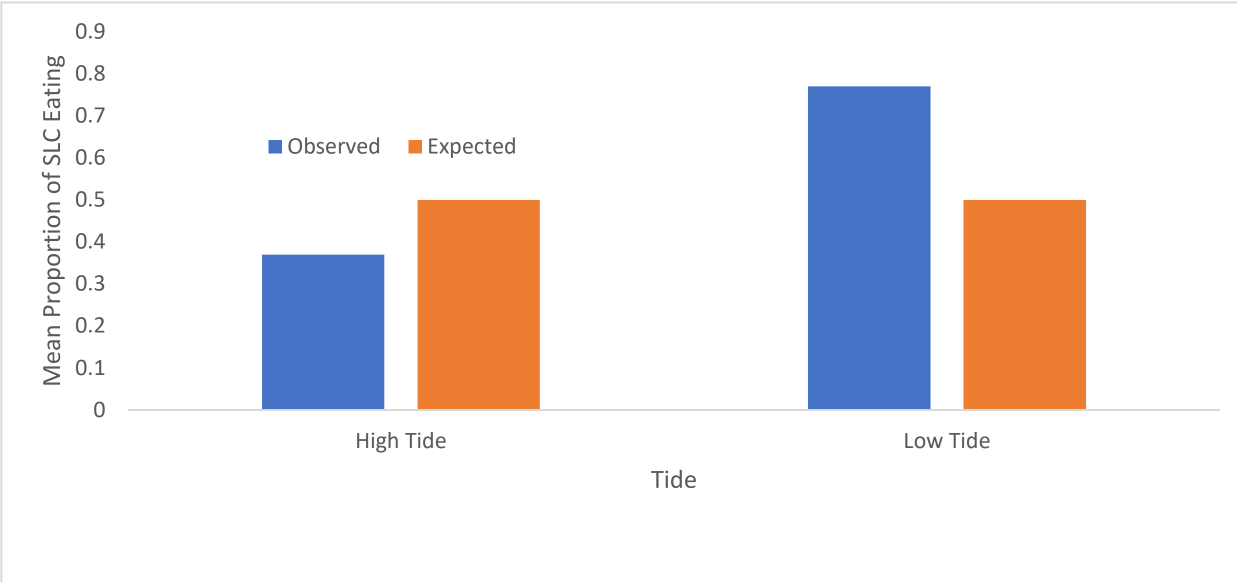

Figure 6. The mean proportion of SLC eating based on different tidal patterns of the day. Data collected in Puerto Baquerizo Moreno San Cristobal Island, Galápagos Islands $x^2 = 0.18$, df=1, p>0.05

The intermediate age group of the SLC ate the most out of any age group during low tide, and juveniles ate the least out of any age group during high tide (Figure 7). The proportion of adults eating during high tide was 0.38 and low tide was 0.81. The proportion of intermediates eating during high tide was 0.45 and low tide was 0.83. The proportion of juveniles eating during high tide was 0.27 and low tide was 0.66. There was no significance difference in the mean proportion of SLC eating and their age group along with the tides ($x^2 = 7.16$, df = 5, $p > 0.05$).

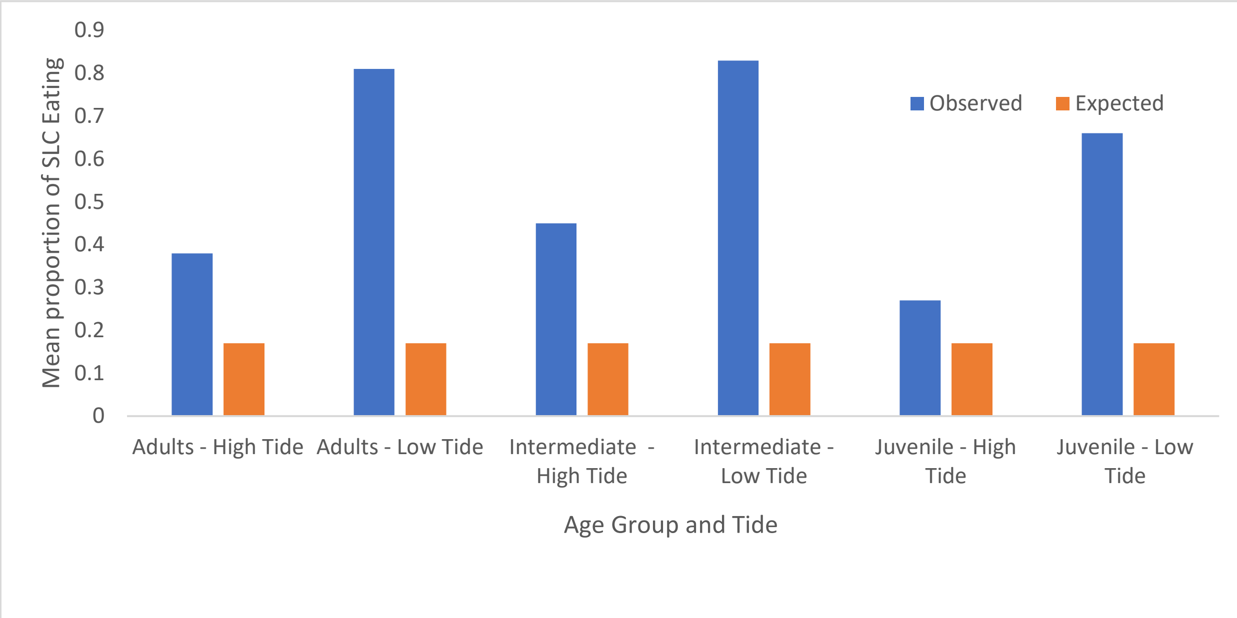

Figure 7. The mean proportion of SLC eating based on age groups and tides. Data collected in Puerto Baquerizo Moreno San Cristobal Island, Galápagos Islands. $x^2 = 7.16$, df=5, p>0.05

Discussion:

Although our results were not statistically significant, there was a general trend shown in our research. The SLC were more likely to be seen eating at low tide compared to high tide. One reason for this could be that during low tide the rocks are covered in fresh and abundant algae that is easiest for the crabs to reach. Low tide also provides an easier path for the crabs to navigate the rocks without being hit by crashing waves.

Another pattern that was observed was the crabs aggression towards each other. The adult crabs seemed to scare off the others, especially the juveniles. It was rarely seen having a juvenile feed next to an adult; they tended to keep distance from one another. If the adults scared the juveniles away from the algae rich areas, it may have caused the juveniles to adjust their eating behaviors which could explain why the observed juvenile eating proportion is not much higher than the expected proportion (figure 5). In another study performed on the feeding preference of herbivorous crabs, the availability of the algae was found to be a determining factor for when they feed and what they are consuming (Kennish and Williams 1997). This would support the SLC eating at times when the algae is abundant and accessible.

Factors that might have influenced our results include weather, the season, and the observers determination of what age group a SLC belonged in. On days where it had just rained or was raining during observations, the SLC tended to be all over and not concentrated in one place. It was noticed that the crabs followed the tide, so if every rock was wet the crabs may have treated it as high tide when it could have possibly been low. Another factor could have been the season.

Since our observations took place at the end of June, it was the beginning of the cold-dry season on the Galápagos Islands. The Humboldt current comes from Peru and South America during the cold season providing nutrient-rich water which benefits the crabs eating. Our observations may have been influenced by the season and the duration of time we researched the SLC. Results indicated from a study on the spatial and temporal diet of crabs showed that crabs were more likely to consume more food during the summer months of May-September for the *Metopograpsus frontalis* and *Perisesarma bidens* species of crabs (Poon et al 2010). With this information it is likely that the SLC also could be consuming more during the time at which we observed them. This could be seen in the higher mean proportion of SLC eating observed than expected (Figures 5-7).

Age determination was another factor that was harder to control. As described in the methods section, observers used color to determine what age category the SLC belonged to. Some of the intermediate crabs were hard to distinguish from adult crabs and vice versa, so for data collection observers may have been categorizing them as intermediates when they should have been adults and possibly adult when they should have been an intermediate. There was not a guarantee way to have consistency of age determination when there were two different observers.

To further our work in the future, more studies can be done on the SLC crab in general, but also including expansion on their feeding behaviors. An extended period of time can be used to study their feeding patterns in relationship to tides but also daylight and specific times of day. Another topic to explore is the SLC feeding patterns based on the presence of predators or other animals within their environment.

This study explored the SLC feeding behavior in relationship to different tidal times. Our results were not statistically significant, but there was a general trend shown that SLC are often found eating during low tide rather than high. A possible reason for this pattern is due to the greater availability of algae during low tide compared to high. A common observation found was that the adult crabs tend to show more aggression than the intermediate and juveniles. Those are the two main findings of our study, yet there is undoubtedly many more behaviors and tendencies of the SLC to be observed and discovered.

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