Seabirds and Tides at Fine Temporal Scales

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Pelagic Ecosystem Function in the San Juan Archipelago Research Apprenticeship

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ABSTRACT

Intricate tidal dynamics are the main drivers of ecosystem processes in coastal estuaries. Previous Pelagic Ecosystem Function studies have explored the relationship between tidal activity and seabird abundance in the San Juan Channel, Washington, but no strong or consistent temporal patterns were found. My objectives were to investigate: the fine scale temporal changes in bird abundance over the flooding tidal cycle; taxa specific responses to tides; and the influence of other environmental factors on variation among days and between years. I did this through sampling seabird abundance at half-hour intervals during the flooding tide on four consecutive days in the fall of 2013. Seabird abundance results showed consistent response to tidal phase for total birds and alcids in both 2013 and 2012. Variation between years suggested different foraging strategies were used by local gulls based on a change in feeding conditions. Additionally, the variation between years was related to large-scale oceanographic conditions, such as El Nino Southern Oscillation (ENSO). The differences in tidal response between taxa and between years suggests that fine temporal scale sampling can provide more insight into previously undetected factors affecting seabird abundance. Based on the results of this study, fine scale sampling can provide better predicting power and thus more informed decisions for management and conservation.

INTRODUCTION

Intricate tidal dynamics are the main drivers of estuarine ecosystem processes. These processes can operate at weekly, daily, and hourly scales. Daily ebb-flood tidal exchange in an estuary can bring in cold, prey rich waters and create turbulent mixing that aggregates prey in the water column providing higher prey availability to predators. Seabirds are known to correlate with areas of high prey availability (Benoit-Bird 2013) and predictability (Parrish et. al. 1998). However, complex tidal patterns cause patchy and ephemeral prey availability, leading to rapid changes in seabird abundance over short periods of time (Drew 2013). This means that, understanding and predicting seabird abundance in tidally active areas is extremely difficult. Thus, fine-scale tidal influences can interfere with our ability to clearly define population size and status, and make informed management decisions.

Several studies on the relationship between tides and seabirds have been conducted in Cattle Pass in south San Juan Channel, an estuarine area of strong diurnal tides and high seabird abundance. Zamon (2000) found that with-in day changes in seabird abundance were correlated to changes in tidal current speed. Specifically, that higher numbers of seabirds occur during fast flooding tides. Based on Zamon's work, subsequent Pelagic Ecosystem Function studies focused on the relationship between seabird abundance and tidal activity at weekly or daily scales, but these studies did not find strong or consistent temporal patterns (Navratil 2011, Palmer 2010, Clatterbuck 2009, Jennings 2007). The sampling interval used in these studies was unable to account for fine-scale temporal changes bird abundance. Other studies at finer scales (Eisenlord 2012, Spatz 2008), confirmed a difference among species in response to tidal currents and conditions. Without higher resolution environmental data, the key changes in physical processes affecting bird abundance are still unclear.

Eisenlord (2012) determined the precise timing of seabird response to changes in tidal currents on a fine temporal scale in the south end of the San Juan Channel, Washington. She found that seabirds increased from early to late in the flooding tidal cycle. This pattern was consistent day-to-day but varied among species with different feeding ecologies.

For this project, I continued to study the effects of tidal activity on fine scale temporal variation in seabird abundance in fall 2013 in the south end of the San Juan Channel, Washington. In order to produce comparable data, I replicated the methods used by Eisenlord (2012). My objective was to use data from both years to answer three questions regarding the relationship between seabird abundance and tidal dynamics at fine temporal scales:

1. Did seabird abundance vary over the flood tidal cycle on a fine (with-in day) scale in fall 2013?
2. Did the pattern of variation in abundance differ among seabird taxa?
3. Did the timing and strength of the with-in day tidal response vary from day-to-day?

METHODS

Study Site and Tides:

The 2013 surveys were conducted on four consecutive days, from 16-19 October 2013 in the south end of the San Juan Channel, Washington (Figure 1). I chose this site because of its strong tidal activity and high bird abundance. Predicted values for tidal current speed were obtained for the San Juan Channel South Entrance tidal station using the software program Mr. Tides 3. Based on the predicted time for max current speed (max flood) and the slack low (SL) for each day, I divided the tidal cycle into eight temporal categories (Figure 2). Four consecutive days within one week were sampled in order to minimize sampling error due to fall migrations and weekly tidal variation. All surveys were done on a flooding tide.

Seabird Abundance:

Seabird abundance was measured using strip transects conducted from a small boat at 8-10 knots. Surveys began at the time of the predicted slack tide and were repeated every thirty minutes for 7-10 transects. All birds within 200 meters on each side of the boat were counted and identified to the species, in cases where this was not possible, the lowest identifiable taxon. The 4.46 km transect was surveyed from south (N48 28.248, W122 57.588) to north (N48 30.644, W122 57.887), for a total survey area of 1.78 km^2. Surveys were only conducted with relatively calm seas (Beaufort Sea State ≤ 3) when the entire transect was clearly visible and free from fog.

Oceanography:

Changes in surface water masses over fine temporal scales were measured with a Sea Bird Electronics (SBE) Conductivity-Temperature-Depth (CTD) sensor package, SBE 19, equipped with sensors for temperature, salinity (conductivity), and depth (pressure). The SBE 19 was deployed from a small boat to depth of 10 meters at half-hour intervals before each seabird abundance survey.

Data analysis:

Seabird surveys:

Seabird abundance was calculated as density (individuals/km^2) for each of the 7-10 surveys. Mean density and standard error were calculated for all days and combined for each of the tidal categories: SL, early flood, max flood, and late flood. Bird totals were also averaged by day for each of the eight days and compared to maximum current speed and tidal range. Tidal height data were obtained from the NOAA Friday Harbor Weather Station and daily maximum current speed was obtained using the program Mr. Tides 3 for San Juan Channel, South Entrance. Tidal range was defined as the difference between maximum and minimum tidal height in the 18 hours preceding sampling, based on NOAA's tidal height predictions for Friday Harbor station. Although Eisenlord (2012) focused on only six seabird species of the gull and alcid families I included 20 seabird species in my analysis of "total birds" unless otherwise noted. For all 2013 tidal cycle analysis there was one SL transect, four early flood transects, two max flood transects, and three late flood transects. Tidal cycle is a temporal scale and in 2012 the early flood was one half-hour longer than 2013, thus five transects are categorized as early flood in 2012. Gull and alcid abundance was further analyzed, using average abundance over the tidal cycle, curves were fit using R (Version 3.0.2).

RESULTS

Within-day variation:

In 2013, seabird (all species combined) abundance varied with tidal phase. During each of the four consecutive days of this survey, net abundance increased from early to late in the flooding tidal cycle (Figure 3). The exact pattern of increase, however, was not identical every day. October 16th had a steady successive increase from early to late in the tidal cycle; October 17th and 18th had moderate abundance in early flood, low abundance near max flood, and peak abundance in the late flood; October 19th had more variability among each half-hour interval. In 2013 average seabird abundance (all four days combined) increased over the flooding tidal cycle, from about 64 ($\sigma = 9.9$) birds per km^2 at slack low to 230 ($\sigma = 0$) birds per km^2 at late flood (figure 4). In 2012, the number of birds was much larger, 525 ($\sigma = 0$) birds per km^2 at peak, but the pattern was very similar (figure 5). While the net increase was seen in both years, the pattern of increase was different between the years. In 2012, abundance increased steadily in a nearly stair-step pattern, whereas in 2013 abundance was more variable at half-hour intervals.

Variation over the tidal cycle differed between taxa. Average alcid abundance showed a strong relationship with tidal phase in 2012 and 2013 (Figures 6 and 7). In both years alcid abundance was low during the early flood period, increased slightly during max flood, and peaked during the late flood. The last transect had the highest abundance, about 174 ($\sigma = 0$) birds per km^2 in 2012 and 77 ($\sigma = 0$) birds per km^2 in 2013. Alcid abundance variation over the tidal cycle was similar in both years: a sharp increase, or nearly exponential rise, in abundance over the tidal cycle. This relationship was best described as a power function in both years. Alcid response to tides was consistent between years.

Average gull abundance varied over the tidal cycle in 2012 and 2013, but the pattern was different than for alcids and differed between years (figures 8 and 9). In 2012 gull abundance increased over the early flooding tidal cycle, peaked at max flood, and decreased to moderate levels thereafter. In 2013 gull abundance fluctuated greatly at half-hour intervals. There was no strong increase at max flood and the highest abundance was found on the last transect. Gull abundance variation over the tidal cycle was very different between years. The pattern was best described as parabolic in 2012, and almost linear in 2013. Gull response to tides was not consistent between years.

Among day variation:

Seabird (all species combined) abundance also varied from day to day in both 2013 and 2012, but there was no significant trend (Figure 10). When only gull and alcid (combined) abundance was considered a clear trend emerged (Figures 11 and 12). In each year there was a net increase in abundance from day one to day four of the survey. Gull and alcid abundance increased 100% during this four day period in 2013, and 23% in 2012.

Oceanography:

Analysis of the physical oceanography in this study verified tidal mixing on a fine temporal scale (Schlatter 2013), and resulted in three important findings. First, there was a stronger cold water signal on October 19th than on October 16th (Schlatter 2013). Second, both the tidal exchange and the maximum daily current speed decreased successively each day from October 16th to October 19th. The lowest tidal exchange and lowest daily current speed was on October 19th. However, the tidal range increased from October 16th to October 19th (figure 13). Similar conditions were found in 2012 (figure 14). The variation among days of gull and alcid abundance in 2013 was positively correlated to tidal range with a R^2 of 0.626, and weakly in 2012 with an R^2 of 0.176 (figures 11 and 12). Third, the oceanographic differences between north station and south station were larger this year than last year. In 2012, the average temperature in the San Juan Channel was lower; the channel conditions had less variation in temperature and salinity from north to south, and thus there was more overlap in temperature range between north and south station (Schlatter 2013). In 2013 the ocean conditions across the San Juan channel were more distinct, north and south station had little to no overlap.

DISCUSSION

In this study we demonstrate a method for measuring the fine temporal scale response of seabirds to tides in a complex estuarine ecosystem. Seabirds are important components of pelagic marine ecosystems, and with 28% listed as threatened they are the most endangered marine taxonomic group in the world (Croxall et al. 2012). Despite their conservation status, our understanding of the factors that affect their abundance are fairly limited. According to bottom-up control theories, physical oceanographic processes drive primary production that then affect the abundance of progressively higher trophic levels (Parrish 2003). Tidal dynamics are one of the most important physical processes in an estuary such as the San Juan Channel; hourly changes in nearshore tides can cause patchy and ephemeral prey availability, making seabird abundance change quickly over short periods of time (Drew 2013). Additionally, interactions with complex bathymetry can strongly influence prey abundance and distribution.

The increase in seabird abundance over the flooding tidal cycle found in this study is consistent with the tidal-coupling hypothesis (Zamon 2003), which states that prey abundance and availability increases with increasing current speed. Tidal exchange brings in cold prey-rich waters, strong tidal currents create turbid waters that interact with bottom bathymetry forcing prey into the water column. Therefore, the highest prey availability is found at and after the high current speed, max flood. Jets and rips caused by tides aggregate plankton and planktivorous fish, thereby attracting seabirds and other top predators to the area. In this study, seabird abundance was highest at and after the max flood in both years. The trend is clear from both years that at this scale for coastal waters, with-in day bird abundance is a function of predictable prey available as a result of tidal dynamics.

Alcids varied over the tidal cycle predictably in both 2012 and 2013, with highest abundances after the max flood. Although the tidal-coupling hypothesis states that high abundances are correlated to high current speed, this study shows that timing in the tidal cycle is more important than current speed for alcids. Alcids are predominantly piscivores divers that forage at depth (Piatt 1984), therefore it is possible that alcids come in to the channel after max flood in order to save energy. Diving during fast current speeds can be energetically demanding; waiting until prey are aggregated near the surface, but current speeds are lower, can reduce foraging costs. Other studies have found alcids implementing similar strategies in an effort to reduce dive foraging costs: although some alcids can dive up to 180m (Piatt 1984), they have been found to eat the majority of their food from the first 10 meters of the water column (Burger 2004). Previous studies have shown that alcids are strongly affected by bottom-up control and physical forcing, such as prey availability and tidal conditions (Parrish 2003). In my study, alcids seem to be limited by high current speeds and wait for both high prey availability and lower current speed before they enter the channel for foraging.

Between 2012 and 2013, average gull abundance showed very different patterns with respect to the tidal cycle. In 2012 gulls responded strongly to tidal current speed, with maximum abundance at highest current speeds. Gulls are highly mobile aerial sight searchers and opportunistic surface feeders (Burger and Gochfeld 1996), therefore they should be able to respond quickly to surface evidence of increasing current and should not be limited by fast current speed. In 2013 however, gulls had no strong pattern in relation to tidal cycle. Seabirds have been known to return to and spend more time around predictable feeding sites in order to reduce foraging costs (Vliestra 2005); earlier in 2013, gulls may have found the feeding conditions unsuitable at the study site and perused other feeding opportunities. In 2013, the highest abundance of gulls was found at the last transect. In order to reduce searching costs, seabirds often feed socially and respond to “feeding events” by joining multi-species feeding flocks (Wittenburger and Hunt 1985). The high gull abundance in the late flood may have been gulls responding to the high alcid abundance in the late flood. In summary, due to different oceanic conditions a difference in gull foraging strategies was observed between years.

The number of birds observed in 2012 was much larger than 2013. The highest average total bird abundance in 2012 was 525 ($\sigma = 0$) birds per km^2 in the late flood, and only 230 ($\sigma = 0$) birds per km^2 this year. This abundance discrepancy was also seen in at the family and species level. The major driver of these differences in abundance seems to be climate; 2012 was a weak El Niño/neutral year, the San Juan Channel was cooler and saltier than average (Pelagic Ecosystem Function 2012, unpublished data) and thus more similar to oceanic conditions. These conditions lead to increases in most trophic levels, including a common forge-fish the pacific sand lance (*Ammodytes hexapterus*); in 2012 its abundance was an order of magnitude higher than in 2013 (Pham 2013). Furthermore, the phytoplankton bloom was larger than average, and seabird abundance was higher than average (Pelagic Ecosystem Function 2012, unpublished data). This large difference between years makes it clear that large-scale climate influence is an important factor in predicting and understanding seabird abundance changes.

Gull and alcid variation among days correlated to tidal range in 2012 and 2013. Although the maximum current speed and tidal exchange were decreasing over the four days in both years, the tidal range was increasing and thus oceanic input was increasing. The 2013 data support this, the fourth survey day in 2013 had colder, saltier water at SL than the first survey day (Schlatter 2013). In 2012 however, the difference between day one and day four was not as distinct. As previously discussed, the San Juan Channel water had warmer temperatures and lower prey abundance in 2013, therefore the effect of incoming prey-rich oceanic water was stronger in 2013. The tidally driven influx of oceanic water was not such an important factor in 2012, because the water was already cold and prey-rich. Previous studies have suggested that plankton brought in by tides drive the abundance of successively higher trophic levels (Zamon 2003), thus a warmer year with lower prey abundance would see a larger response to daily oceanic input.

The lack of pattern between seabird abundance and tidal range in both years suggests that combining all species for analysis is inaccurate. When all species data were combined, it showed that seabird abundance was unaffected by among day variation in oceanic input and differences in water properties between years. Since gull and alcid abundance correlated to tidal range in both years, it is possible that gulls and alcids were feeding in the channel more than the other seabird species observed and may be a better representation of channel conditions. Therefore, habitat use and feeding ecology are very important factors to consider when assessing a multi-species population.

In conclusion, using fine scale sampling methods I found that seabirds and alcids consistently had predictable variation over a temporal tidal cycle in both years. Gulls, however, showed variability in tidal response between years. The results of this study demonstrated that tidal coupling is an important driver of seabird response to tidal cycle, but this relationship is clearly very complicated and affected by many environmental factors, some of which may be out of the scope of this study. Moreover, response to tidal dynamics can be taxa specific, and can vary between years based on feeding ecology and area feeding conditions. Further fine temporal scale studies in the San Juan Channel, in a variety of tidal conditions, will provide a better understanding of these effects. Quantification of these trends and their drivers will improve the understanding of seabird populations by providing better predicting power and thus more informed management and conservation decisions.

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FIGURES AND GRAPHS

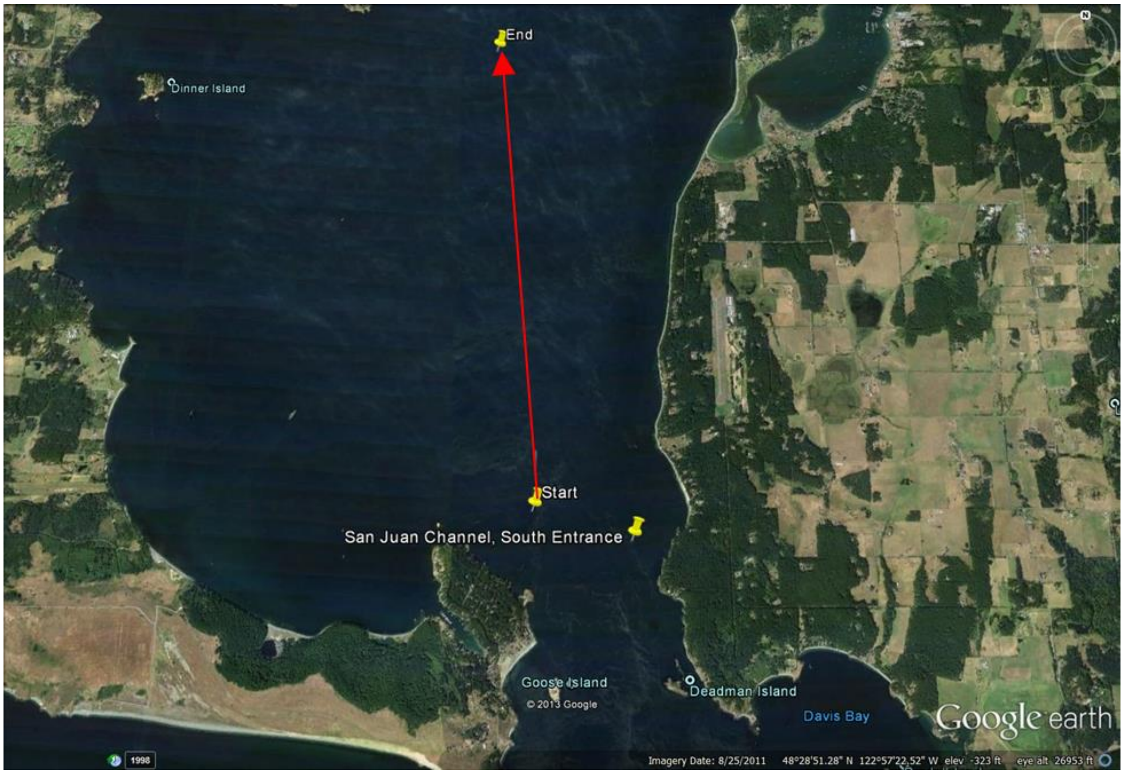

Figure 1: The study site was location in the south end of the San Juan Channel, Washington. Transects were run from south (N48 28.248, W122 57.588) to north (N48 30.644, W122 57.887).

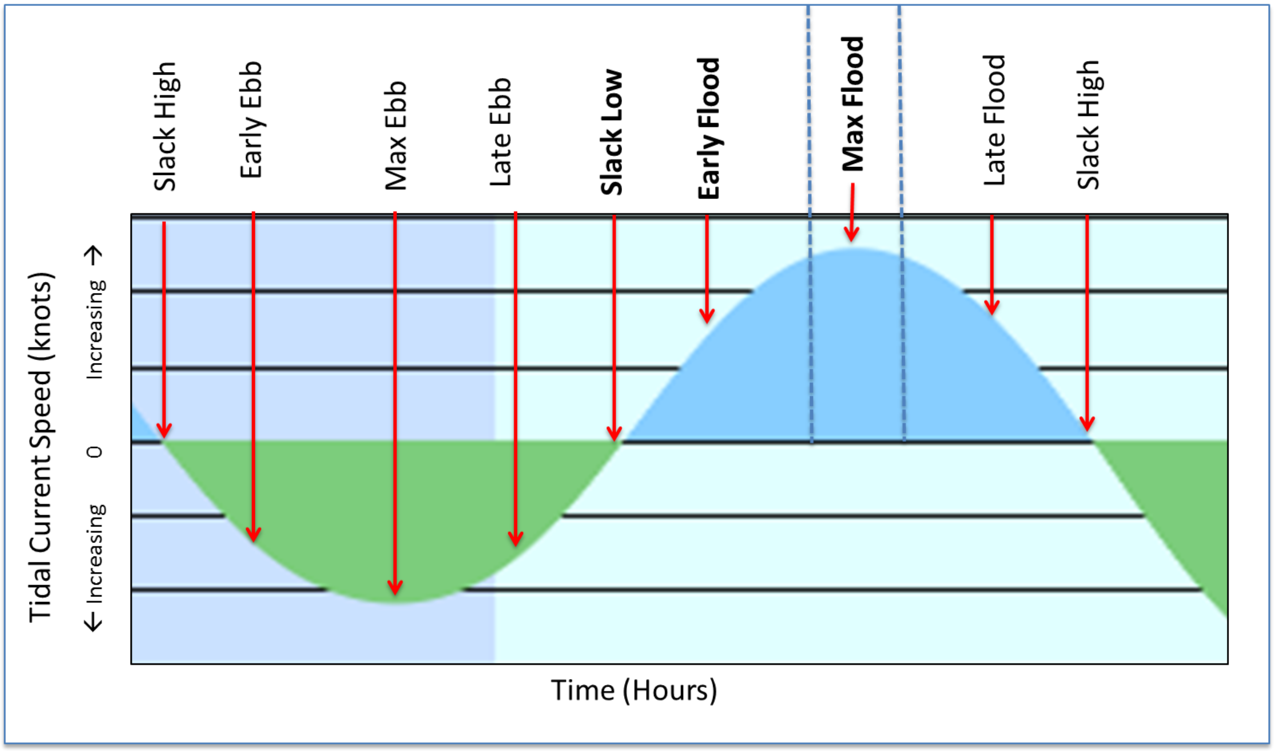

Figure 2: Temporal tidal cycle divided into 8 groups.

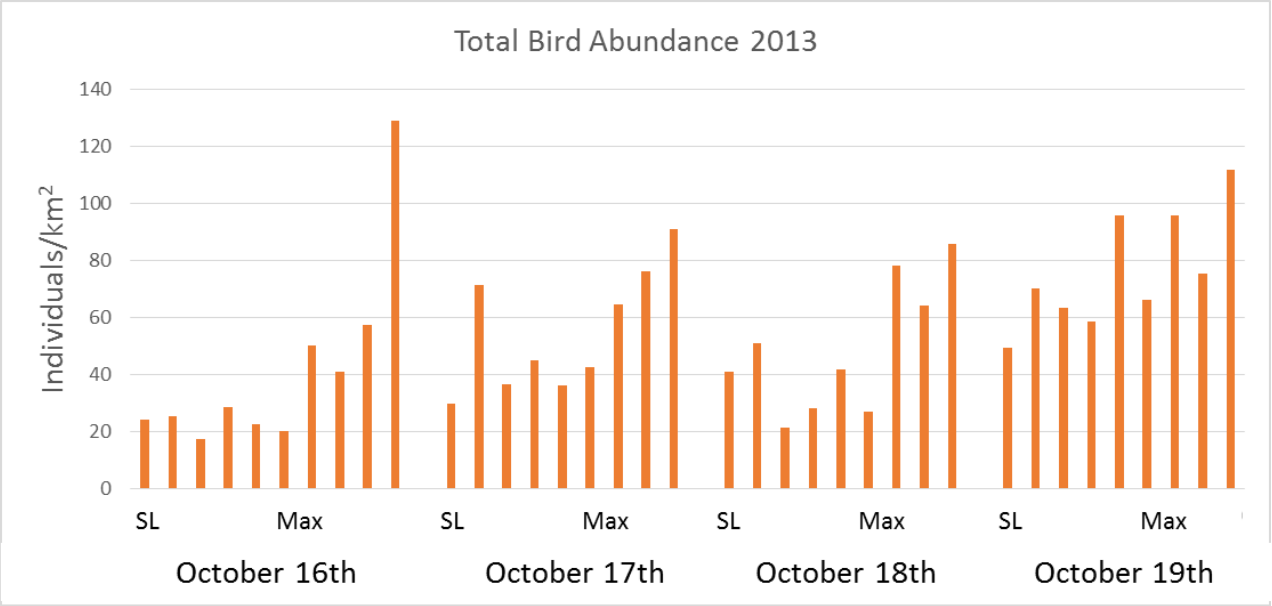

Figure 3: Total seabird abundance over the tidal cycle for all four consecutive days in 2013.

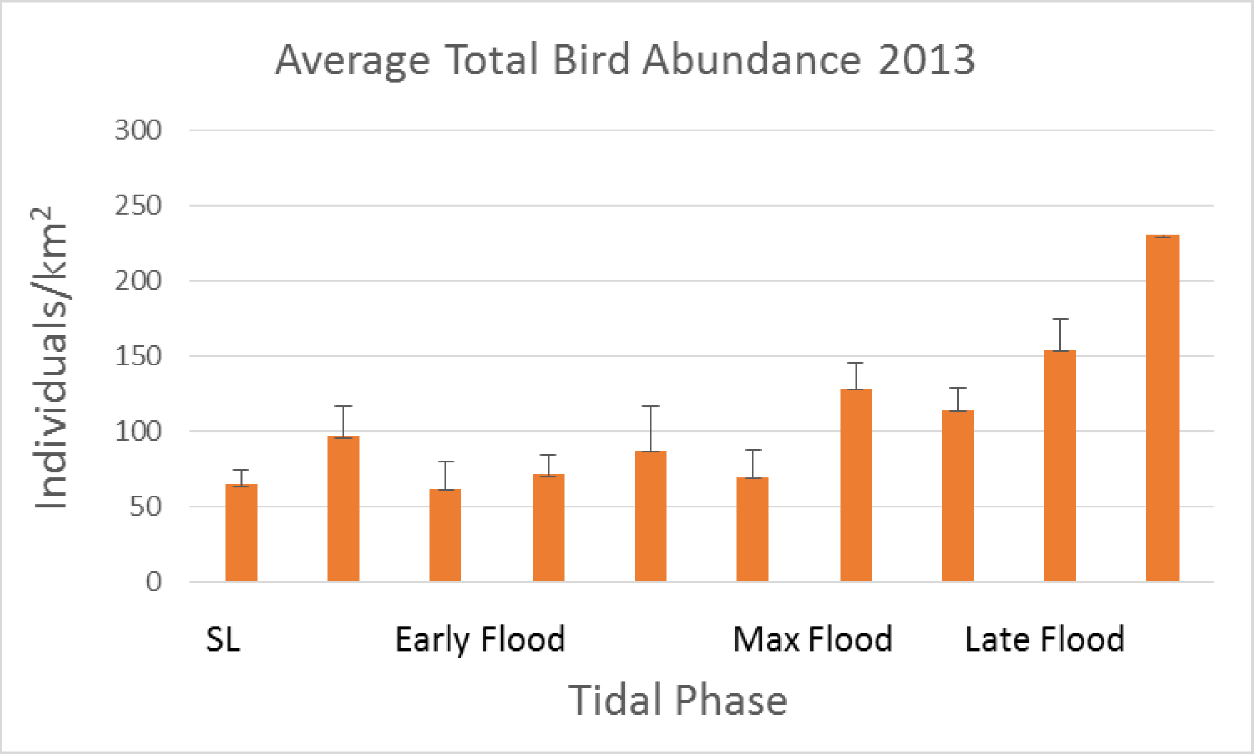

Figure 4: Average total seabird abundance over the tidal cycle 2013

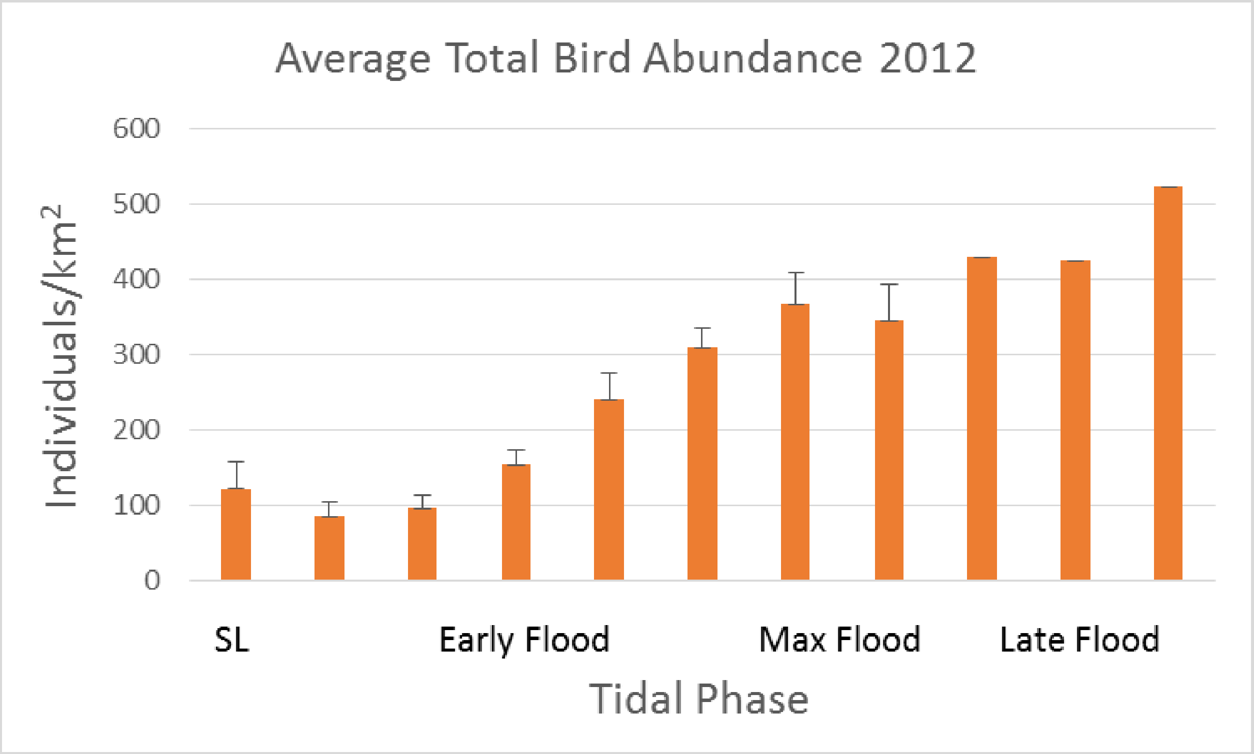

Figure 5: Average total seabird abundance over the tidal cycle 2012.

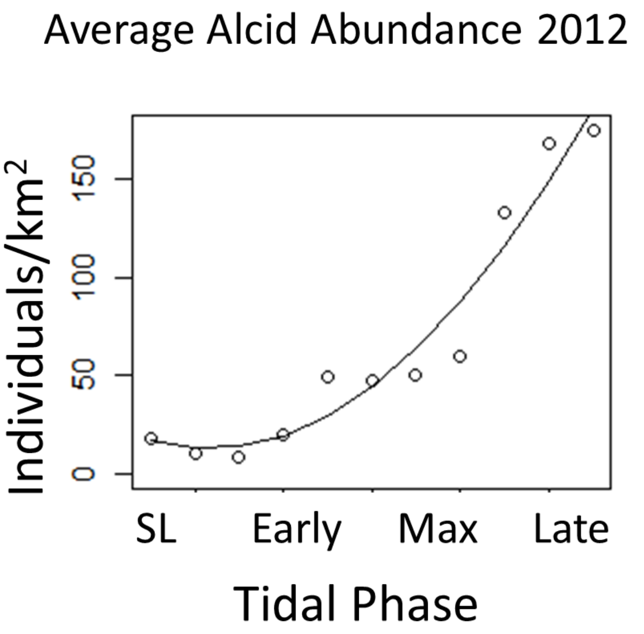

Figure 6: Average alcid abundance over the tidal cycle 2012.

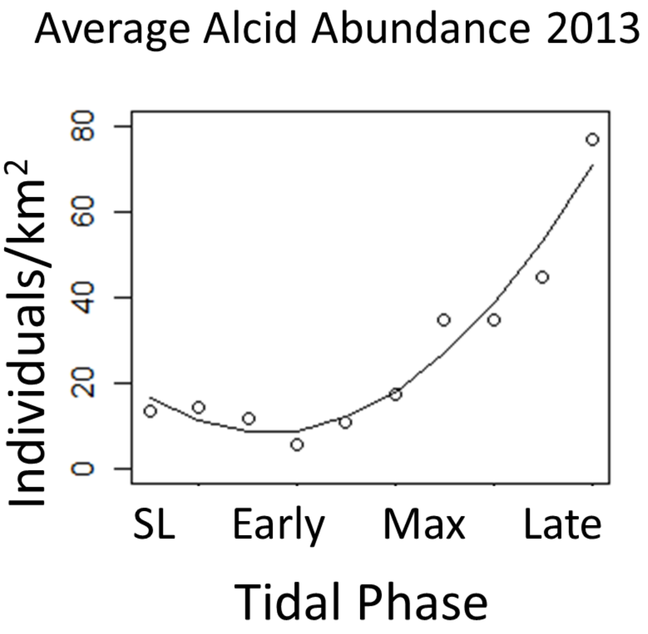

Figure 7: Average alcid abundance over the tidal cycle 2013.

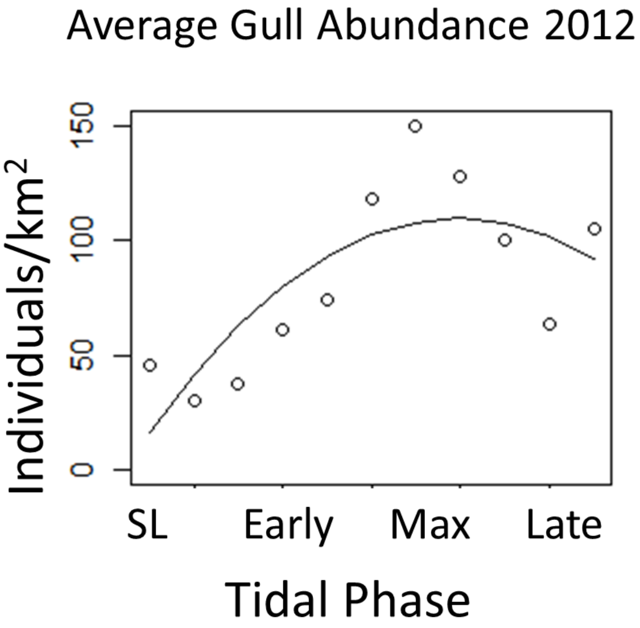

Figure 8: Average gull abundance over the tidal cycle 2012.

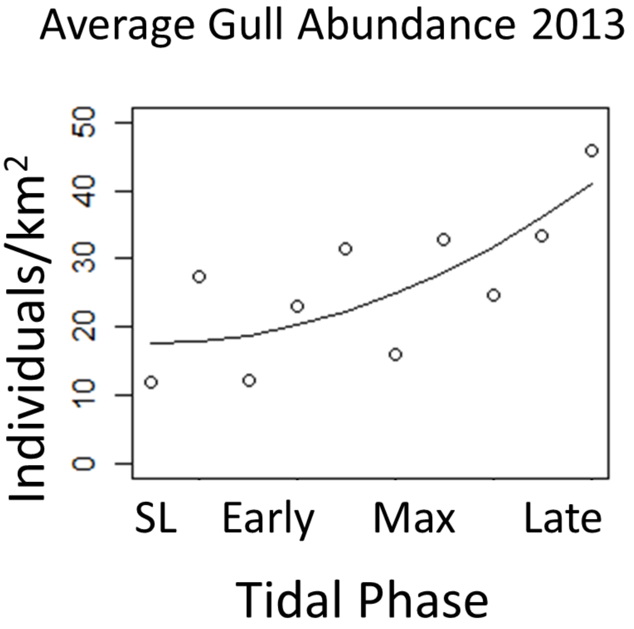

Figure 9: Average gull abundance over the tidal cycle 2013.

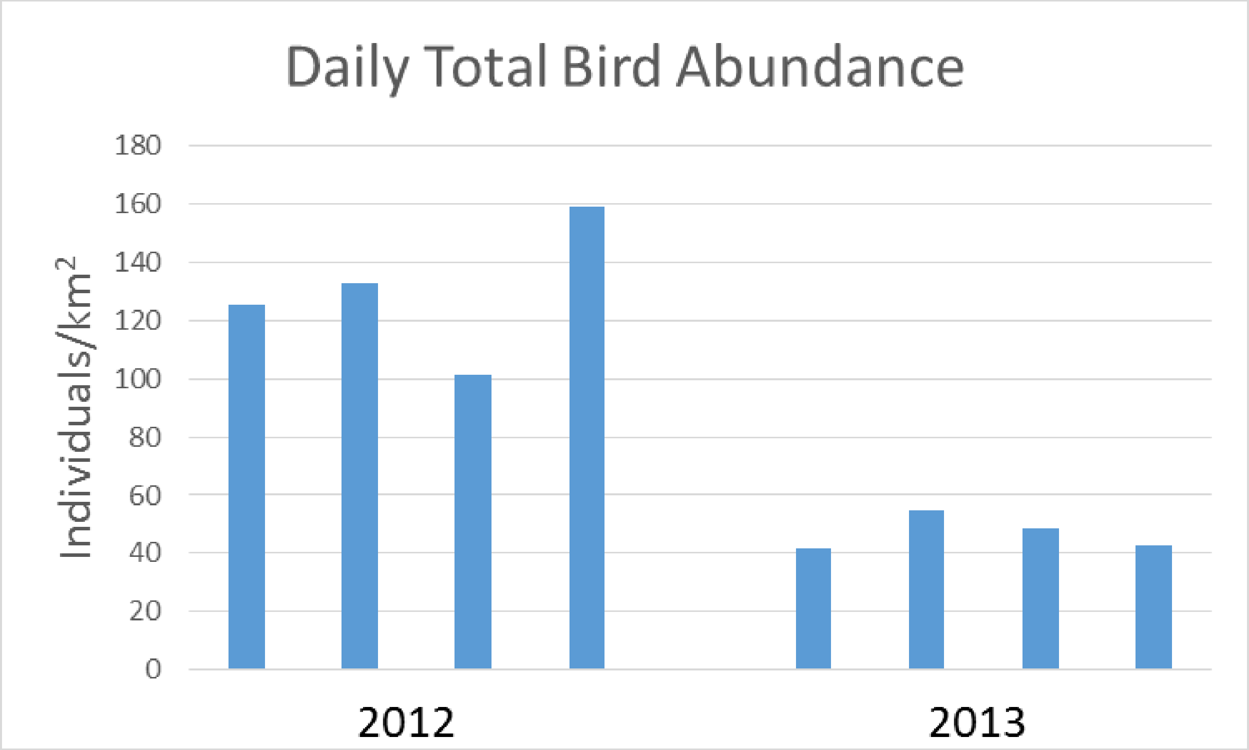

Figure 10: Daily total bird abundance for each survey day in 2012 and 2013.

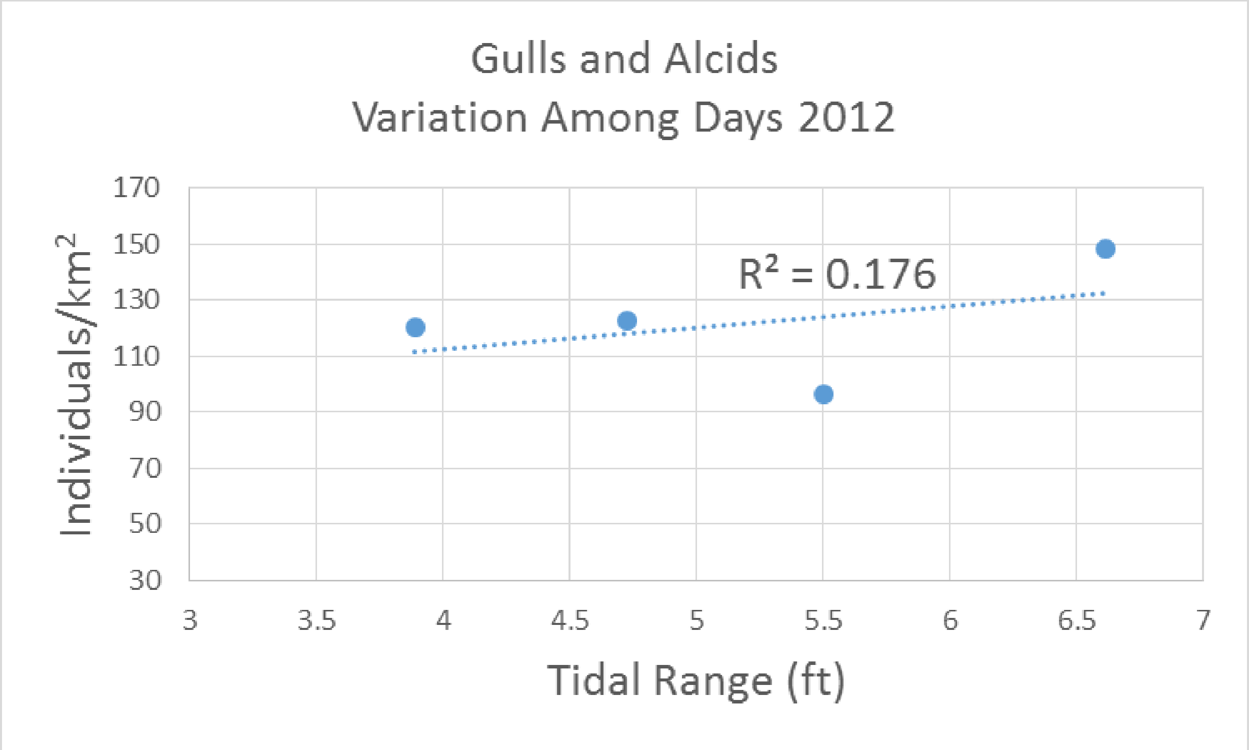

Figure 11: Variation among days versus tidal range for gulls and alcids in 2012.

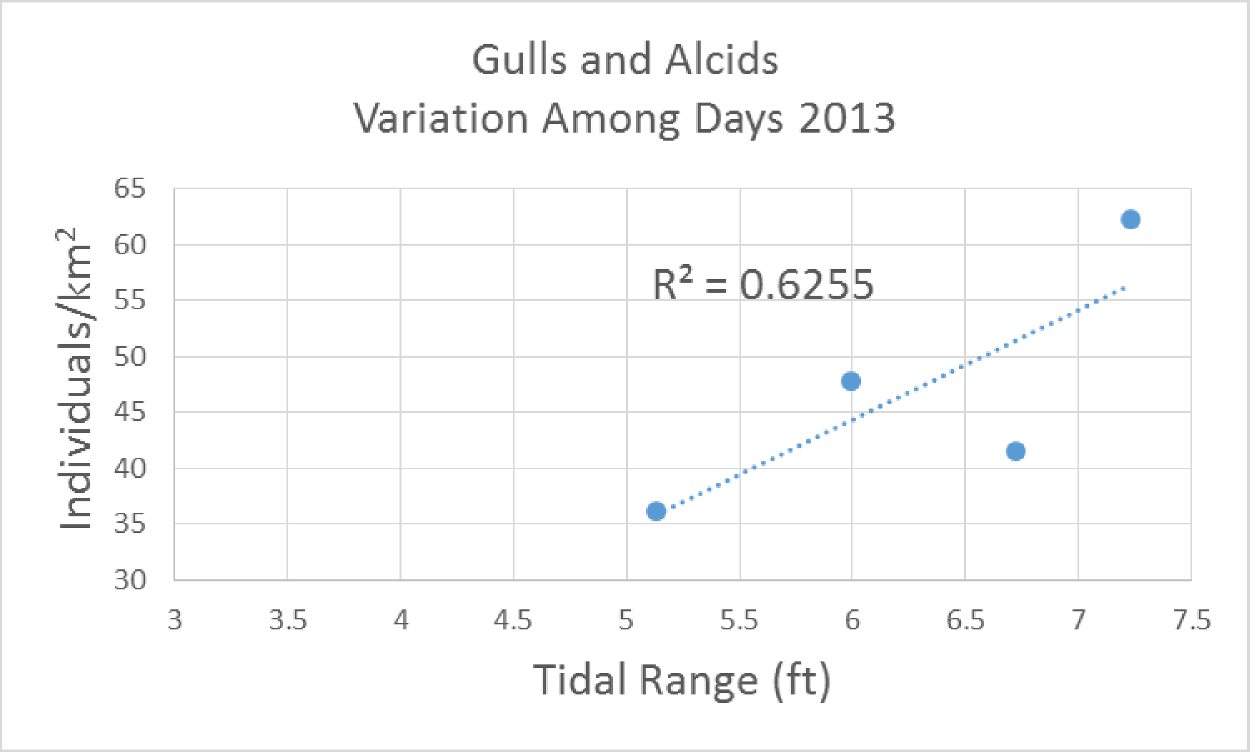

Figure 12: Variation among days versus tidal range for gulls and alcids in 2013.

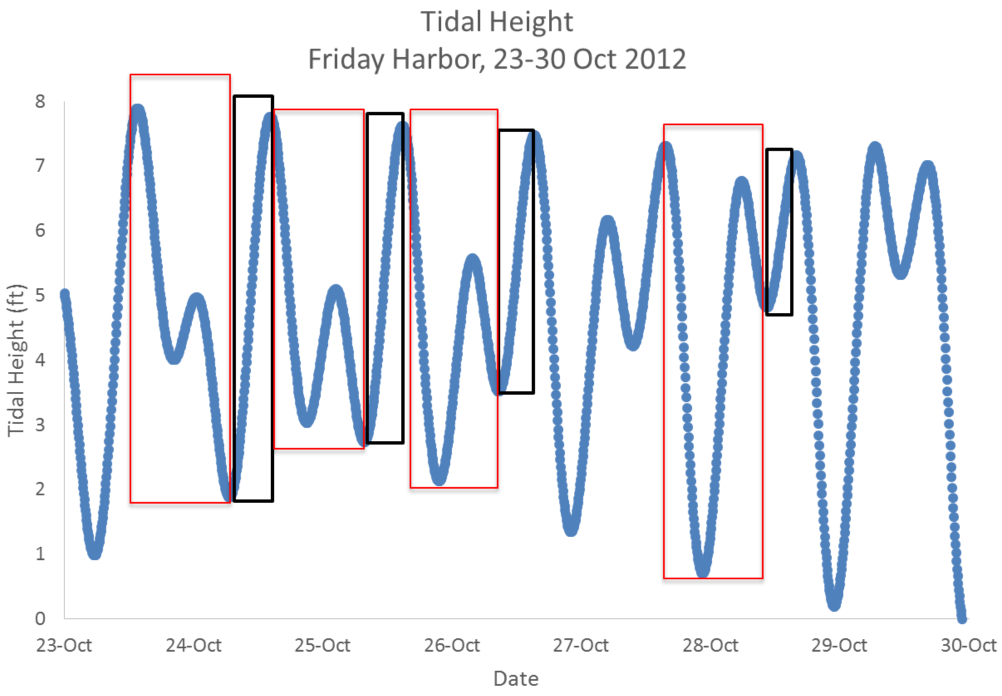

Figure 13: Tidal height from the Friday Harbor Weather Station, October 23rd-30th 2012. The black boxes shows tidal exchange, the red boxes show tidal range.

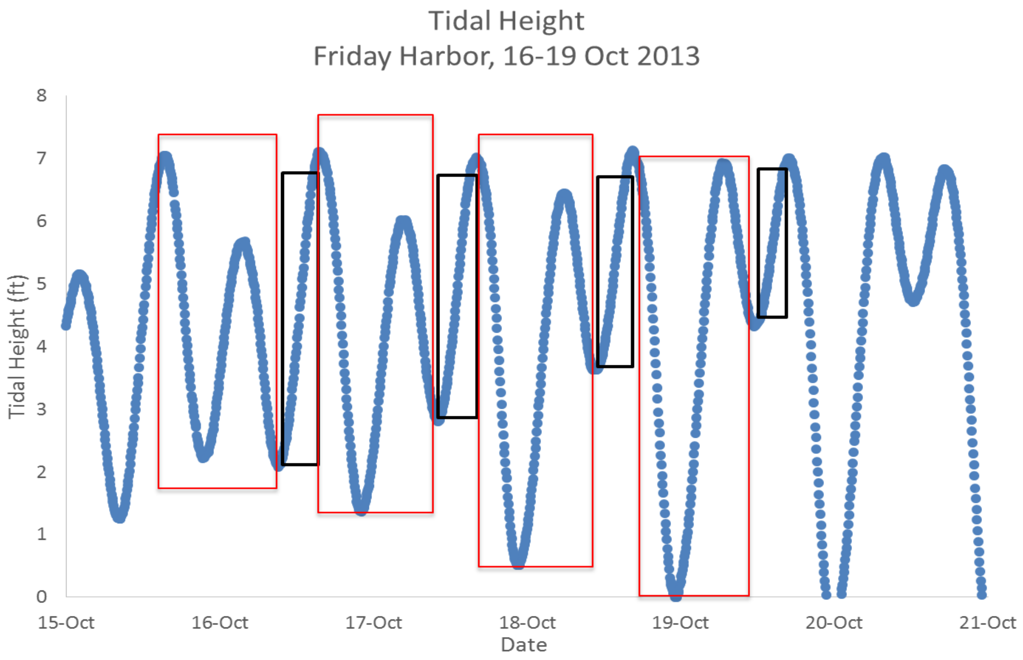

Figure 14: Tidal height from the Friday Harbor Weather Station, October 16th-19th 2013. The black boxes shows tidal exchange, the red boxes show tidal range.