COMPARISON OF FOOD PREFERENCE AND BEHAVIOR OF TWO WATERSTRIDERS *HALOBATES HAWAIIENSIS* AND *LIMNOGONUS LUCTUOSUS* (HEMIPTERA: GERRIDAE) IN MOOREA, FRENCH POLYNESIA

MELISSA K. RILEY

Environmental Sciences, University of California, Berkeley, California, 94720 USA, mkriley@berkeley.edu

Abstract. While water striders (Hemiptera: Gerridae) have a global distribution different species have adapted to very different habitat types. Freshwater water striders such as *Limnogonus luctuosus* live in areas along streams and rivers with little to no flow. Marine water striders, such as coastal species *Halobates hawaiiensis,* have adapted to life on the surface of the ocean. Since these types of water striders live in such different habitats, and face different environmental factors their food preference and behavior can be quite different. In this study, average density of *L. luctuosus* individuals was measured along the Opunohu River. Also, food preference, behavior, and the effects of increased density were tested in the laboratory for both *L. luctuosus* and *H. hawaiiensis*. Response time and frequency of approach to mobile and immobile prey items were recorded for *H. hawaiiensis* and *L. luctuosus*. *H. hawaiiensis* preferred immobile prey while *L. luctuosus* preferred mobile prey. Frequency of several behaviors (i.e. movements, moving away from others, approached by others, approaching others, attacking, being attacked, jumping, and cleaning) were compared between species, and within species at increasing densities. There were differences between species in the frequency of movements, approaching others, being approached, jumping, and cleaning. Density affected movements, moving away from others, jumping, and cleaning for *H. hawaiiensis.* Density affected movements, moving away from others, and cleaning behaviors for *L. luctuosus*. The different ecology of these two species can be used to explain why differences exist in both food preference and frequency of behaviors.

Keywords. Water striders; Moorea; French Polynesia; Hemiptera, Heteroptera, Gerridae; Halobates hawaiiensis; Limnogonus luctuosus, *food preference, behavior, density*

INTRODUCTION

Water striders (Hemiptera: Gerridae) are widely dispersed in both marine and freshwater environments due to their ability to adapt to different habitats (Cheng 1985, Foster and Treherne 1980). According to Spence and Andersen (1994) there are about 1500 species of gerromorpha that have adapted to life on the surfaces of various bodies of water. Adapting to life on the surface of water allows many advantages for dispersal; however it also comes with many challenges especially concerning movement, reproduction, and the ability to find food (Spence and Andersen 1994). Water striders have learned to cope with these challenges, but can be affected greatly by environmental factors.

One of the main environmental factors that affect water striders is food availability. Both freshwater and marine water striders are scavengers and predators (Foster and Treherne 1980, Spence and Andersen 1994, Cheng 1985) that feed on floating insects.

Usually this consists of terrestrial insects, such as arthropods, which become stuck on the surface of the water (Cheng 1985, Spence and Andersen 1994, Sih and Watters 2005). According to Cheng (1985), *Halobates sp.* that live near the coast are able to feed on terrestrial insects that have been taken out to sea. Water striders feed as individuals as well as in groups by using sucking mouthparts and using their front legs to grasp prey items (Cheng 1985, Spence and Andersen 1994). Although water striders are not very specific in food preference, location and abundance of food items influences their distribution and abundance (Cheng 1985).

Another environmental factor that affects water striders is group dynamics and behavioral types. The number of individuals and the types of individuals within a group of water striders can have an affect on how a single individual responds to their surroundings (Sih and Watters 2005). Sih and Watters (2005) also explain how group composition can affect the aggressiveness of individuals, frequency of mating, activity level, and feeding behavior.

The objectives of this study were: 1) to explore the prey type preference of two water strider species of Moorea, *Halobates hawaiiensis* (Montousier 1864) and *Limnogonus luctuosus* (Usinger). 2) To examine the affect of varying densities of individuals on behavior, and 3) to determine the difference in frequency of behaviors between *H. hawaiiensis* and *L. luctuosus.*

METHODS

Field sites

Each field site (n=4) was visited periodically in order to collect individual water striders of each species, and to conduct field observations. The field sites were located on the island of Moorea in French Polynesia (Fig. 1). Sites 1 and 2 were marine sites while sites 3 and 4 were freshwater sites.

Site 1: The Gump Station Dock- The Gump Station is located on the western side of Cook's Bay. A light was used to attract marine water striders to the dock at night.

Site 2: Cook's Bay- The western edge of Cook's Bay was surveyed for the presence of marine water striders by kayaking about 100 meters from shore, out toward the reef crest.

Site 3: Opunohu River- The mouth of the Opunohu River is located at the base of Opunohu Bay. The study site was located at a mid reach of the river near Marae Tetiiroa. The substrate was predominately fine sediment and small rocks. The bottoms of many pools were also covered in leaves, and debris from the overhanging *Inocarpus* sp. trees.

Site 4: Vaioro River- The Vaioro River is located on the eastern side of the island. A mid-low reach was surveyed for freshwater water striders. The banks of the stream were densely vegetated, and the water was extremely turbid.

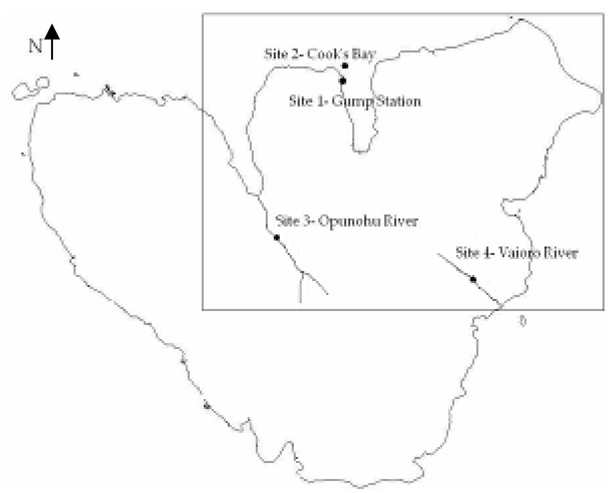

FIGURE 1: Map of Moorea, French Polynesia (17º30'S, 149º50'W). See figure 2 for expanded view of study sites.

Study organisms

H. hawaiiensis (Appendix Fig. 7) is a widely distributed organism which ranges from Hawaii to the Society Islands (Cheng 1985). A typical life cycle from egg to adult lasts around 60 to 70 days (Cheng 1985, Tsoukatou et al. 2001) although little is known about the complete life history of this organism. Individuals are wingless and have a maximum body length of about 6.5 mm according to Cheng (1985 and 1989). Males and females are very similar in body size and shape. Special adaptations include front legs that are able to hold prey, and for males to grab females during mating (Cheng 1985). Also according to Cheng (1985), *Halobates sp.* have developed good eye sight to aide in hunting and predator defense against birds and fish.

L. luctuosus is also widely distributed. *L. luctuosus* is especially wide spread in the southeastern Pacific at varying altitudes and habitats such as lakes, streams, and pools of water (Andersen 1971). *L. luctuosus* has a distinct pattern (Appendix Fig. 6) on its back that is yellow (Andersen 1971). *L. luctuosus* can also be wingless, and it may use ripples as a form of communication and prey location (Cheng 1989, Spence and Anderson 1994, Wilcox 1972). Fish and birds are common predators for water striders in freshwater environments.

Collection

Both species of water strider were collected using aquarium nets at each of the four study sites. Individuals of *L. luctuosus* were transported from the field in dry plastic bags, and placed in a container with a diameter of 36 cm and covered in mesh.

H. hawaiiensis individuals were attracted to the Gump Station dock using a 60 watt lamp that was placed about 1 meter above the water level around sunset (from about 5pm to 12am). Individuals that were attracted to the light were also collected using aquarium nets, and were stored in a 36cm diameter tub covered in mesh. Individuals were also collected by kayaking on the western side of Cook's Bay out toward the reef crest, around sunset. Individuals were collected by paddling into large aggregations of waters striders and using an aquarium net.

Field observations

Group size and location of marine water striders were observed in Cook's Bay.

Average density of water striders along the Opunohu River was estimated by measuring the length and width of fifteen pools along the river. Number of individuals, water depth, temperature, and type of substrate were also recorded.

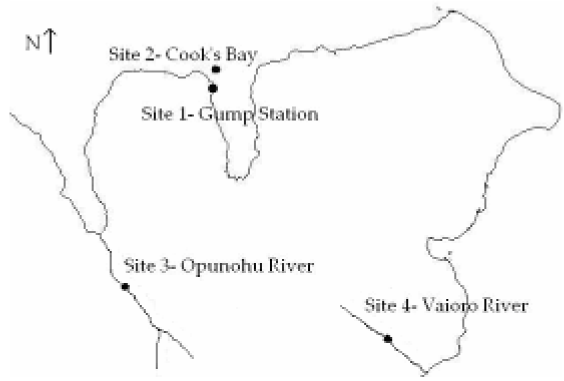

FIGURE 2: Expanded view of study sites on Moorea.

Laboratory experiment- food preference

Individuals were placed in an observation tank (0.33 meters x 0.33 meters), and allowed to acclimate for at least five minutes. After five minutes one mobile and one immobile ant was dropped in the observation tank at equal distances away from the individual being evaluated. The time that it took the individual to approach a prey item, and the number of times individuals approached each prey item were recorded. Twenty-five individuals (males and females) of *L. luctuosus* and twenty individuals (males and females) of *H. hawaiiensis* were evaluated. The experiment was repeated with two immobile prey items. Response time and frequency of approach were recorded.

Laboratory experiment- density and behavior

Individuals were observed and frequency of behaviors was recorded in groups of different sizes for five minutes at a time in the observation tank (0.33 meters x 0.33 meters.) Ten individuals of each species were evaluated individually, in pairs, and in groups of three. Ten individuals of *L. luctuosus* were evaluated in groups of four and five individuals of *Halobates hawaiiensis* were evaluated in groups of four. Behavioral categories included: number of movements, approaching other individuals, being approached by others, moving away from others, attacking others, being attacked by others, jumping, feeding, and cleaning.

Statistical analysis

Food preference observations were evaluated using Chi Squared Test (Ambrose et. al 2002). In addition, behaviors were compared between groups and within groups at varying densities. First the data was checked for normal distributions. If the data did not show a normal distribution, it was log transformed and rechecked for a normal distribution. If the distribution was normal then ANOVA and student's t-test were used in JMP 5.1 (SAS Institute Inc. 2004.) If data were not normal after log transformation Wilcoxon and Tukey-Kramer tests were used in JMP 5.1 (SAS Institute Inc. 2004.

RESULTS

Field observations

Large aggregations (thousands of individuals) of *H. hawaiiensis* were encountered at study Site 4 (Fig. 2) in Cook's Bay. The most common time that individuals were observed was around dusk. However, under windy conditions sightings of large aggregations and single individuals were rare. At Site 3 the light was successful at attracting individuals of *H hawaiiensis.* Individuals were most common around 7pm, and when individuals were observed at the light, there was an average of three individuals per night.

Average surface area of pools along the Opunohu River was 1.67 meters squared. The average number of individuals in each pool surveyed was 4.4. Average density was 3.297 individuals per square meter. Temperatures of pools ranged from 23 degrees Celsius and 25 degrees Celsius. The substrate was primarily small rocks and fine sediments with fallen leaves from overhanging trees.

Laboratory experiment- food preference

The total Chi Squared value between *H. hawaiiensis* and *L. luctuosus* for food prey preference was above the critical value (Ambrose et al., 2002) indicating that there was a difference in prey preference between species. *H. hawaiiensis* tended to approach immobile prey most often (Fig. 3). Only three individuals of *H. hawaiiensis* approached mobile prey first, while eight individuals did not approach prey at all. The average time for *H. hawaiiensis* to approach a prey item was 60.91 seconds (values were only counted if the individual approached a prey item). *L. luctuosus* was more likely to approach mobile prey (Fig. 3) and only two individuals choose not to approach prey. The average response time for *L. luctuosus* was much less at 36.65 seconds. Figure 4 examines the response *H. hawaiiensis* and *L. luctuosus* when both prey items were immobile. Nine individuals of *L. luctuosus* approached prey while only six *H. hawaiiensis* approached the prey. Average response time in this experiment for *H. hawaiiensis* was 10.9 seconds and *L. luctuosus* on average took 98 seconds to approach prey items.

Laboratory experiment:t- density and behavior

Tables 1 and 2 summarize the results of ANOVA and Wilcoxon tests. Table 1 compares the frequency of the eight behaviors between species. *H. hawaiiensis* individuals were approached by others, approached others, jumped and moved more frequently than *L. luctuosus.* However *L. luctuosus* cleaned more frequently than *H. hawaiiensis*. All other behaviors remained the same.

Table 2 explores how the frequency of behaviors changes with increasing densities of individuals in both species of water strider studied. For *L. luctuosus* movements and moving away from others increased infrequency while the amount of cleaning decreased. *H. hawaiiensis* moved away from others, jumped, and cleaned more frequently while all other behaviors remained the same.

The mean frequency of interactions (i.e. approaching others and being approached) and its relationship to increasing densities is illustrated in Figure 4. For *L. luctuosus*, there is a fairly steady increase in the frequency of interactions as density increases (L1-L4). *H. hawaiiensis* also increases frequency of interactions overall (H1-H4), however there is not as clear of a pattern as with *L. luctuosus*.

TABLE 1. Comparison of the frequency of behaviors between *H. hawaiiensis* (Marine) and *L. luctuosus* (Fresh Water). For tests with significant p-values, the species that preformed the behavior most frequently is indicated.

Test	Result	p-value
Frequency of Movements	Marine> Fresh Water	**.0015**
Moving Away from Other	No difference in Frequency	.3194
Approached by Other	Marine> Fresh Water	**.0005**
Approaching Other	Marine>Fresh Water	**.0043**
Attacking Other	No difference in Frequency	.9485
Being Attacked	No difference in Frequency	.7644
Jumping	Marine> Fresh Water	**.0002**
Cleaning	Fresh Water> Marine	**.0250**

Note: Significant values are in bold.

TABLE 2. The frequency of behaviors within species at different densities. Significant values are those with p≥ 0.05, and (+) indicates an increase in frequency of behavior with increased density and (-) indicates a decrease in frequency.

Test (Frequency of) Organism	*L. luctuosus*	*H. hawaiiensis*
Movements	+	n/a
Moving Away from Other	+	+
Approached by Other	No change	No change
Approaching Other	No change	No change
Attacking Other	No change	No change
Being Attacked	No change	No change
Jumping	No change	+
Cleaning	-	+

Note: Significant values (p≤0.05) are highlighted. Frequency of movements for *H. hawaiiensis* were unable to be counted in groups of two, there, and four individuals because they were too frequent.

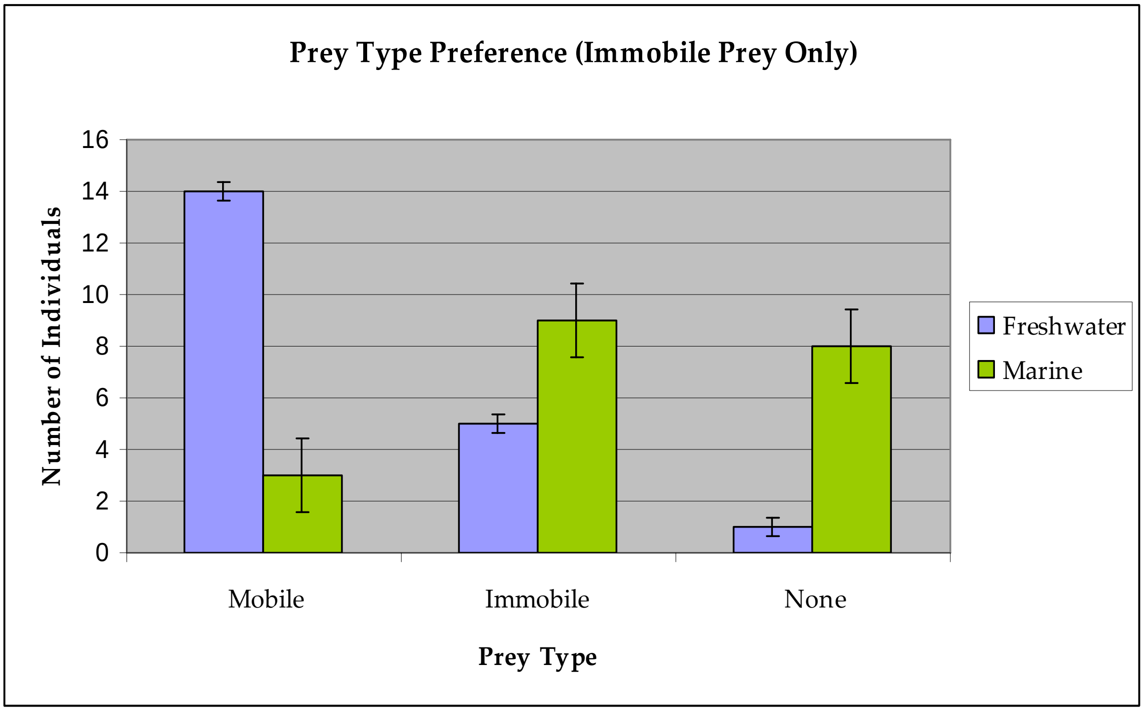

FIGURE 3. Summary of prey type preference experiment for both *H. hawaiiensis* and *L. luctuosus*. Figure includes the number of individuals approaching each prey type (immobile or mobile) and the number of individuals that did not approach prey items after a five minute observation period.

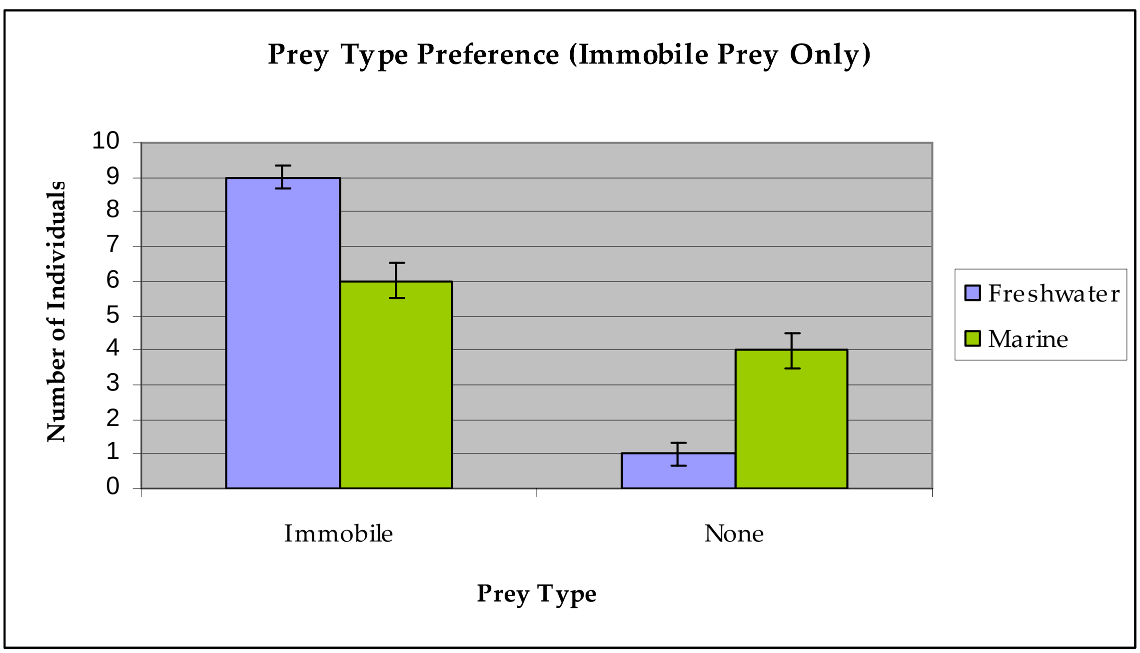

FIGURE 4. Summary of *H. hawaiiensis* and *L. luctuosus* prey type preference experiment using two immobile prey items; includes number of individuals the approached prey and number of individuals that did not approach prey items within a five minute observation period.

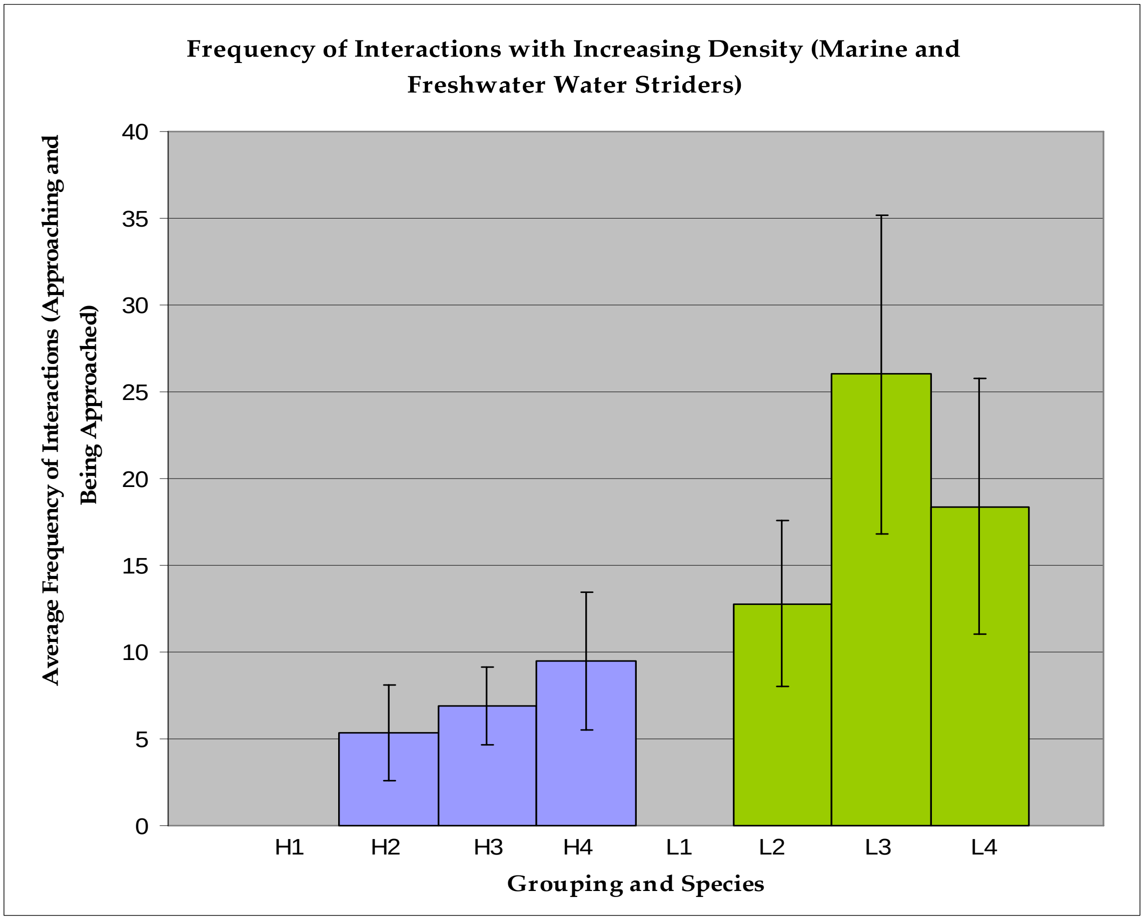

FIGURE 5. Mean Frequency of interactions (approaching others and being approached) with increasing density in two water strider species, *H. hawaiiensis* and *L. luctuosus*. H1 to H4 represent *H. hawaiiensis* alone (H1), in pairs (H2), in groups of three (H3), and in groups of four (H4). L1-L4 represent *L. luctuosus* alone (L1), in pairs (L2), in groups of three (L3), and in groups of four (L4). Error bars represent standard deviations from the mean.

DISCUSSION

The findings of this study indicate that both *H.* hawaiiensis and *L. luctuosus* have a prey type preference. *L. luctuosus* went to mobile prey most often, and had a shorter response time than *H. hawaiiensis* when given the choice between different prey types (Figure 3). When both prey items were immobile, *L. luctuosus* still approached prey items nine times out of ten (Figure 4). Other studies have shown that freshwater gerrids are more partial to prey that is still mobile (Jamieson and Scudder 1977, 1979). There is a relationship between the stillness of water, and prey type preference. Foster and Treherne 1980 explain that "gerrids on still water show a marked preference for moving prey." This could be due to their ability to use ripples on the surface of water as a means of communication.

In contrast, *H. hawaiiensis* approached immobile prey more often (Figure 3). The genus *Halobates* have been shown to be sensitive to prey movements (Foster and Treherne 1980). Even though they will approach moving and non-moving prey items, if prey starts to struggle they will move away quickly (Foster and Treherne 1980, M. Riley unpublished data 2006). In the field, *Halobates sp* were most often found with non-moving prey that had recently died, and was not decomposing (Foster and Treherne 1980). When given the choice of two prey items that were immobile, *H. hawiiensis* approached prey items six times out of ten (Figure 4). While Cheng (1985) found that two other species of *Halobates* (*H. sobrinus* and *H. sericeus*) will approached struggling prey more often than prey that is not struggling, Foster and Treherne (1980) showed that *H. robustus* (a marine water strider from the Galapagos) avoided struggling prey. By approaching only immobile prey, *Halobates* may be avoiding predators (Cheng 1985) by reducing the amount of movement and disturbance on the surface of the water. Other possible explanations could be body size, or availability of food (Foster and Treherne 1980). In rough seas *Halobates* may not have a choice as to what type of prey it encounters, and it may not be able to make the distinction between mobile and immobile prey items (Jamieson and Scudder 1979, Foster and Treherne 1980).

Also, there are some differences in behavior between *H. hawaiiensis* and *L. luctuosus. H. hawaiiensis* are more active than *L. luctuosus*; as a result they approach others and are approached more frequently. *H. hawaiiensis* also jumps more frequently than *L. luctuosus* as a way to avoid others. These differences can be explained by the different habitats that these species live in. *H. hawaiiensis* lives on faster flowing water with more disturbance, while *L. luctuosus* was found in areas with slow moving water or in pools without flow (M. Riley unpublished data 2006). Marine water striders are more commonly found in large aggregations which provide protection against predators (Foster and Treherne 1980, Cheng 1985). In these aggregations they may approach and come into contact with other individuals more often than *L. luctuosus*.

Increased density also has some affect on the frequency of behaviors for both *H. hawaiiensis* and *L. luctuosus.* As density increases, both species become more active, and the mean number of interactions of individuals shows an increase (Figure 5). As density increases from one individual to groups of four, *L. luctuosus* shows a steady increase in its interactions with others. This could be a result of trying to avoid other individuals. It also explains the greater frequency of each species to move away from others. As *H. hawaiiensis* increases in the density of individuals, it shows a rise in the mean frequency of interactions with other individuals, (Fig. 4) but there is not as clear of a pattern as with *L. luctuosus.* Since *H. hawaiiensis* is most often found in larger aggregations, individuals may not be as affected by increasing densities as individuals that are normally found in smaller groups like *L. luctuosus.* However *H. hawaiiensis* may express a need to avoid others by increasing the frequency of behaviors like jumping (Table 2). In addition, cleaning behaviors make an interesting change as density increases. *H. hawaiiensis* increases this behavior with increased density, and *L. luctuosus* decreases this behavior with increased density. *L. luctuosus* may decrease this behavior because it is coming into contact with more individuals, and is disturbed more frequently.

Environmental factors greatly impact water strider species like *H. hawaiiensis* and *L. luctuosus*. Due to their different habitats these two species show a significant difference in both food type preference, and the frequency of behaviors. However, there is still much to learn about water striders and the environmental factors that affect their behaviors and distributions. While frequency of behaviors increase with higher densities of individuals, it would be interesting to look at the composition of individuals that make up these groups. It would also be interesting to study marine water striders more closely, and follow there day to day distributions looking at different factors that may have an influence them like wind speed or currents and water flow. Another area that could be explored is the attraction of marine water striders to light, to see if this attraction relates to navigation or other factors. *H. hawaiiensis* and *L. luctuosus* are both fascinating organisms that still offer much to learn about the behaviors and environmental factors that influence water striders in different areas of the world.

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Appendix

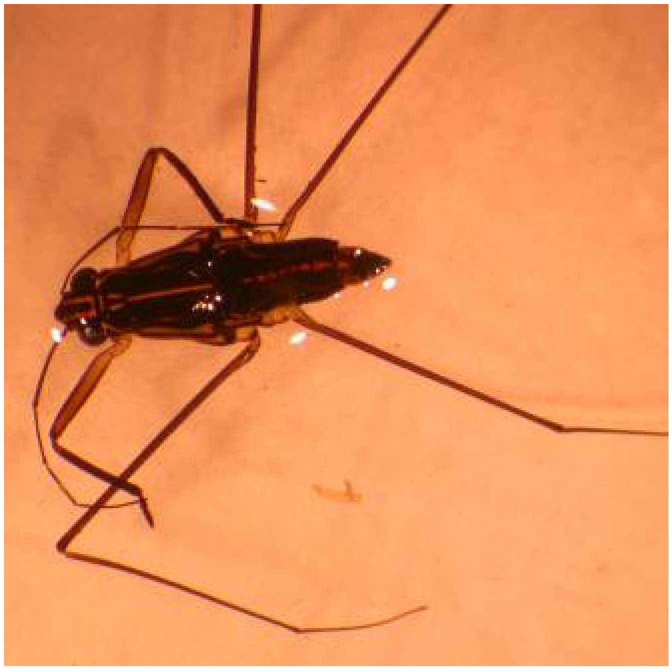
FIGURE 6. Photograph of *L. luctuosus*.


FIGURE 7. Photograph of *H. hawaiiensis*.