Tidal influence on harbor seal foraging activity in the San Juan Islands, WA: Indirect insight on salmon in Cattle Pass.

Abigail Andrews[1,2], George Hunt[1,3]

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[1]Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250
[2]School of Marine Science, University of Maine, Orono, ME 04469
[3]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195

Contact Information:
Abigail Andrews
School of Marine Science
University of Maine
Orono, Maine 04469
abigail.j.andrews@gmail.com

Abstract

Due to the generalist nature of its diet, the harbor seal (*Phoca vitulina richardsi*) has been thought to be an indicator of change in ecosystems. By utilizing expected patterns in salmon presence, this study sought to assess the capacity of harbor seal foraging to act as an accurate proxy for salmon presence and activity in Cattle Pass, Washington. Salmon were expected to be present in the channel beginning mid-summer, at which point it should be easier for individual fish to migrate northward through Cattle Pass during northward-flowing flooding tides. During the summers of 2010 and 2011, harbor seal presence and foraging was observed with respect to tidal phase and current velocity. Of all salmon captures observed during 2010, 79.2% occurred during flooding tides and 65.81% occurred during the month of August. During 2010, harbor seal foraging reflected expected seasonal and tidal patterns of salmon presence in the pass. Results support the proposal that with additional data collection, harbor seal foraging has the potential to act as successful indicators of salmon presence and activity in Cattle Pass.

Keywords: harbor seal (*Phoca vitulina*); foraging behavior; predator-prey interactions; salmon (*Oncorhynchus*); San Juan Islands; tidal currents

Introduction

Seals are piscivorous generalists, meaning their diet is made up of fish that are plentiful and most easily attained (Perrin et al. 2008, Lance & Jeffries 2007, London 2006). Harbor seal diet therefore varies not only by season and region, but also over time. This characteristic, along with a long life span, allows for the harbor seal to act as an indicator of change in an ecosystem (Zamon 2001, Lance & Jeffries 2007). Patterns in harbor seal foraging reflect variability in the composition, relative abundance, and distribution of their prey. By analyzing seal behavior in a particular region, one is able to understand what is happening in its prey base.

In the coastal waters of the San Juan Islands, Washington, harbor seal diet is largely made up of forage fish and salmon (Zamon 2001, Lance & Jeffries 2007). These fish are of economic concern due to their commercial value as bait and table fish, respectively (Penttila 2007, Michael 1999, Higgs 1996). While most forage fish have been disregarded, herring populations have been monitored over the last thirty years. The Washington Department of Fish and Wildlife has found a decrease in the total estimated spawning biomass of herring in Puget Sound over this time period (Penttila 2007). Forage fish serve as both direct and indirect food sources to societally important predators, including larger fish, seabirds and marine mammals. Of more mainstream concern, native salmon populations are also in decline (Michael 1999, Higgs 1996, Nehlsen et al. 1991). Declines in salmon abundance have been attributed to habitat degradation, anthropogenically-impaired migratory routes, overfishing, and predation (Nehlsen et al. 1991, Scheffer & Slipp 1944). An alternate hypothesis would be that depleted forage fish stocks have impacted salmon populations.

A portion of the salmon returning to the Fraser River travels north through Cattle Pass, between San Juan and Lopez Island. While it is assumed that this begins some time during mid-summer, little else is known of the nature or timing of the event. Flooding tides move northward through Cattle Pass toward the Fraser River. One may therefore assume that it would be more efficient for a fish to achieve a net northward movement during an incoming tide than any other tidal phase. Ultrasonic tracking observations by Stasko et al. in the San Juan archipelago support this behavior (1976).

By directly observing harbor seal diet, insight is given on prey availability in space and time, as well as the potential impact these predators may have on salmon populations. While more technical and challenging methods exist, the air-breathing and speed constraints of seals allow for basic visual scan techniques, deemed an "effective study approach" by the Pacific States Marine Fisheries Commission (Scordino 2010). During the summers of 2010 and 2011, at-surface forage events of harbor seals were observed in attempts of describing prey availability in Cattle Pass. I hypothesize that an abrupt increase in at-surface seal predation events on salmon will be observed when the salmon arrive, after which seals will take advantage of flooding tides as an increased foraging opportunity. Thus, more seal predation events on salmon will consequently be observed during this tidal phase. Furthermore, I hypothesize that seal non-salmon feeding events will be observed more often before the salmon arrive, after which they will be observed more often during non-flooding, and possibly less salmon-abundant tides. Finally, I hypothesize that patterns in seal presence in water will follow those of preferential foraging activity with respect to tidal phase.

Methods

The study site was located at approximately 48°28.7'N and 122°57.1'W on San Juan Island, Washington. This land-based observation point overlooks Goose Island, on which ledges are exposed at low tide, and Cattle Pass, the channel between San Juan Island and Lopez Island. Data was collected between June 12, 2010 and September 21, 2010, and between June 14, 2011 and July 27, 2011. Eagle Optics' Ranger 8x42 binoculars were used to scan nine spatial sectors. These sectors are of unequal areas and are delineated by easily identifiable landmarks. Each sector was then divided into three sections corresponding to distance from observer. This spatial system was utilized to keep track of individual organisms, as well as a mode to describe presence and distribution throughout the channel.

Sampling took place over all daylight hours, divided into four separate four-hour periods (Table 1), and tidal phase, divided into eight categories based on current velocity (Table 2). Current velocities were calculated by JTides software based on data from San Juan Channel South Entrance Buoy. Observations were made over all possible combinations of time of day and tidal conditions. Sampling was limited by weather conditions, mainly fog and precipitation, which reduced visibility.

Two types of observations were made. Instantaneous hourly censuses, approximating ten minutes each, recorded the time, spatial sector and feeding behavior, if applicable, of seals present in the channel and on Goose Island. During continuous half hour surveys time, spatial sector, and feeding behavior, if applicable, of individual harbor seal sitings were recorded. Hourly censuses and foraging surveys are comparable to past data sets from 1996-97.

Foraging events are categorized as either predation on schooling fish or at-surface feeding on large fish. Due to the small size of forage fish, seals are able to consume them underwater (Zamon 2001). It is difficult to impossible for one to observe and quantify all of these feeding events. However, seals can be observed as associating with avian forage flocks cooperatively feeding on small schooling fish, during which gulls and diving birds congregate at the water's surface. Through non-disturbing, close proximity observations from a small vessel, Zamon was able to determine that a seal within twenty-eight feet of a forage flock was participating in the forage event (2001). Seals may also drive schooling fish to the surface while foraging. Both of these events are visible from the study site. Feeding on forage fish was quantified by the number of individual seals involved in the event. In contrast, salmon are generally too large for seals to consume at depth. Seals hunt salmon underwater, but must bring their catch to the surface in order to tear it into edible pieces. Thrashing, splashing, and bits of pink flesh are indicative of these foraging events (Zamon 2001) and are easily visible. For the cases when pink flesh is not directly observed, and prey can therefore not be identified as salmon, prey is determined to be an unknown large fish. Large fish predation events were quantified by the number of large fish captured.

Table 1 Times of Day

Morning	before 10:00
Morning/Afternoon	10:00 - 13:59
Afternoon	14:00 - 17:59
Evening	18:00 - dusk

Table 2 Tidal Phases

Slack Low (SL)	-0.25 m s-1 to +0.25 m s-1
Slow Flood 1 (SF1)	+0.25 m s-1 to +1.0 m s-1
Fast Flood (FF)	> +1.0 m s-1
Slow Flood 2 (SF2)	+1.0 m s-1 to +0.25 m s-1
Slack High (SH)	+0.25 m s-1 to -0.25 m s-1
Slow Ebb 1 (SE1)	-0.25 m s-1 to -1.0 m s-1
Fast Ebb (FE)	< -1.0 m s-1
Slow Ebb 2 (SE2)	-1.0 m s-1 to -0.25 m s-1

Results

June 12, 2010 – September 21, 2010

During the summer of 2010, 117 harbor seal foraging events were observed over the course of 186 half hour surveys and 186 instantaneous censuses. Too few definite predation events on forage fish (N = 3) were observed to analyze for significant patterns. This is largely an underestimation due to observational constraints on the behavior. Twelve unknown at-surface predation events were observed. A total of 102 at-surface predation events on salmon were observed.

Foraging by Date

Plots of mean foraging events as a function of date indicate that there is a seasonal component to seal predation (Figure 1). Forage events were not distributed uniformly with respect to month (d.f. = 6, Pearson ChiSquare = 56.189, $p < 0.0001$*). No predation events on salmon were observed in June. Salmon captures comprised 19.66%, 65.81%, and 1.71% of total predation events during July, August and September, respectively.

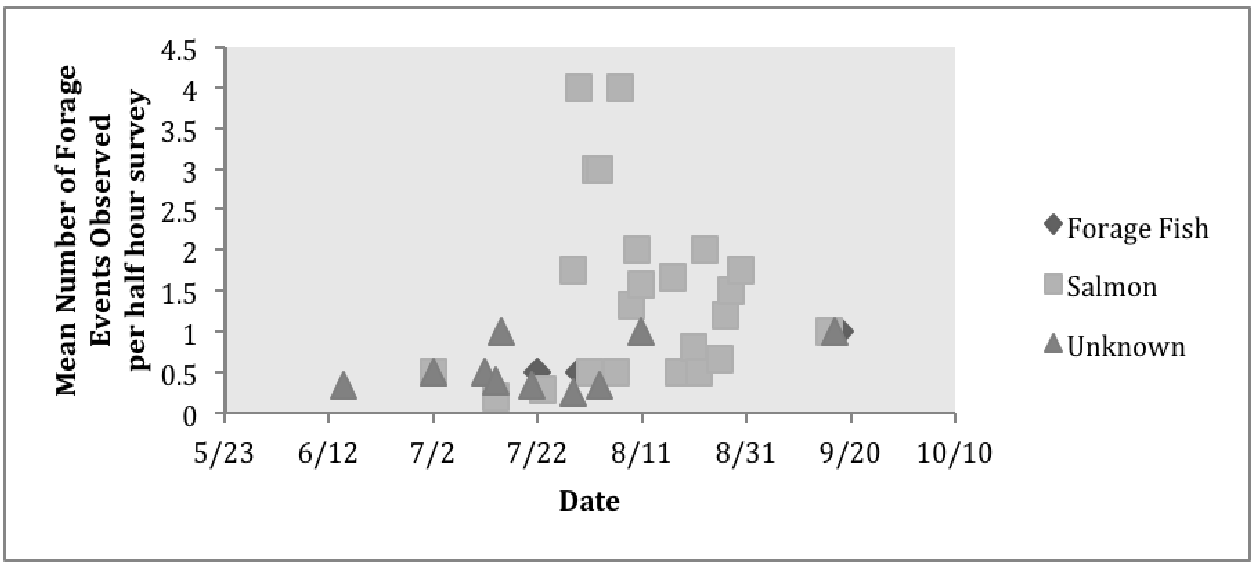

Figure 1 2010 Mean number of forage events observed per half hour as a function of date.

Foraging by Tide

Plots of foraging events by tidal phase showed that the majority of harbor seal foraging in Cattle Pass takes place during flooding tides, especially fast flood, and that foraging continued into slack high phases (Figure 2). Forage events were not distributed uniformly with respect to tidal phase (d.f. = 14, Pearson ChiSquare = 39.209, $p < 0.0003$*). Of all observed foraging events, 77.59% occurred during flooding tides, 32.76% of which occurred during fast flood, and 11.2% occurred during slack high. Despite the fact that no capture events were observed during the majority of surveys, plots of non-zero capture rates as a function of tidal phase showed that highest non-zero capture rates occurred during slow flood periods, and that the lowest non-zero capture rates occurred during fast ebbing periods (Figure 3).

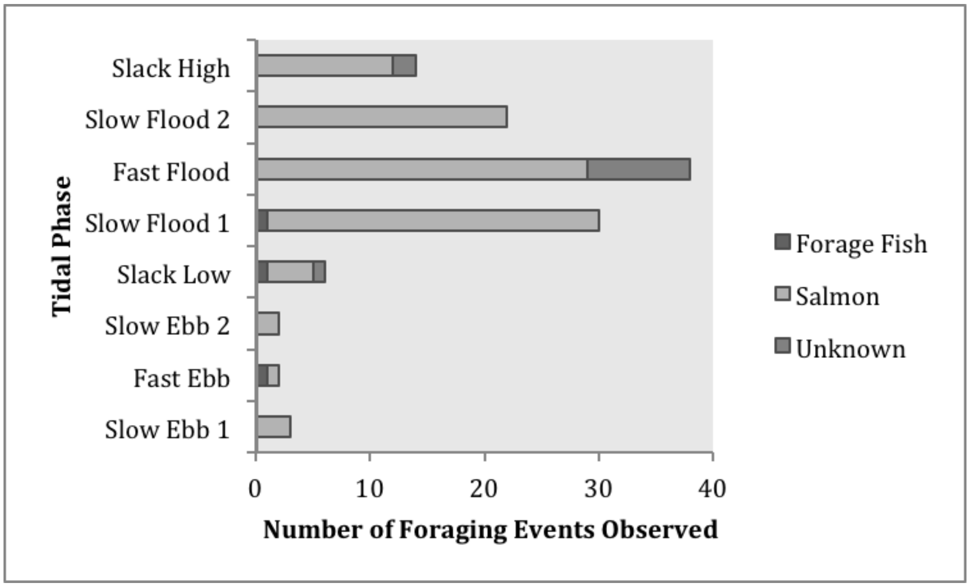

Figure 2 2010 Total number of foraging events observed with respect to tidal phase.

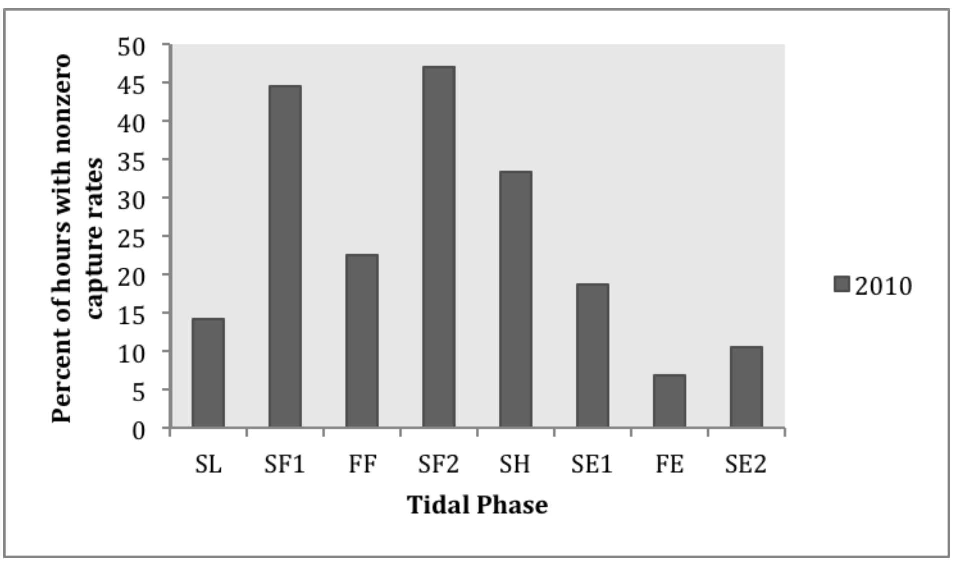

Figure 3 Distribution of nonzero capture rates with respect to tidal phase.

Hourly Per Capita Salmon Capture Rate

While plots of hourly per capita salmon capture rate as a function of tidal phase appear to show trends towards higher rates during flooding and slack high tidal periods, there was not enough data to be tested with significant power (Figure 4). The mean per capita capture rate was highest during slow flood 2 (1.36 fish $seal^{-1}$ hr^{-1}), with that of slow flood 1 close behind (1.23 fish $seal^{-1}$ hr^{-1}).

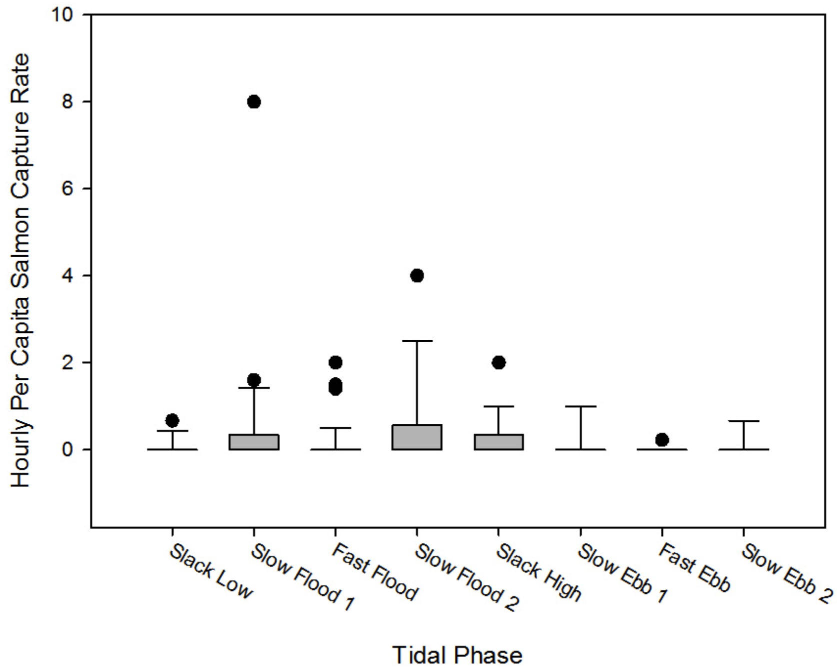

Figure 4 2010 Per capita salmon capture rates as a function of tidal phase.

Presence in Water by Tide

Plots of hourly seal counts as a function of tidal phase demonstrate that median counts were largest during flooding tides, especially fast flood (Figure 5). Hourly counts were not distributed uniformly with respect to tidal phase (d.f. = 21, Pearson ChiSquare = 432.898, $p < 0.0001$*). Of all seals observed, 59.81% were during fast flood periods and 19.44% were during slow flood periods.

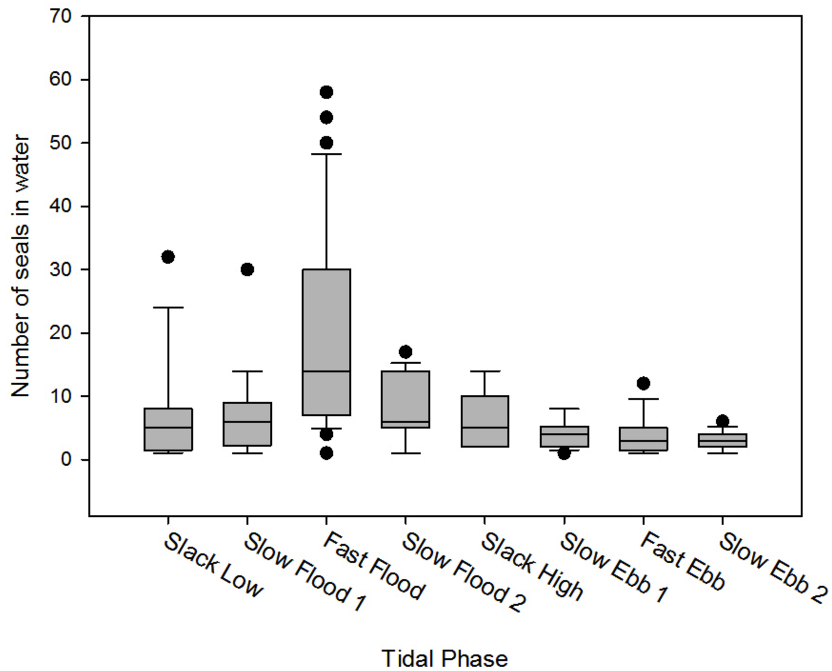

Figure 5 2010 Hourly Census: In-water seal count as a function of tidal phase.

June 14, 2011 – July 27, 2011

To date only 16 predation events have been observed during the 2011 field season over the course of 136 half hour surveys and 100 instantaneous censuses. Four of these predation events were on forage fish, eleven were salmon captures, and one was of unknown nature.

Foraging

Too few predation events have been observed to date to analyze for significant patterns. Observations will continue through the observation season and be analyzed at a later date. The majority of the forage events observed to date have been during slow flood 2 periods.

Presence in Water by Tide – to date

Plots of hourly seal counts as a function of tidal phase demonstrate that median counts were largest during flooding tides, especially fast flood (Figure 6). Hourly counts were not distributed uniformly with respect to tidal phase (d.f. = 7, Pearson ChiSquare = 120.620, $p < 0.0001$*). Of all seals observed, 32.91% were during fast flood periods, 21.47% were during slow flood periods and 19.55% were during slack tidal periods.

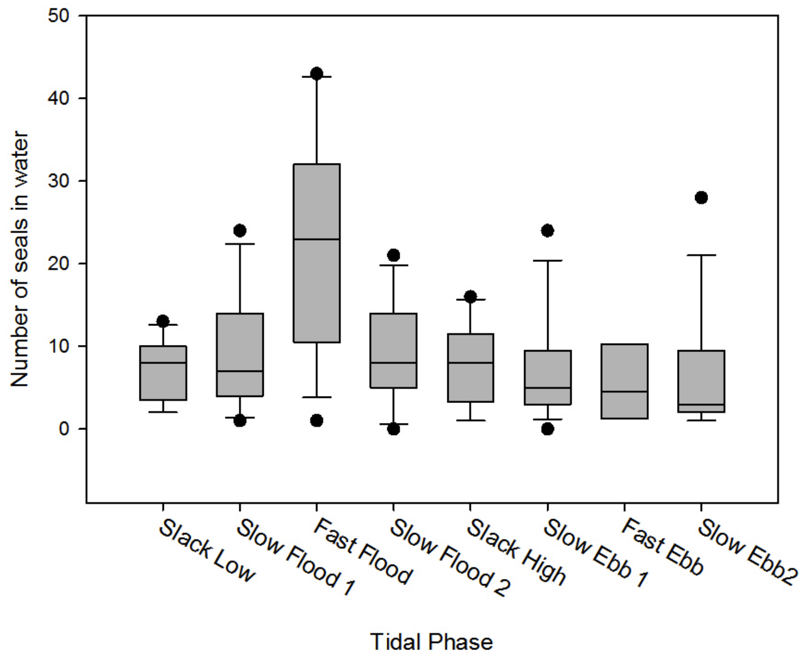

Figure 6 2011 Hourly Census: In-water seal count as a function of tidal phase.

Discussion

Observed harbor seal predation events on salmon reflected patterns expected of salmon presence in Cattle Pass. Minimal captures were made until late July, at which point an abrupt increase in events was observed (Figure 1). This has the potential to have translated into a pulse of fish migrating through the channel. Steady captures were observed through the end of August, indicating that significant numbers of salmon were still present through this time period. If the several unknown captures during June, July and September were not salmon, these data would support my hypothesis that seals would supplement their diet with non-salmon fish during times of low expected salmon abundance. However, without accurate identifications these captures could also possibly be salmon. If this were the case, it would be interesting to know the reason behind the differences in capture rates. If it is not due to a change in seal presence and therefore foraging effort, there is a potential for the nature of the salmon migration itself to produce this effect. For example, perhaps salmon need to be coming through the pass at a certain flux or height in the water column for the seals to reach such increased capture rates.

Results demonstrated a clear pattern in foraging as a function of tidal phase (Figure 2, 3). The vast majority of foraging events occurred during flooding tides. Seal presence very closely followed this pattern, as hypothesized (Figure 5, 6). If increased foraging events resulted from the higher number of individuals present, there would be no variability in per capita capture rates with respect to tide (Figure 4). Although said variability did not produce significant differences, I believe that it is due to the large magnitude of zeros involved in observational survey data. Patterns in per capita capture rates, in conjunction with patterns in proportions of non-zero capture rates, sufficiently support the trend of increased seal foraging during flooding tides.

My hypotheses regarding non-salmon predation events, i.e. forage fish, were not supported by these data due to a lack of definite observations. Forage fish attack rate approximations could be improved by enacting boat surveys involving non-disturbing, close proximity observations to quantify harbor seal participation in avian forage flocks as Zamon (2001) performed. This technique would still be an overall underestimation, as seals do not feed exclusively in a cooperative nature with sea birds. Deploying underwater cameras in Cattle Pass would be another approach to better quantifying harbor seal predation on forage fish (Zamon 2001).

It should also be noted that this study was originally executed in order to allow comparison to results of seal distribution and foraging in Cattle Pass from 1996 and 1997. Unfortunately, raw from these years are unavailable, making statistical analysis difficult. Based on comparison of figures alone, it appears as though changes have occurred in the seal population present in Cattle Pass, as well as corresponding per capita capture rates of large fish. These changes have the potential to affect salmon populations present in the channel. A basic approximation of total captures observed divided by total hours observed indicates that more fish are being captured over time with rates of 0.24, 0.54 and 0.83 captures hr^{-1} in 1996, 1997 and 2010, respectively. In order to accurately analyze any changes in harbor seal impact, one would first need to use per capita capture rates, a form of centralized seal count, and historical tidal current data to calculate the number of fish captured in Cattle Pass during each year.

Regardless of impact, I believe the results of this study have supported the potential for harbor seals to act as indicators of their prey base in a specific area. These data lack a mode of calibration for seal foraging. To correctly utilize seals in this manner, one would need to take an independent measure of salmon, or another fish population of interest, traversing Cattle Pass to calibrate harbor seal foraging against. Furthermore, one would have to address the relative influences of prey abundance versus availability on seal foraging. Increases in foraging could be attributed to changes in the nature of prey availability or distribution, such as a shift to swimming higher in the water column. I believe that this additional information, along with my initial assessment that seal foraging reflects expected trends in salmon presence, will allow for successful calibration of harbor seal foraging. Harbor seals have the capacity to be utilized as useful indicators of salmon stocks migrating through Cattle Pass.

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