Effects of Time, Tide, and Currents on Pacific Great Blue Heron (*Ardea Herodias fannini)* Abundance, Behavior, Prey, and Strike Rates at False Bay, San Juan Island

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Abstract

Pacific Great Blue Herons (*Ardea herodias fannini*) are large, non-migratory wading birds residing on the coast of Washington State, British Columbia, and Alaska. Herons are commonly found near shores of wetlands and tideflats, feeding primarily on small fish. Although pre-existing studies have looked at the individual effects of either tide, time, or current on herons, we aimed to compare the effects across all of these components on abundance, behavior, prey, and strike rate and how they differ in their correlations. We conducted continuous and opportunistic field surveys between August 7 and August 12 at False Bay on San Juan Island and found the abundance of herons was highest while located in the water during mornings and low tide, whereas a smaller group of herons were roosting in the afternoon and at high tides. Additionally, herons in the water spent a majority of the observation period hunting, with attempted and successful strike rates highest at low tides and ebb currents. We found prey size and handling time were directly proportional. Our data showed current impacted the size and type of prey caught. We recommend that future studies extend our methods to a broader range of tides and times of day, as well as to other sites and times of year to attain a more holistic understanding of factors that influence the natural history of herons.

Key Words: Pacific Great Blue Heron, *Ardea herodias fannini,* False Bay, San Juan Island, behavior, strike rate

Introduction

Pacific Great Blue Herons (hereafter referred to as "herons") are a widely distributed subspecies of Great Blue Heron (*Ardea herodias)*. Great Blue Herons are a large wading bird ranging across North and Central America, but the non-migratory Pacific subspecies ranges from Alaska to Washington's Puget Sound region. Unlike the species as a whole, the Pacific subspecies (*A. h. fannini*) is listed as a species of special concern, mainly due to human disturbance and eagle predation (Baudin and Butler 1999). These birds typically feed along shallow tidal flats, estuarine ecosystems, and any type of calm or slow moving water. Herons utilize various hunting strategies within these environments, including standing and waiting for prey or slowly walking through shallow water in an attempt to flush prey before quickly striking (Kushlan 1976). Herons feed mainly on small fish and invertebrates but can also feed on amphibians, small rodents, mammals and birds. They are visual hunters and have specially adapted rods in their eyes making them equipped for hunting in lower visibility (Brown et al. 2021).

Existing literature mainly emphasizes how tide height affects feeding of herons. Literature on how factors other than tide may interact and affect heron ecology is limited. Thus, the objectives of our study were to identify how heron abundance, behavior, prey, and strike rates changed with time of day, tide height, and current direction.

False Bay is a unique intertidal environment located on San Juan Island, Washington. Diurnally or semidiurnally, water in the bay recedes to reveal a vast flat of mud, sand, and shallow water, creating frequent influxes of water and nutrients that influence organism abundance and diversity (Friday Harbor Laboratories).

Methods

Study Site

This study was conducted from August 7 to August 12 in a 0.25 km^2 section of the northwestern region of False Bay Biological Preserve on San Juan Island, Washington. False Bay's uniquely shallow landscape allows for foraging across much of the bay during low tide, which exposes a variety of sub habitats across the mudflat (Figure 1). These include a sandbar with eelgrass, mudflats, sandflats with ulva, and a non-vegetated sandbar. (Friday Harbor Laboratories).

Field Surveys

We conducted continuous 15-minute focal surveys using a Celestron Ultima 80 spotting scope on 60x magnification to collect behavioral data and strike frequencies. This data was manually recorded on the TallyFlex app. The following behaviors were recorded as total durations per 15-minute interval: loafing, preening, hunting, prey handling, and flying. Loafing was defined as anytime herons were inactive, stationary with a neck collapsed close to the body. Preening was defined as feather or body maintenance, identified by ruffling or running their bill along feathers. Herons were categorized as hunting by having vigilant posture, with extended or coiled necks and a slightly downturned bill. Hunting herons were located either in the water or along the shoreline and were slowly walking or standing still. Prey handling consisted of a hunting heron either holding caught prey stationary in its bill or repositioning the prey; time began when the prey was caught and stopped once it was completely swallowed. Flying was measured as either the period when herons were relocating within the observation window, maintaining visibility, or when flying out of visibility, in which case the observation period was ended. Tide height and current direction (flood, ebb, or slack) were recorded for each observation period using NOAA tide and current predictions for Kanaka Bay, San Juan Island. Strike attempts, strike successes, and aggression were recorded as frequencies. Strike attempts were defined as a plunging of the bill into water; strikes either occurred from a coiled, collapsed neck posture, or preceded by an extended neck. Successful strikes were strike attempts resulting in a prey item. Aggression occurred when two or more herons interacted in a manner that included wing flapping, vocalizing, or hopping.

Abundance, prey size, and prey were recorded opportunistically. We recorded total herons present at the time immediately upon our arrival to the study site and any changes to the abundance during the duration of each field outing. Binoculars and night optics, depending on the light availability, were used to scan for herons arriving and leaving the study site. Whenever visible, prey size was measured as a percentage of bill size. Prey type was categorized into four groups when possible– flatfish, gunnel, sculpin, and baitfish. Tide height and current direction were noted for each opportunistic observation.

Analysis

Heron abundance was averaged for every hour of the day when data was collected. This was done separately for herons in the water versus trees. Abundance was averaged for classes of tide height; tide height was grouped by foot ranging from -1 to 7 feet. The same was done for the current direction.

Durations for each behavior were averaged and converted to percentage of total duration observed for 3 categories of time of day. Morning was defined as 0500-1000, afternoon was defined as 1000-1600, and evening was defined as 1600-2100. This was repeated for 3 categories of tide height: low tide was defined as -0.5 to 2 feet, medium tide was defined as 2 to 5.5 feet, and high tide was defined as 5.5 to 7 feet. This was repeated again with 3 categories of current direction: flood, ebb, and slack. We made the categories for both time of day and tide by equally dividing the full range by 3. The percentages of time spent in each behavioral category were also calculated for the total observed duration across the entire study. All of the above was done separately for herons in the water versus herons roosting in trees, as only herons in the water had the opportunity to hunt and strike.

Prey size relative to bill was converted to percentage bill size. This was then compared against current directions of flood, slack, and ebb. Prey type was separated into four categories of prey observed throughout the study. These included sculpin, gunnel, flatfish, and baitfish.

Average strike rates per minute and average successful strikes per minute were calculated for each hour of the day when hunting was observed. Average strike success was calculated as a percentage of total attempts for each hour. This was repeated for tide height and current direction with the same categories outlined above.

Aggression was not analyzed as we did not collect enough data points to assess its relation to heron activity.

Results

Abundance

Total heron abundance at the study site ranged from 0 to 11 birds between the hours of 0400 and 2000, with the average total heron abundance per hour ranging from zero to eight. Herons arrived in the water at dawn between the hours of 0400 and 0500. Abundance of herons in water was greatest at 0700 with an average of 8 total birds (Figure 2a). Abundance of birds in the water after these hours varieds and was comparatively low. Average roosting heron abundance was the earliest and highest at 1100 with a count of 4 birds; however, the majority of roosting herons were present between the hours of 1500 to 2000. Abundance also varied with tide height; it was highest between -1 to 2 feet with averages of 5-7 herons (Figure 2b).

Behavior

Overall, herons in the water were either hunting, preening, or loafing 97% of time observed. The remaining 3% included flying and prey handling (Figure 3a). In the water, herons were observed hunting 78% of the time, loafing 10% of the time, and preening 8% of the time. Average percent time spent hunting between the morning, afternoon, and evening ranged from 70-84%, peaking in the morning. Herons spent the highest percent time preening in the morning; average percent time ranged from 2-8%. Herons in water spent the highest percent time loafing in the afternoon; average percent time ranged from 7-28% (Figure 3b).

Overall, roosting herons spent 57% of their time preening and 43% of their time loafing (Figure 3c). In the afternoon, roosting herons spent 81% of their time preening the rest of the time loafing. In the evening, roosting herons spent 66% of the time loafing and were preening the remainder of the time (Figure 3d). No roosting was observed in the morning.

Herons in the water spent the most time hunting at low tide, compared to no time hunting at high tide. During low tides, herons were observed hunting 83% of the time, 8% of the time was spent preening, and 5% loafing (Figure 3e). The remaining 4% of the time was spent flying or handling prey. At medium tides, herons spent 57% of their time hunting, 12% of preening, and 31% loafing. At high tide, no herons were observed hunting as all herons observed were roosting in trees. While roosting at medium tides, herons in trees spent 71% of their time preening and 29% loafing. At high tide, herons in trees loafed 53% of the time observed and preened for 47% (Figure 3f).

Herons in the water did not show a preference for current direction. At ebb tides, herons hunted for 98% of the time and spent the other 2% preening or loafing (Figure 3g). At slack tides, herons hunted 99% of the time spent in the water and preened and loafed for the remainder. During flood tides, herons spent the least amount of time hunting out of the three at 71%. Loafing and preening took up more time than at ebb and slack. Loafing occupied 13% of the time and preening was 11%. Flood tides often correlated with later times of day when herons were roosting in trees, which could be the reason for less hunting at flood tides.

Prey

When comparing the size of prey against handling time, size ranged from 20% to 150% of bill length. The longest time spent handling was 7 minutes and 35 seconds on a prey item 150% of the bill size (Figure 4a). The smallest prey had a comparatively short handling time, ranging from 9 to 20 seconds. The shortest handling time recorded was 1 second for a prey item 33% of the bill size. We observed birds handling prey in two different ways–repositioning a catch in the bill or holding the prey still. We observed herons that remained stationary while handling prey and herons that relocated after the catch.

Prey size and type was also examined in relation to current direction. In flood currents, the average size of the catch was 64% of the bill size, 46% in slack, and 20% in ebb (Figure 4b). Prey type also varied with current. In flood currents, sculpin were caught five times, gunnel twice, flat fish twice, and no baitfish were caught. In ebb currents, baitfish were the only prey observed. Sculpin was caught the most frequently across total observations.

Strike Rates

Average strike attempt and strike success rates were calculated for each hour of the day when hunting was observed. The average strike rates were highly variable when compared with time of day, with attempts ranging from 0.1 to 1.5 per minute and successes ranging from 0 to 0.5 per minute. The frequency of strike attempts was greatest in the early morning during hour 0500 (Figure 5a). Both strike attempts and strike successes declined at 0700 and were relatively low as time continued. Percent strike success was also highly variable through time; however, without a trend. Success ranged from 0-100%, with the highest average percent success during hour 0900.

Average strikes attempts per minute and successful strikes per minute of hunting herons were compared against tide class. We found strike attempts to be highest at low tide, with an average 1.15 attempts per minute, 0.24 attempts per minute at medium tides, and 0.23 attempts per minute at high tides (Figure 5b). Attempted strikes at low tide occurred 4.80 times more than at high tide. When comparing successful strikes against tide, success was highest at low tides with 0.50 success per minute, 0.11 successes per minute at medium tides, and 0.03 successes per minute at high tides. Successful strikes occurred 16.67 times more at low tide than high tide. The overall trend shows attempted strike rates decreasing with an increase in tidal height. The percentage of successful strikes does not show a trend from low to high tide.

Average strike and strike successes per minute while hunting were calculated in relation to tidal current directions. At ebb currents, herons were striking the most with 3.15 attempts per minute, 1.05 attempts per minute on slack, and 0.25 attempts per minute on flood (Figure 5c). Following the same trend, success occurred on ebb currents at 1.35 successes per minute, 0.32 successes per minute on slack, and 0.10 successful strikes per minute on flood. The percent success was highest on ebb at 43%, 31% on success on slack, and 39% on flood.

Discussion

Abundance

We found abundance correlated with time of day and tidal height; earlier in the day, herons aggregated in larger groups. The increase in herons roosting at high tides could be attributed to the coupling of high tides and later times of day across our observation period. High tide rather than time of day could be the indicator for herons to roost as available hunting grounds are limited by the height of the water, making low tide and the morning during our study period a more advantageous time to be in the water hunting. Later in the day, we observed far fewer herons which was conducive with a previous study by Clark et al. 2021 that found no hunters after morning. We did not include abundance versus current direction in our results because we failed to discern between herons that were in the water versus roosting in trees for this category; however, Rillera et al. (2014) found abundance was lower during flood tides.

Behavior

We found both tide and time of day influenced the behavior of herons at False Bay, while current direction was negligent. Specifically, herons strongly prefer to hunt in the mornings Although Figure 3b shows herons spend a large majority of their time hunting at all times of day, it is important to note there were fewer data points (n = 8) for herons in the water in the afternoon and evening, as they were usually roosting in trees at this time. Therefore, Figure 3b shows herons spent comparable amounts of time hunting in the morning and the evening; however, our sample size of herons in the water during the evening was only 2. Due to the brevity of our study, we were not able to collect data at a low tide past 1100 and can therefore not distinguish between a preference for a low tide versus early morning. When looking at their behavior overall, we found herons in the water spend the vast majority of their time hunting (78%), which is comparable to Clark et al.'s (2021) finding of an average of 83% of time standing or slowly walking, matching our definition of hunting.

By virtue of their hunting strategies, herons are limited to foraging in waters equal to or shallower than depth of their legs. We theorize lower tides provide access to more profitable feeding grounds. We observed herons hunting in the mouth of the bay with the most frequency, this habitat is characterized by a sandbar and eelgrass (Friday Harbor Laboratories). This site is also exposed to the most wave and current action which we hypothesize increases the abundance of marine nutrients being delivered by the proximal Haro Strait. Eelgrass beds provide habitat for small invertebrates and aquatic larvae (Munsch et al. 2021), the main prey sources for sculpin, caught by observed herons. Since these eelgrass beds are further from the shoreline at False Bay, they are only accessible as feeding grounds at low tides.

We also recorded frequencies of aggression opportunistically and noticed a correlation between higher abundance and density with aggression; however, we did not collect enough data points to perform a sufficient analysis on its relationship to time, tide, or current direction.

Prey

Prey size and handling time show a positive correlation. When herons were observed to be moving prey in their bill during the handling period, this may serve to reposition catches and allow them to pass into the mouth. As for herons that spent the handling period with prey stationary in their bills, existing literature provided little information. We hypothesize this may be to allow the heron to exhaust the energy of prey until dead, making it easier to swallow.

It is important to note that this data is biased towards prey that was large enough to be visible through the spotting scope, as well towards situations in which the focal heron was facing towards us. We had a large number of data points of zero handling time whose prey size was not visible because it was swallowed immediately.

Average prey size was highest in flood currents and smallest in ebb. This pattern could be attributed to the movement of fish in the current direction. Length and size of fish is directly correlated to depth of habitat; therefore an incoming tide, when the water is increasingly deeper, yields higher catch rates of larger fish (Gibson 1973). In an ebb current, baitfish were caught with higher frequency; the outgoing tide creates shallow habitat and is more populated by an abundance of smaller prey items that are not at high risk of being stranded with the receding tide. This may also explain the increase in strike rates on ebb currents. Smaller catch size results in decreased handling time and subsequently more time for hunting. Additionally, smaller baitfish travel in schools, so an increased density of prey in the water could explain the increased strike and strike success rates we observed. It is important to note prey caught was not always visible through the spotting scope. We were only able to collect limited data points for prey size and category, weakening the strength of our analysis.

Strike Rates

Although herons hunting in the early morning had lower percent strike successes, they had the highest gross frequencies of successful and attempted strikes. Thus, although more energy is spent striking, more energy is obtained, suggesting hunting in the morning is the most energetically beneficial. The increased strike rates cannot be attributed to lower competition for resources as early morning and low tide were also when the most herons were observed. Instead, increased success rates may be attributed to both higher availability of prey and hunting grounds.

False Bay's unique topography allows for foraging across much of the bay during low tide due to how shallow it is throughout. We were also not able to observe herons at all hours of the day at a variation of tides; this may explain why we see such high success at 0900 as there are only two data points for that hour (Figure 5a).

Tide height and strike rate show an inversely proportional relationship. However, Clark et al. (2021) found tide height did not affect strike rates or successes, and Rillera et al. (2014) found 10% more successes in tides 1-4 ft than -2 to 1 ft. The increased strike attempt and strike success rates at low tides may be attributed to an expansion of accessible hunting habitat at these tides.

We found herons had far more strike attempts and percent successes at ebb currents compared to slack and flood currents. Clark et al. (2021) also found herons struck more during ebb tide; however, Rillera et al. (2014) and Clark et al. (2021) both found higher success rates during flood tides rather than ebb tides. At ebb currents, herons were seen capturing smaller baitfish compared to their larger prey of sculpin, gunnel, and flatfish caught during other currents. Current direction may play a role in prey type available and could be the reason for increased strike rates. Herons hunting during ebb tides are likely expending more energy as they are striking far more frequently; however, they are also more successful in this current direction, making this energy investment worthwhile.

Conclusion

In False Bay, we found herons spend the vast majority of their time hunting while in the water. Tide and time of day were paired for the duration of our study, making it difficult to distinguish between their individual effects; however, we are able to conclude herons show a preference for both or either early morning and low tide when hunting. We also found that herons are more successful in hunting during ebb currents. As the time of day got later and tide height got higher, heron abundance in the water decreased and herons spent the majority of their time roosting. We also documented tradeoffs with time spent hunting and time spent handling prey of various sizes as well as between strike attempts and strike success.

Future Research

We propose this study be repeated with some key changes. Most importantly, data should be collected over a longer period of time covering the full range of tide heights and times of day. We also recommend abundance data be collected for a more complete range of hours and at set intervals, as well as to include more information on prey caught. More data on abundance and density of heron foraging clusters may be correlated with aggressive behavior as well as strike success. Time in between the 15 minute behavioral surveys should also be standardized.

Furthermore, this study may be replicated at other sites in order to examine whether or not the unique ecological characteristics of False Bay influence heron abundance, behavior, prey, and strike rates. Prey surveys at each site may also reveal a correlation between gradients of prey and tidal preferences for hunting, as tide height is a proxy for distance from the shore. This study may also be repeated at different times of the year in order to determine seasonal variations in behavior, prey, and strike success and find potential correlations with energetically demanding activities such as reproduction.

Anthropogenic activities are creating new challenges for species and the ecosystems that they inhabit. Understanding how this species interacts with different abiotic factors of its environment helps to better predict how this species of special concern will respond to potential ecological changes and therefore implement effective management strategies.

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Figures

Figure 1: Map of False Bay highlighting where herons hunted/fed and roosted with the observed most frequency. (n = 52)

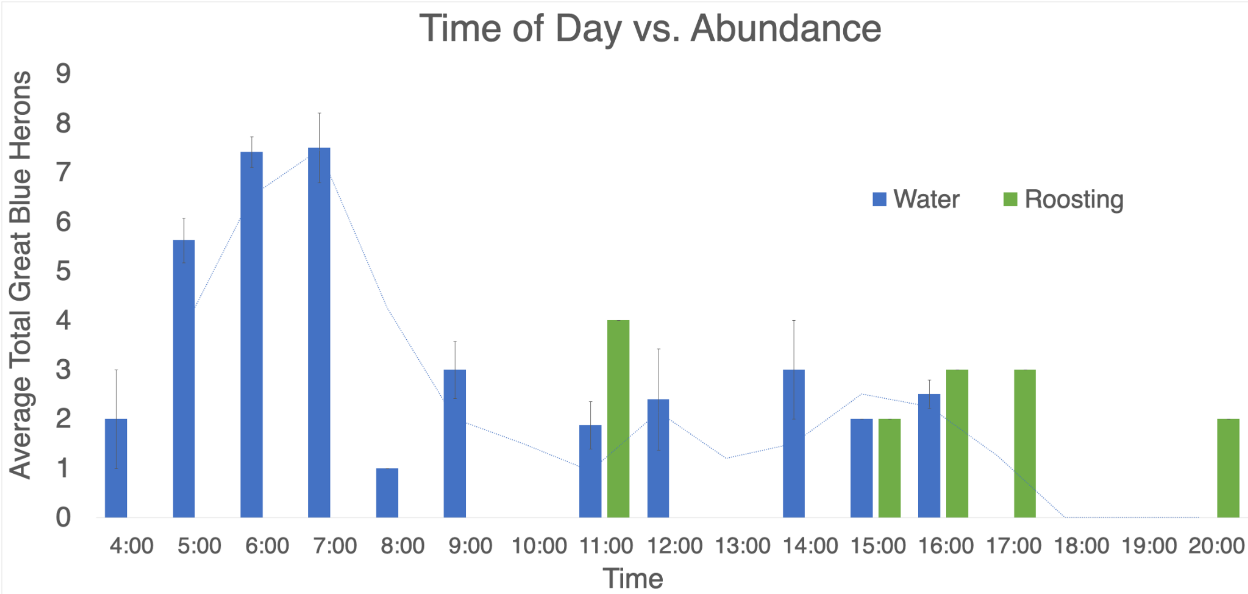

Figure 2a: Average ± SD abundance of herons in water or roosting across observed hours with moving average line. (n = 80)

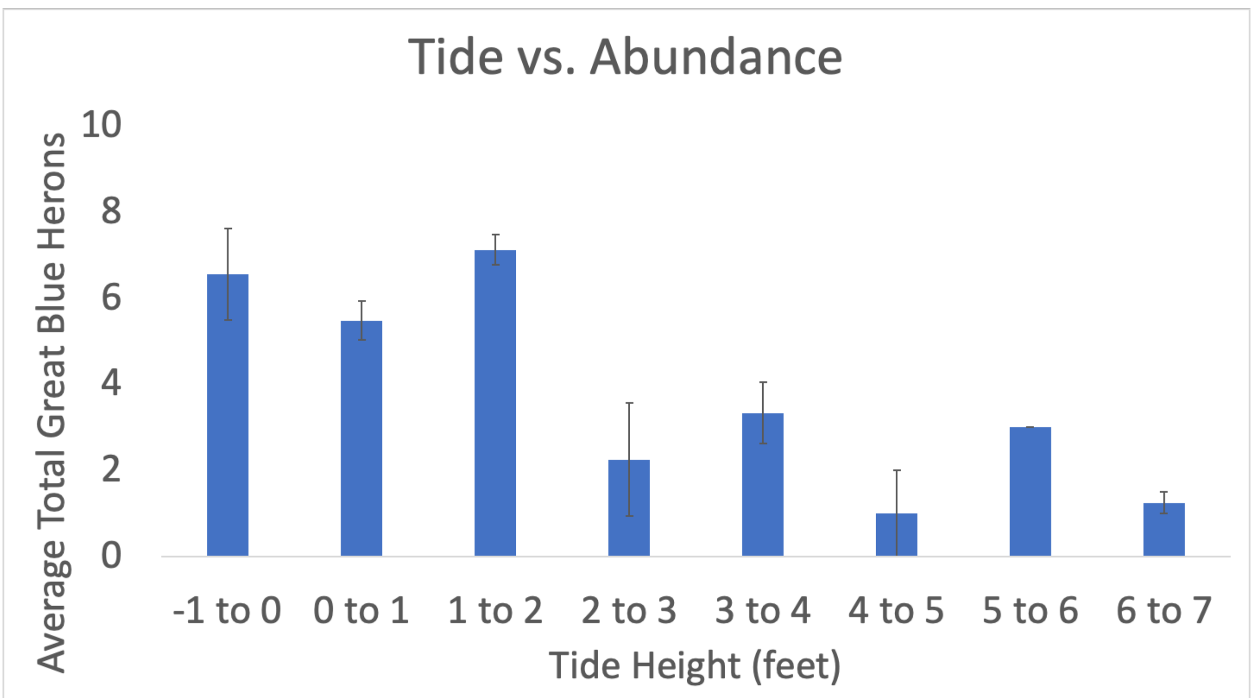

Figure 2b: Average ± SD abundance of herons in water at varying tide heights. (n = 67)

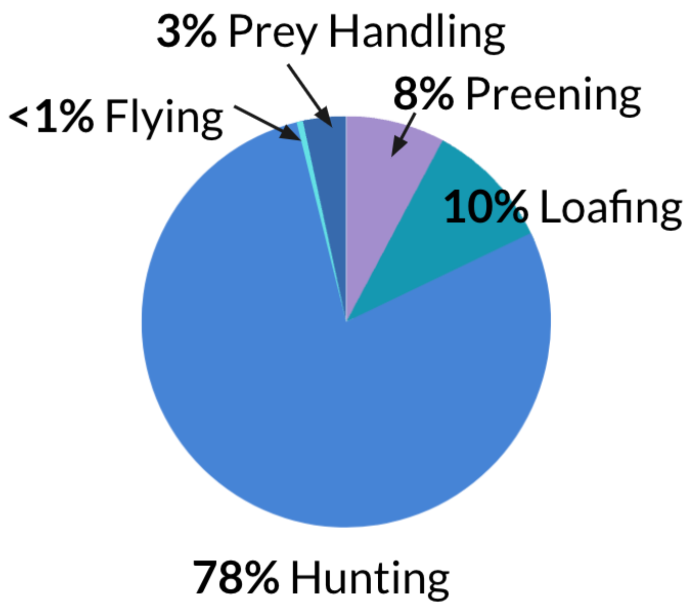

Figure 3a: Average percent behavior across observation periods of herons in water. (n = 38)

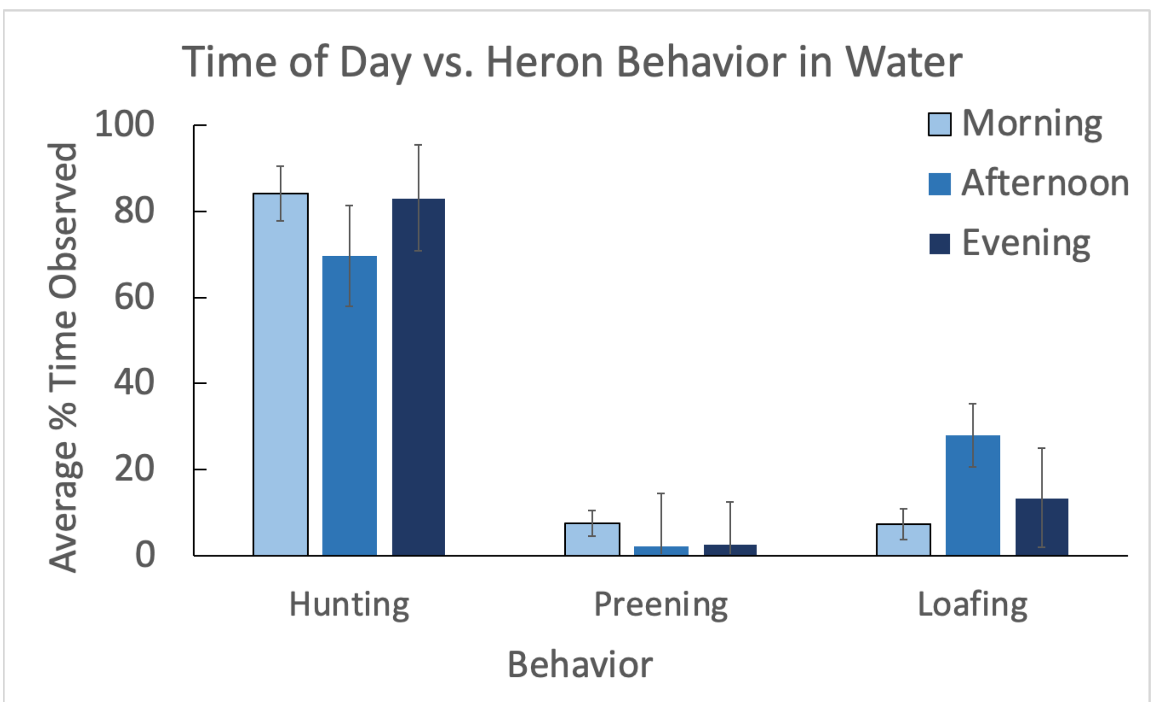

Figure 3b: Average ± SD percent time observed behavior of herons in water at different times of day. (n = 38)

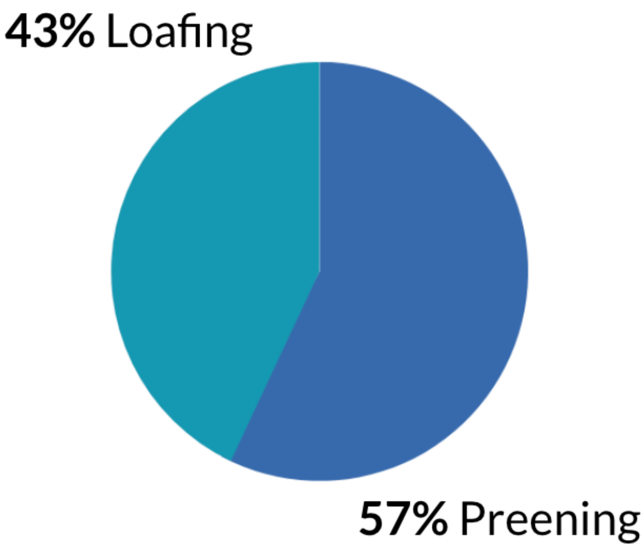

Figure 3c: Average percent behavior across observation periods of herons in trees. (n = 14)

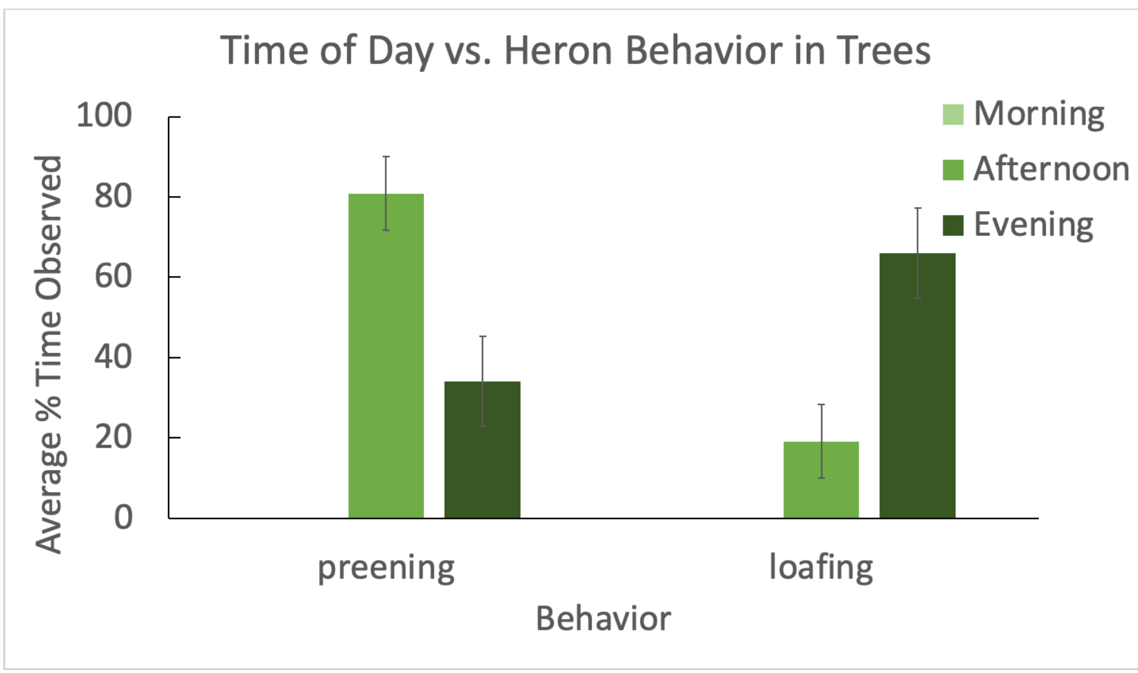

Figure 3d: Average ± SD percent time observed behavior of herons in trees at different times of day. (n = 14)

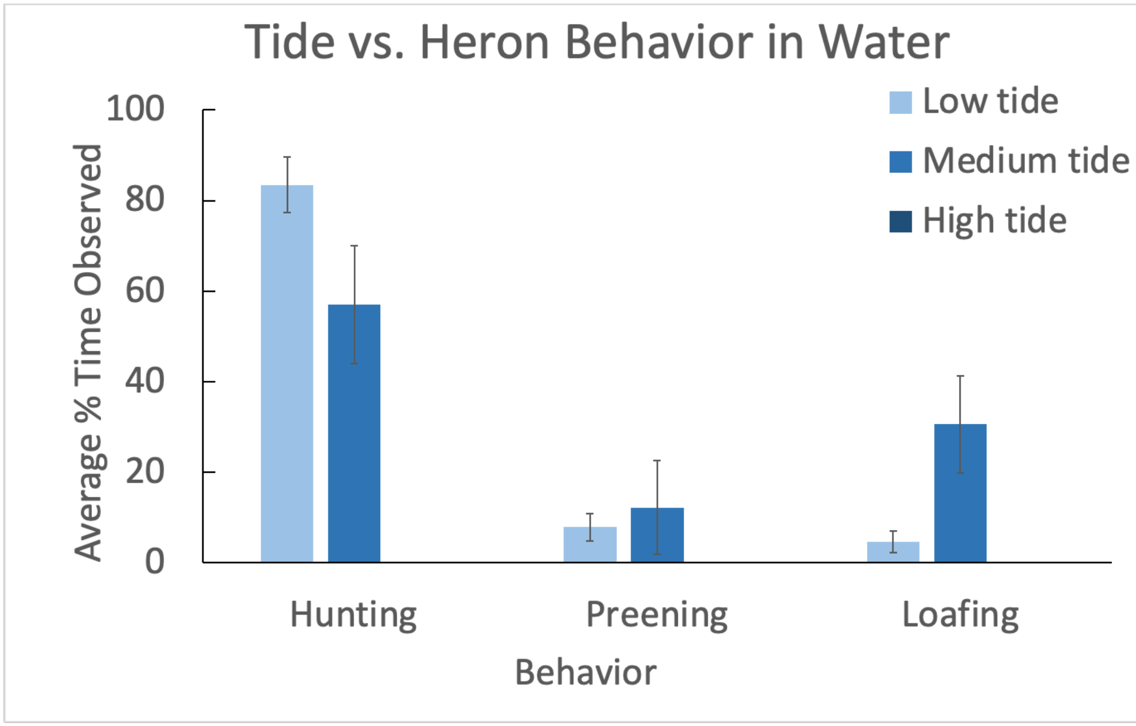

Figure 3e: Average ± SD percent time observed behavior of herons in water at different tidal zones. (n = 38)

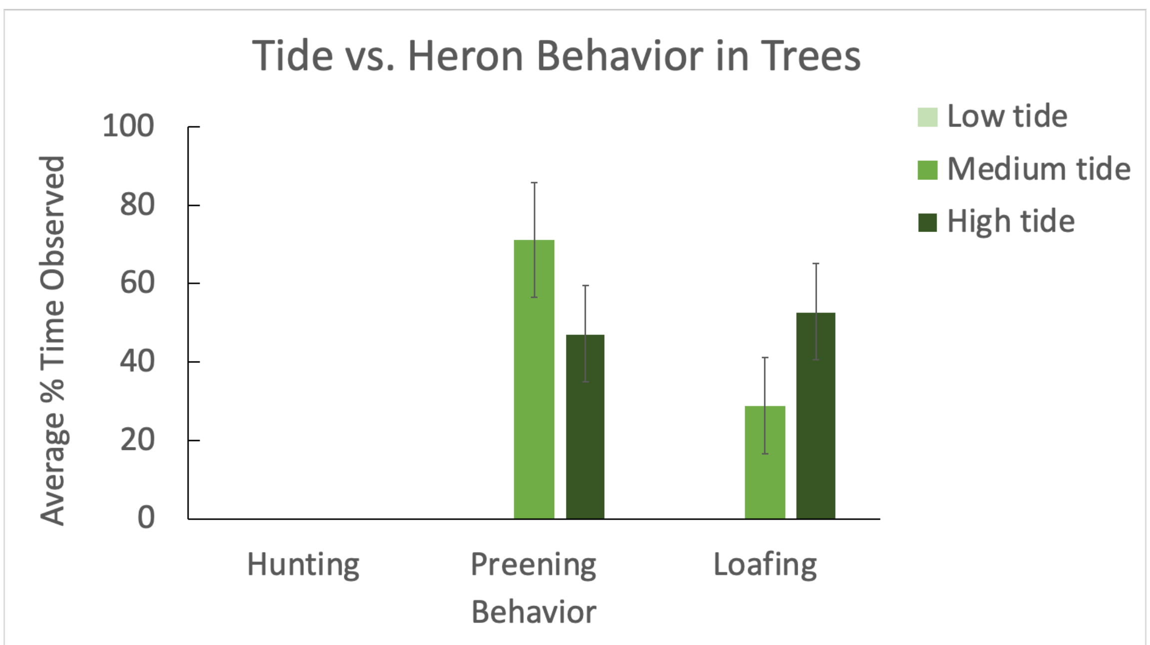

Figure 3f: Average ± SD percent time observed behavior of herons in trees at different tidal zones. (n = 14)

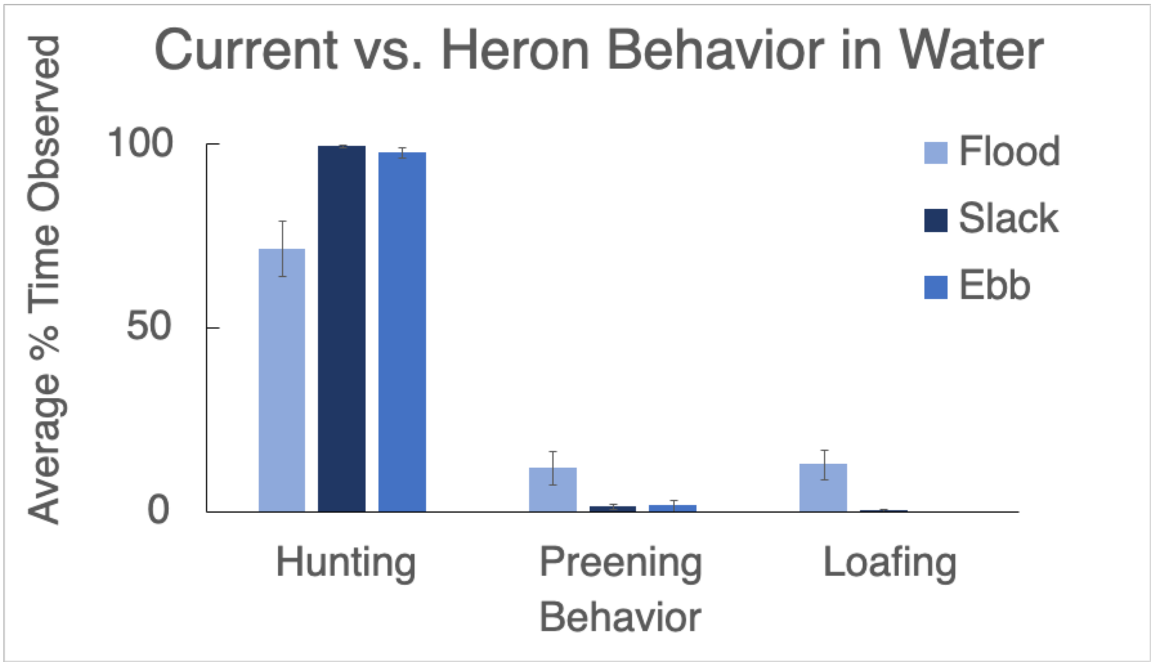

Figure 3g: Average ± SD percent time observed behavior of herons in water at different current directions. (n = 38)

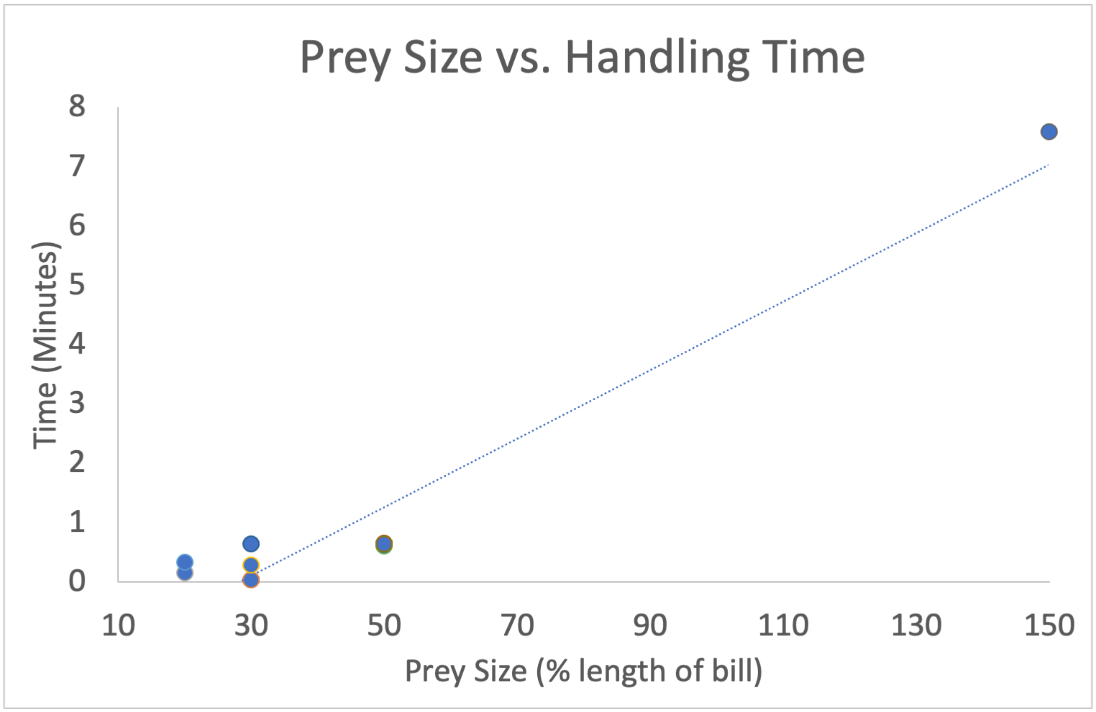

Figure 4a: Prey size relative to bill length at time spent handling with line of best fit. (n = 10)

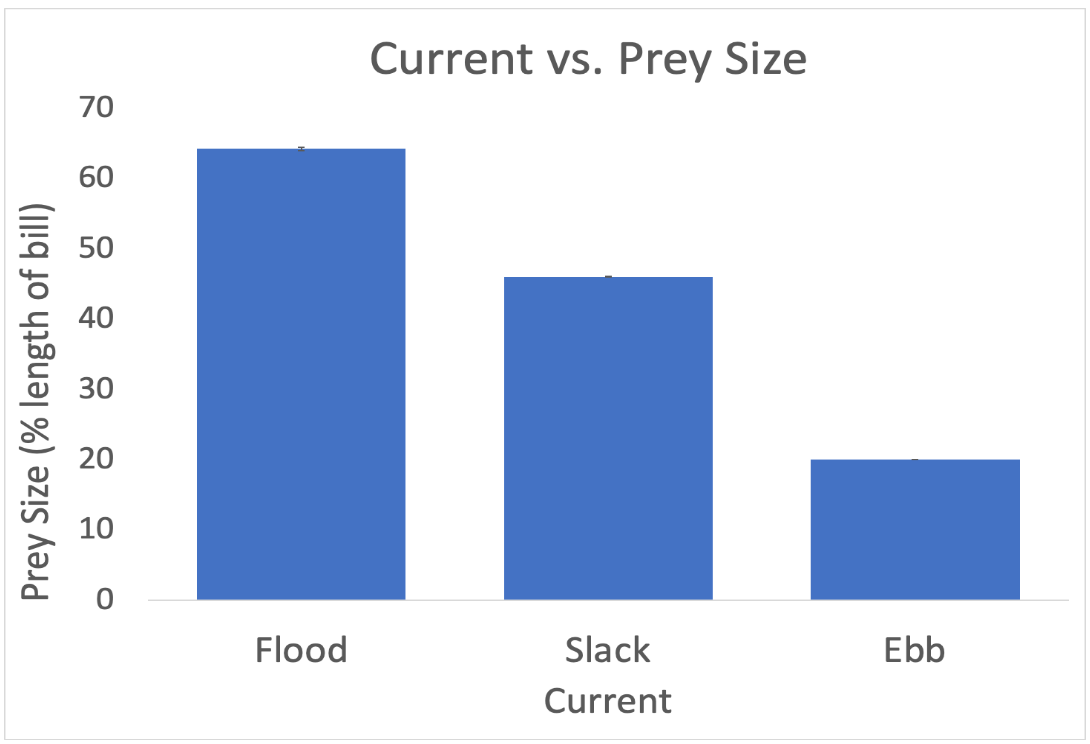

Figure 4b: Average ± SD prey size at different current directions. (n = 10)

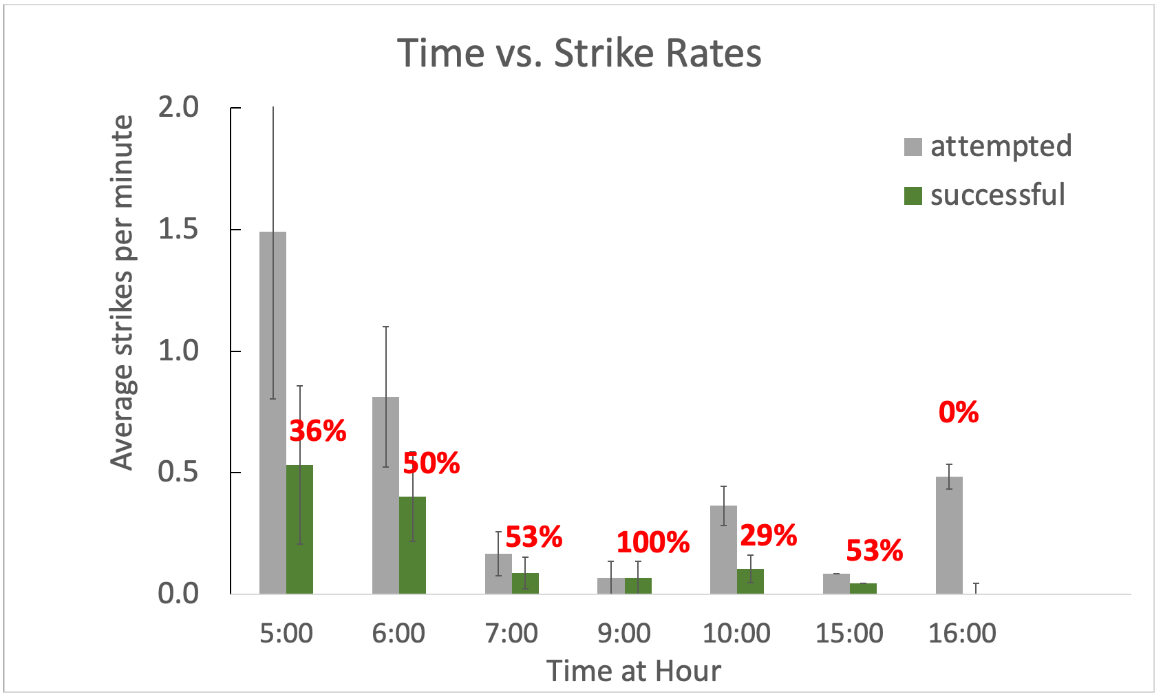

Figure 5a: Average strikes per minute at varying times of day. Percent success rate is displayed above bars showing successful strikes per minute. (n = 35)

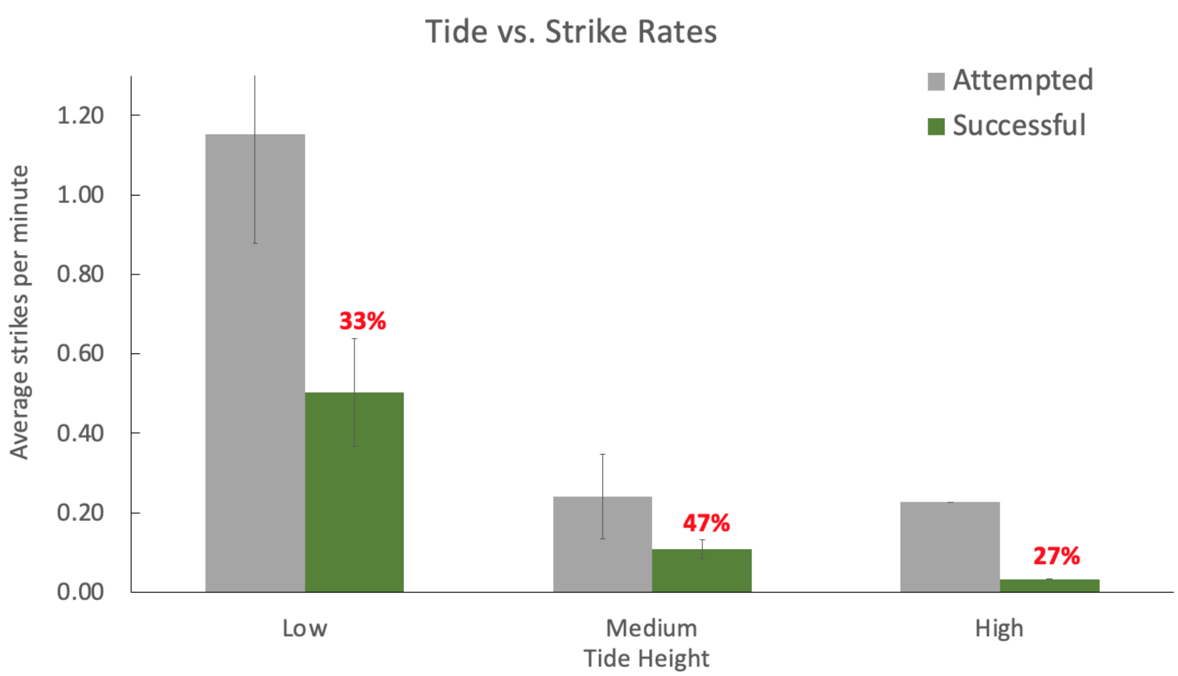

Figure 5b: Average strikes per minute at varying tidal heights. Percent success rate is displayed above bars showing successful strikes per minute. (n = 35)

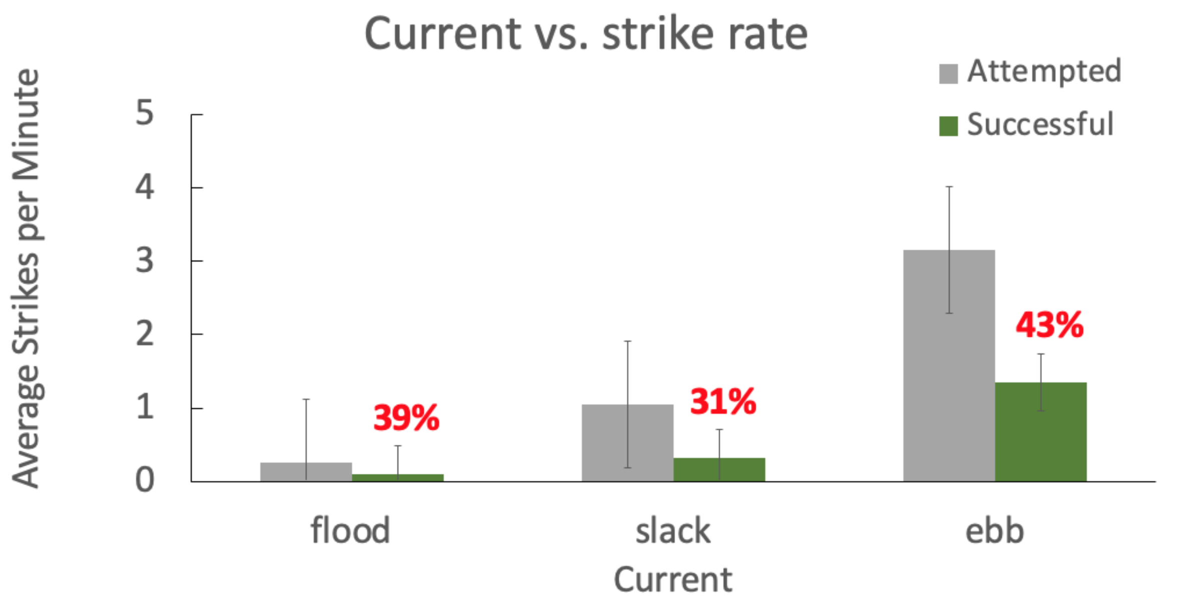

Figure 5c: Average strikes per minute at varying current directions. Percent success rate displayed above bars showing successful strikes per minute. (n = 35)