

**Diurnal and Nocturnal Behaviors of Harbor Seals (*Phoca vitulina*) in the San Juan
Islands, Washington during Summer 2023**

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ABSTRACT

Harbor seal (*Phoca vitulina*) foraging has been well documented during the day, however, research shows that harbor seals frequently feed at night. Our study investigates both the diurnal and nocturnal feeding behavior of harbor seals in the San Juan Islands from August 8-12th, 2023. Diurnal observations near Cattle Pass collected data on dive frequency and surface behavior while nocturnal observations at Friday Harbor Laboratories dock collected data on prey species, foraging duration, as well as strike and success rate. Results from diurnal observations indicated an increase in seal abundance and dive frequency during slack and flood tides which is consistent with the tidal coupling hypothesis. Anecdotal results also showed synchronized group diving, demonstrating evidence for cooperative foraging behaviors. Nocturnal observations identified Pacific sand lance as the primary prey during night feeding. Furthermore, with every additional seal, dive duration decreased, while strike and success rates increased, implying cooperative or opportunistic feeding strategies. Our findings showcase the importance of nocturnal studies and we urge further research to be conducted to better understand the strategies behind nocturnal feeding.

Keywords: San Juan Channel, harbor seal, *Phoca vitulina*, behaviors, nocturnal, cooperative foraging, tidal currents

INTRODUCTION

With the passing of the Marine Mammal Protection Act in 1972, harbor seal (*Phoca vitulina*) numbers in Puget Sound have increased exponentially (Jeffries et al. 2003).

Harbor seals inhabit a vast range in the San Juan Island Channel and exhibit multiple foraging and surface behaviors. Harbor seals tend to forage within about 10 km from their haul-out site and are generalist piscivores, feeding on many species in the Puget Sound such as herring, cod, rockfish, and sand lance (Hammill and Stenson 2000; Lance and Jeffries 2009). The various tidal phases and currents in the San Juan Islands have been shown to concentrate copepods in near-surface waters leading to increases in Pacific herring and sand lance that prey on them (Zamon 2003). This in turn results in optimal foraging habitat for species in higher trophic levels such as pinnipeds.

Likely due to their small size harbor seals exhibit a maternal foraging cycle atypical of most phocid species in which they leave their young to feed during mid-lactation (12 days) (Boness et al. 1994). After this period of lactation, the harbor seals depart for increasing hours in the night to feed (Miller 1988). When foraging at night harbor seals tend to make shallower dives than those made during the day (Boness et al. 1994). This results in males making shallow dives to maximize their encounters with females that are leaving haul-out sites in the evening (Coltman et al. 1997). Thus during the pupping and breeding season (June-September) harbor seals are often foraging in shallow nearshore waters.

Recent literature analyzed data from 2014-2019 suggesting that harbor seals exhibit cooperative foraging techniques. Researchers found that the increased presence of seals correlated with higher chances of successful individual foraging attempts. While this finding is relatively recent, similar patterns have been observed in other pinniped species. Even so, the researchers could not conclusively say that the increase in success was

attributed to cooperative foraging, as it may be a result of factors like prey sharing, scavenging, or opportunistic advantages (Freeman et al. 2022).

To clarify patterns in harbor seals foraging behavior, we conducted both diurnal and nocturnal observations between 8-12 August 2023. We used diurnal observations of harbor seals to assess the frequency of dives and surface behaviors. Nocturnal observations were used to evaluate harbor seal dive duration, strike rate, rate of successful strikes, and diet. Finally, we used diurnal and nocturnal results to assess if seals were engaging in cooperative feeding.

METHODS

Diurnal

Observation Area

We conducted observations near Cattle Pass in the San Juan Channel, at the southern tip of San Juan Island from Hunt's Point (48°27'52.0"N, 122°57'35.2"W) (Fig. 1). This location had been used in previous studies and proved to be a good location to easily see large aggregations of harbor seals during the day (Blyth 2012). Harbor seals were observed within 150 m of the shoreline during daylight hours between 8-12 August 2023.

Field Surveys

Land-based surveys were performed at Hunt's Point across five days, with observation time ranging from 1 to 3 hrs each day. Our survey area consisted of a kelp bed located about 50 m from the shoreline. For a 5 min interval, we recorded the maximum number of seals observed at the surface at one time for an abundance count.

During this interval, we tracked the total number of times the seals dove in the observation area.

Using 10× binoculars, we performed focal animal sampling by observing one harbor seal's behavior for 10 s intervals in a 5 min period. Each behavior was labeled as either vigilance, swimming, diving, resting, chasing, splashing, feeding, or interacting.

Vigilance was identified as a seal frequently turning its head, swimming involved the seal moving in the water, resting was identified as a seal floating or having its eyes closed.

Feeding was noted if the seal surfaced with a fish in its mouth and interaction was noted when two seals were facing one another and very close or touching. If the focal harbor seal left the observer's field of view, the observer transitioned to the next available harbor seal. No behavior was recorded if no harbor seal was present at the 10 s intervals.

Analyses

We analyzed a potential correlation between harbor seal abundance and diving behavior relative to tidal phases in the following way. Observation periods were chosen to represent all possible tidal phases and were identified using deepzoom.com. The tidal cycle was divided into 3 phases: ebb, slack, and flood. Slack tide was represented as a current speed less than 1 kt, whereas ebb and flood tides were speeds equal to or greater than 1 kt. These boundaries were chosen as they evenly divided the data into thirds. We then associated our abundance counts and dive frequencies with these tides. We also created a time budget for our surface behavior observations to analyze what behaviors were the most abundant in the area. We then considered plots with mean values of seals, diving frequency, and surface behaviors with standard error for comparisons.

Nocturnal

Observation Area

We conducted observations at the University of Washington Friday Harbor Laboratories dock (approximately 48°32'43.0"N, 123°00'44.9"W) by inserting a green light into the water about 1 m below the surface (Fig. 2). This was performed from 22:00 to 01:00 each day between 8-12 August 2023.

Field Surveys

Opportunistic land-based surveys were conducted in approximately a 5 m² area. The abundance of prey species was recorded every 35 min and the abundance of harbor seals was recorded every 10 min.

Dive duration was timed in seconds using a stopwatch. The time since the start of the observation period was recorded and the timer would begin once the harbor seal dove. During this, the number of times the harbor seal tried to strike a prey was reported, as well as the moments they succeeded and what prey species they caught. The dive duration ended and was recorded when the focal harbor seal took a breath.

Through distinctive marks and body shapes, all harbor seal individuals that appeared during the observation period were identified: Huxley (male) (Fig. 3a), Heart (female) (Fig. 3b), Hamanda (unknown), and Harvey (unknown).

Analyses

We assessed how the number of seals in the water and the duration of foraging impacted dive duration, strike rate, and success rate. We used the 10 min abundance counts to represent the number of seals in the water for a 10 min period. Since we could not tell when the seals first began foraging for the night, we set the beginning of their foraging period as the start of our observation period, separating the time into 30 min

increments to assess how time spent foraging impacted the seals. We then created plots of mean values \pm one standard error (SE) to assess the correlation between dive duration, strike rate, and success rate with seal abundance and feeding duration.

RESULTS

Diurnal

Abundance & Dive Frequency

Our results show mean harbor seal abundance was three times higher during slack and flood tides than during ebb tides (Fig. 4). Similarly, seal dives per min per seal were greater during slack and flood tides, but much less frequent during ebb tides (Fig. 5). During our diurnal observations, we anecdotally noted many occurrences of seals swimming together and diving synchronously.

Surface Behaviors

Out of our eight observed surface behaviors, swimming was the most frequently observed behavior, followed by resting, diving, and vigilance (Fig. 6). Combined, the four remaining surface behaviors (surfacing, splashing, feeding, and interacting) added up to less than 5% of the total time spent at the surface.

Nocturnal

Prey Species

In our observation area, we reported juvenile salmon, walleye pollock, Pacific herring, and Pacific sand lance. Walleye pollock and sand lance were the most abundant species, however, the harbor seals were shown to continuously only prey on sand lance (Fig. 7).

Foraging Duration

The duration of dives increased during the first 60 min of feeding and then subsequently decreased for the rest of the observation period (Fig. 8). Contrastingly, the number of strikes increased and reached a peak after 120 min of feeding and declined after (Fig. 9). However, the average success rate for all five increments was around 70% (Fig. 10).

Abundance

Our analysis shows that seal diving duration decreased as the number of seals in the observation area increased (Fig. 11). This is the opposite case for strike and success rate as they both increased with increased abundance of seals (Fig. 12, 13).

DISCUSSION

The correlation of high harbor seal abundance and diving frequency with flood tides and slack tides supports the idea that piscivorous feeding activity is coupled to tidal cycles. This is supported by the tidal coupling hypothesis which explains why a constricted channel, such as Cattle Pass, would be a suitable feeding habitat for seals. Notably, the diurnal seals exhibited synchronized, group diving potentially to enhance feeding efficiency, presenting possible evidence for cooperative foraging. Additionally, in our nocturnal studies, we found that harbor seal feeding behaviors changed with increasing abundance of seals. This involved shallower dives and higher catch rates, similarly suggesting cooperative feeding. However, alternative explanations such as opportunistic foraging can't be ruled out. Cooperative and opportunistic feeding may both

contribute to an increased strike and success rate when more seals are present, highlighting the complexity of cooperative behaviors versus individual strategies.

Diurnal

Abundance & Dive Frequency

The increase in abundance and frequency of dives during the slack and flood tides is likely due to the tidal coupling hypothesis (Zamon 2003). The high density of planktivorous fishes occurs most commonly in fast and slow flood tides resulting in an increase in harbor seal abundance during these tides as the harbor seals come to feed. The high dive frequency per seal can similarly be explained by the increase in prey abundance. During ebb tides when prey is less abundant harbor seals would have to dive for longer to search for these less concentrated schools and thus would have a lower dive frequency and longer dive time. Contrastingly, during flood tides when prey abundance is high, harbor seals would need shorter dives to find the prey and thus would have a high frequency of short dives.

Our results showed that harbor seals were also highly abundant during slack tides, which may have resulted in part from our broader definition of slack tide (>1kt). Past studies defined slack tide as less than 0.5 kts, and as such our data included slow flood in our slack tide definition, which explains the high abundance and dive frequency (Zamon 2003).

We noticed that many of the seals would surface apart from each other and then swim together and form small groups. There was usually one seal in the front that would dive and after watching this, the seals in the back of the group would follow and dive moments later. We believe this group diving could potentially be a sign of cooperative

feeding which has been documented in harbor seals and other pinniped species (Freeman et al. 2022). However, we can not disregard alternative explanations such as an opportunistic advantage where one seal follows another so it doesn't have to expend energy finding food itself.

Surface Behaviors

Swimming was the most frequently observed surface behavior likely due to harbor seals aggregating at the surface before group diving. Due to currents in the area, seals would be pushed away from their original location, resulting in swimming at the surface to relocate. Alternatively, this action may be a result of them trying to find other seals that signal better feeding opportunities.

Nocturnal

Prey Species

Previous studies in Puget Sound have identified rockfish, salmon, herring, and gadids as the predominant prey for harbor seals (Ward et al. 2011). However, our results suggest Pacific sand lance is the dominant prey during night foraging. One explanation is that the Pacific sand lances are slower and less skittish than the walleye pollock. Alternatively, sand lances are more energy dense with 21 kJ per gram compared to 12.6 kJ per gram for walleye pollock, making sand lances a more nutritious prey (Perez 1994, von Biela et al. 2019). This is important to consider for conservation decisions as an impact on primary prey species can trigger bottom-up effects that ultimately impact harbor seal populations.

Foraging Duration

The shorter dive duration after 60 minutes can be explained by shallower dives. These shallow dives are evidence of potential fatigue or satiation. However, the strike rate

increased for 120 minutes and the success rate stayed the same. Although the dive duration may be evidence of fatigue or satiation, the strike and success rate show the seals making more shallow dives while feeding more. This can be explained by the number of seals increasing over time, which leads to more fish fleeing to the surface, in turn resulting in shorter dives as the seals feed at the surface more.

Additionally, we noticed that each seal is highly individualized with different nocturnal feeding strategies. At the beginning of our study period, we observed one of the seals diving for longer periods of time and another diving for shorter. However, towards the end of the week, we saw these behaviors swap between the two seals. While more research is needed to assess this, it is important to note for conservation purposes that not only can foraging behaviors vary within a week, but also between individuals.

Abundance

The increase in seal abundance results in an increase in strike rate, showing that seals are feeding more when there are more seals present. Similarly, we noted an 8% increase in success rate for each additional seal present—the same percent increase observed in previous studies (Freeman et al. 2022). While the reason for this increase is unknown, this observation may be explained by cooperative feeding, where the seals work together to increase their chance of catching prey by schooling the fish or scaring them towards the surface. Alternatively, as mentioned earlier, we can not disregard opportunistic feeding as an explanation for this increase, demonstrating the need for further research into individual benefits from this feeding behavior.

CONCLUSION

Our study is the first of its kind in this region and presents an opportunity for future research to incorporate high-speed underwater cameras and aerial surveillance to better understand the nocturnal and diurnal feeding behaviors of harbor seals. Our research proves the importance and value of nocturnal studies, as they provide insight into a large aspect of species' behaviors and foraging strategies. During both the day and night, we found that harbor seals may be exhibiting cooperative feeding behaviors. If studied more, these behaviors could provide insight into more complex feeding behaviors and potential social structures in harbor seals.

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FIGURES

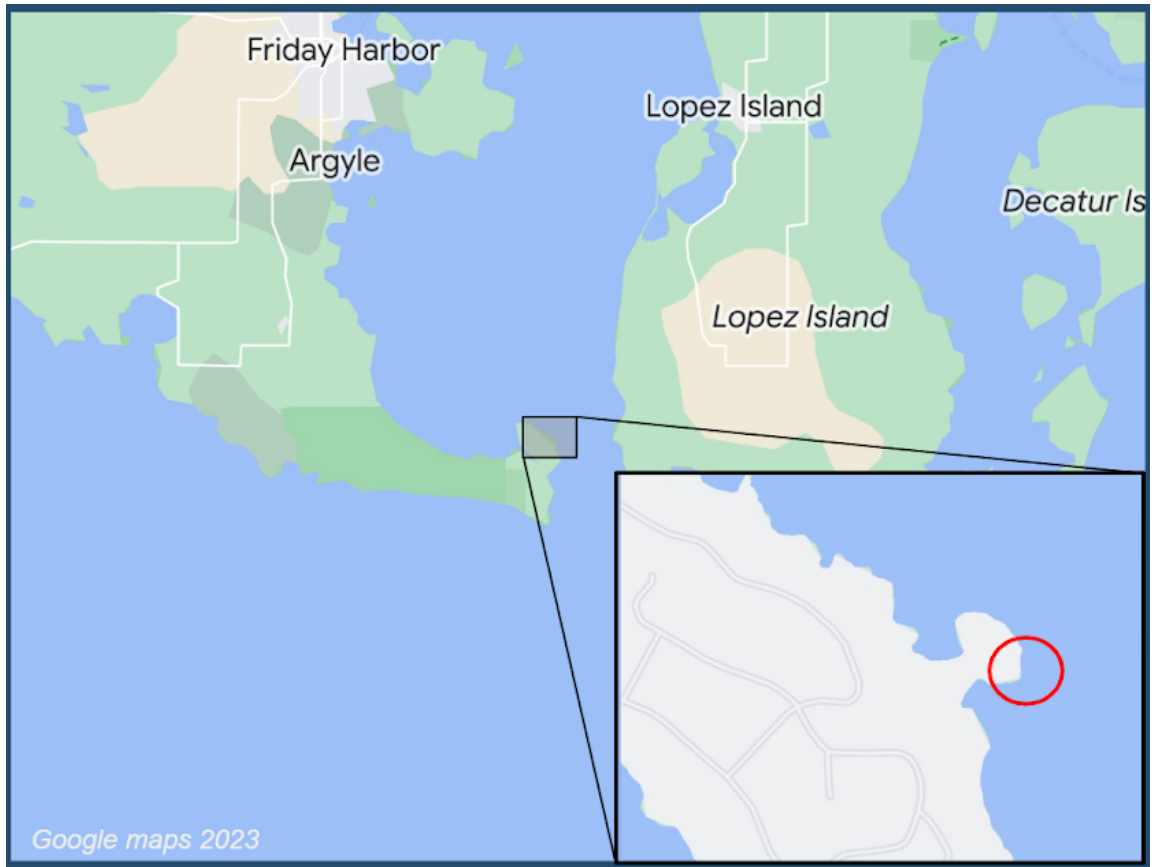


Figure 1: Map of the diurnal survey site, Hunt Point. Seals were observed within 150 meters from the shore, see “Methods” for explanation.

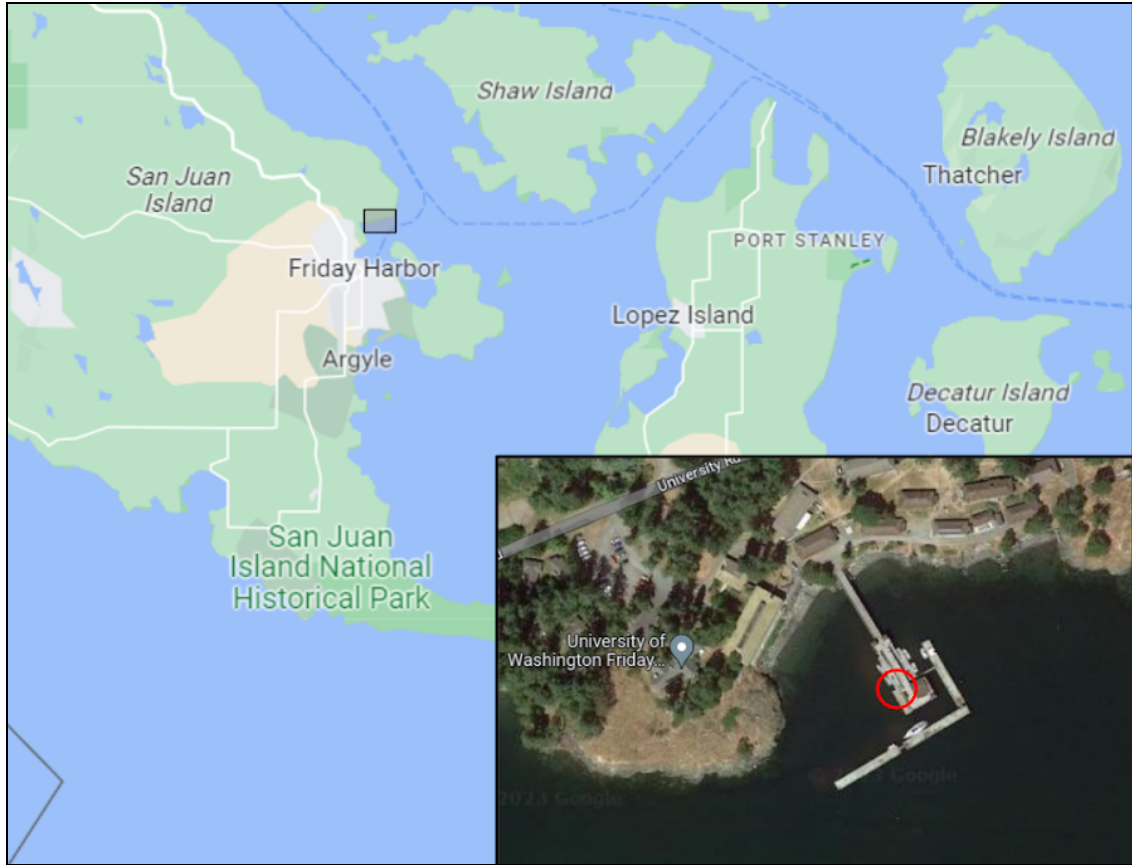


Figure 2: Map of the University of Washington Friday Harbor Laboratories dock, where the nocturnal data were collected.

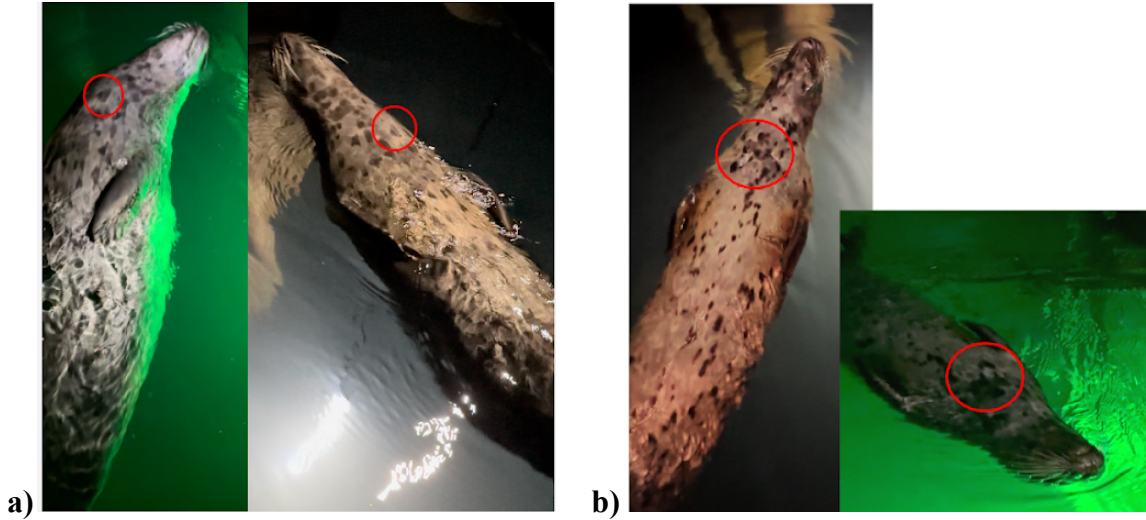


Figure 3: The identifying marks of 2 out of 4 of the harbor seals that we observed during nocturnal observations are circled in red. a) Huxley has a grey triangle with a black dot in the bottom left corner of his chest. b) Heart has a small black heart-shaped mark on her chest near the right flipper. The sex of both harbor seals was determined by Julia Angell.

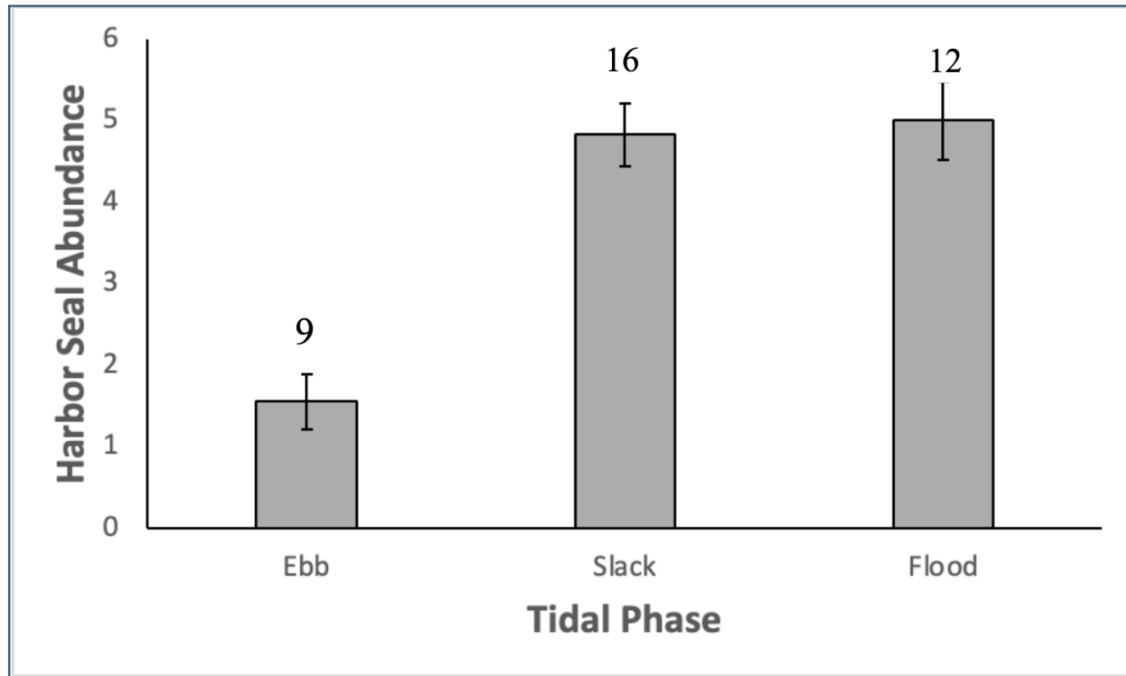


Figure 4: Mean (\pm SE) abundance of harbor seals relative to ebb, slack, and flood tidal phases. Numbers above bars indicate sample size. Data were collected between 8-12 August 2023 at Hunt's Point during the day.

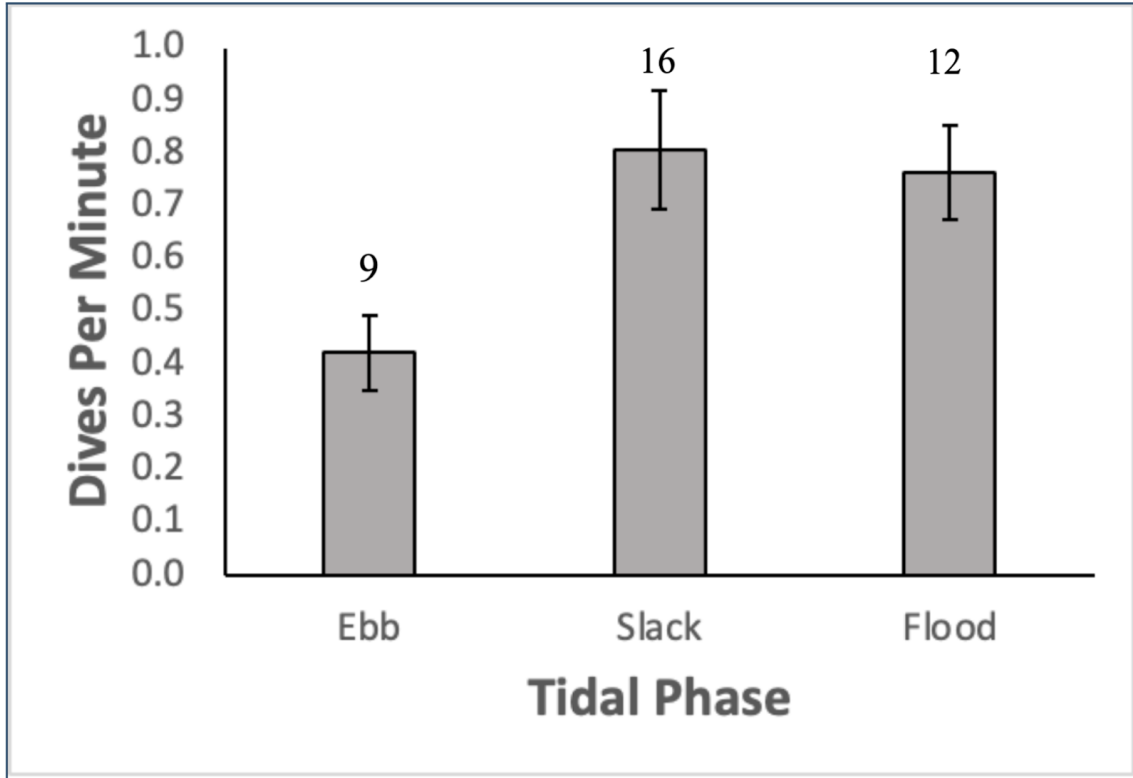


Figure 5: Mean (\pm SE) number of dives per min per individual seal during ebb, slack, and flood tidal phases. Numbers above bars indicate sample size. Dives were identified as a seal going underwater and not resurfacing for at least 3 s. Data were collected between 8-12 August 2023 at Hunt's point during the day.

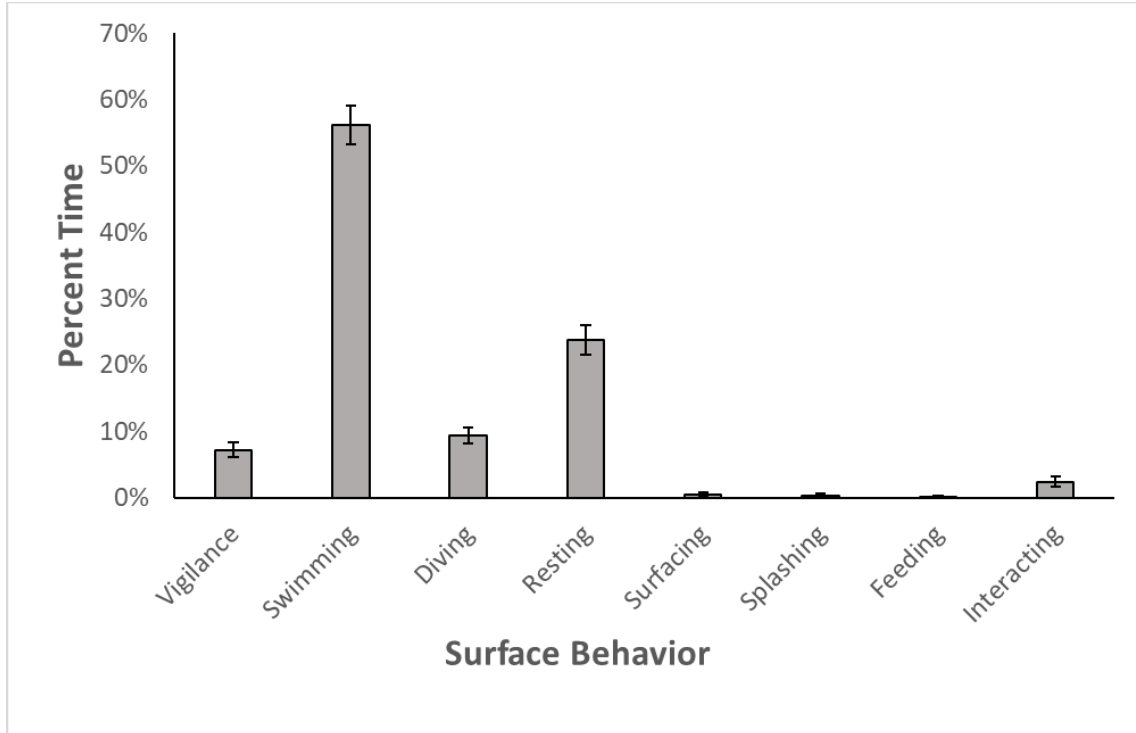


Figure 6: Mean (\pm SE) percent of time at surface spent performing each behavior (n=34). Behaviors were identified by using the explanations in “Methods”. Data were collected between 8-12 August 2023 at Hunt’s Point during the day.

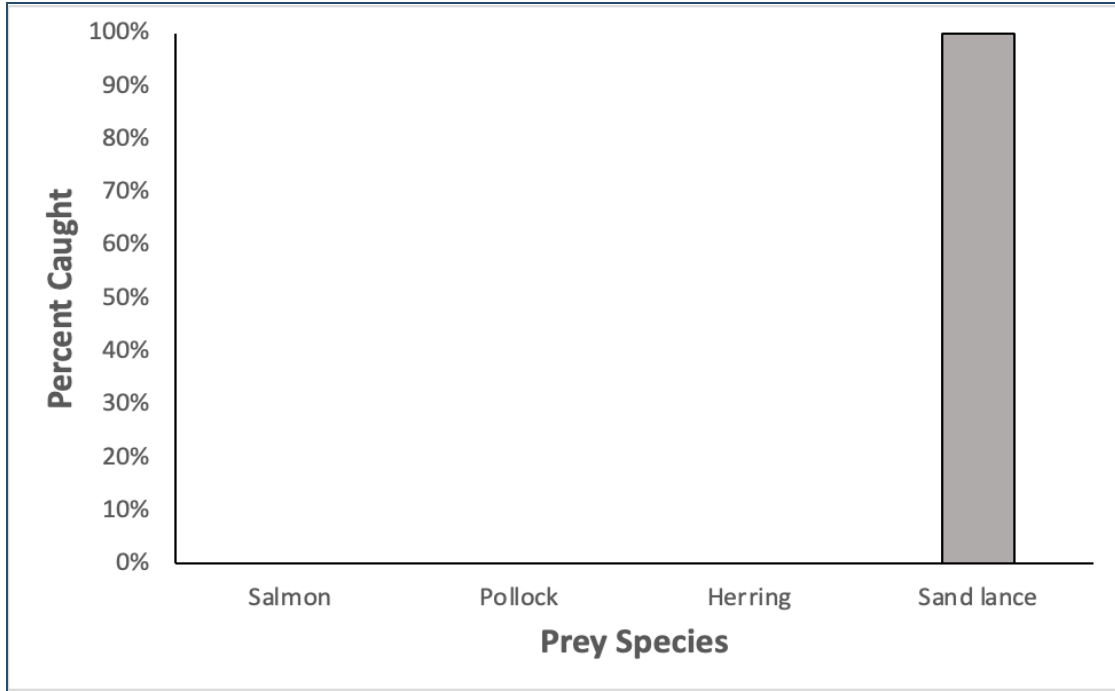


Figure 7: Prey species caught as a percent of the total prey caught across the entire nocturnal study period. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

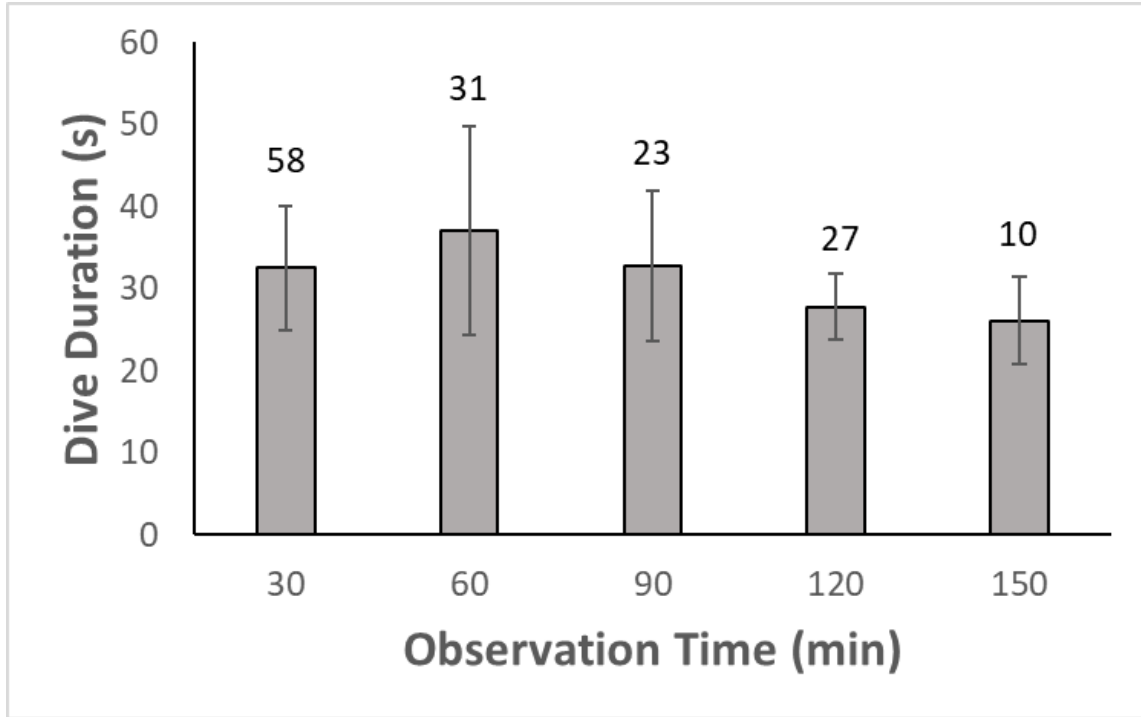


Figure 8: Mean (\pm SE) dive durations in seconds of harbor seals during 30 min intervals throughout the observation period. Numbers above bars indicate sample size. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

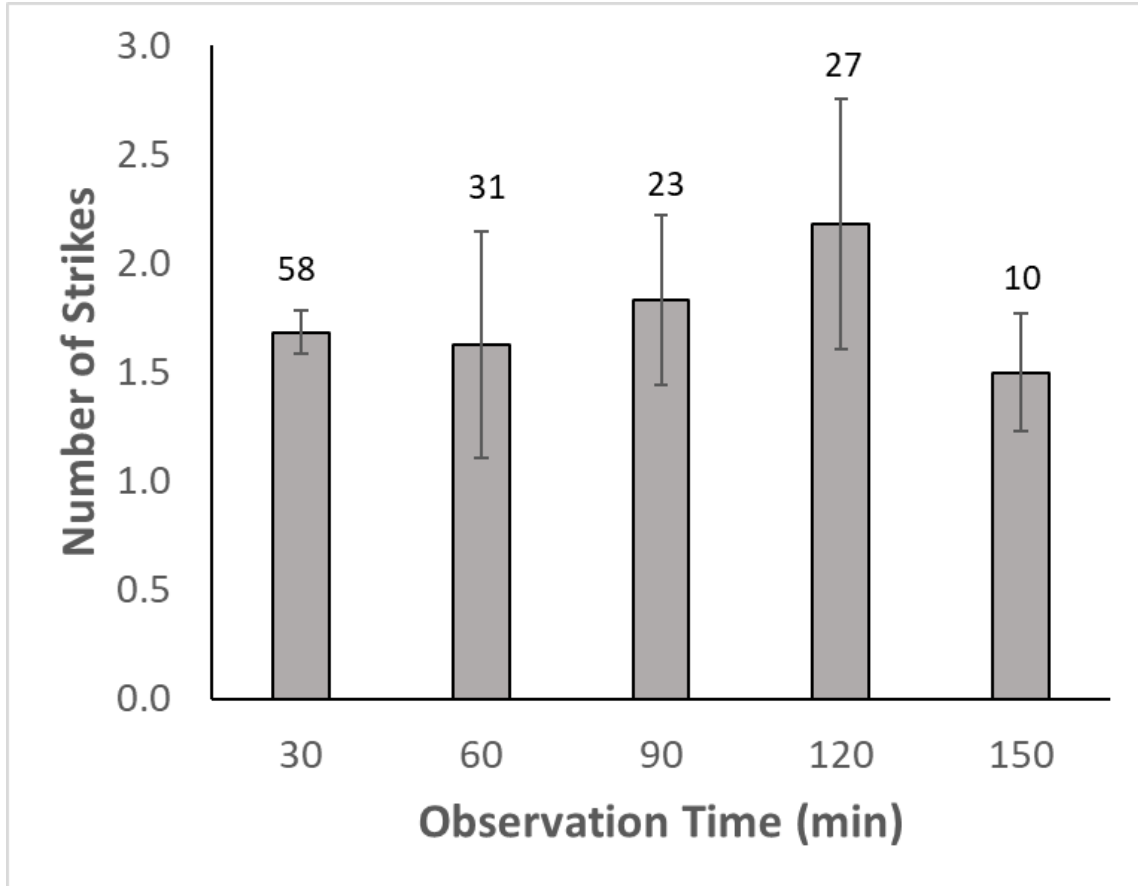


Figure 9: Mean (\pm SE) number of strikes per dive of harbor seals during 30 min intervals throughout the observation period. Numbers above bars indicate sample size. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

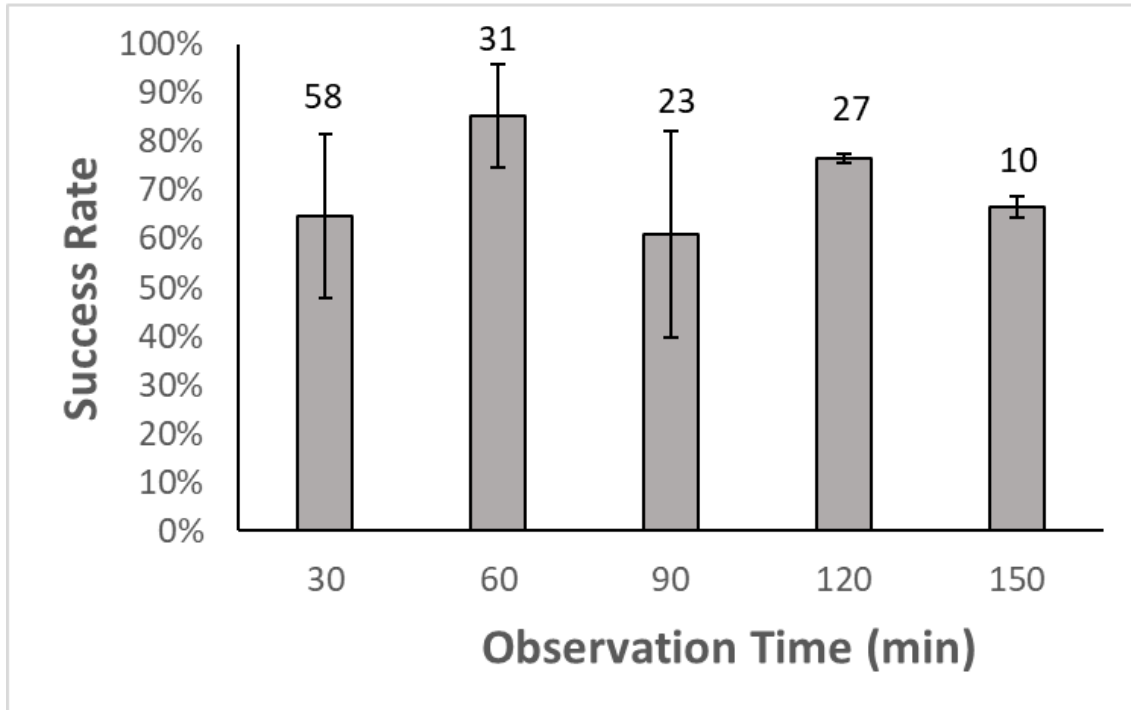


Figure 10: Mean (\pm SE) percent of successful strikes of harbor seals during 30 min intervals throughout the observation period. Numbers above bars indicate sample size. Successful strikes were recorded when a harbor seal would lunge and catch a fish. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

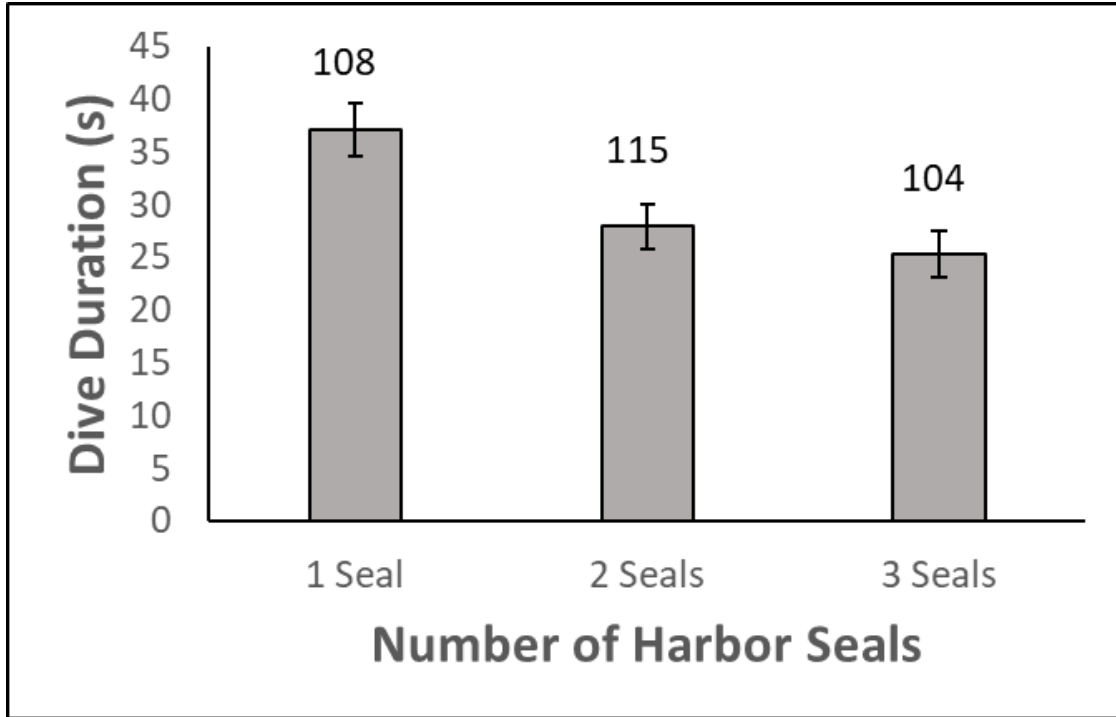


Figure 11: Mean (\pm SE) dive durations in seconds of harbor seals at times when there were one, two, and three harbor seals in the water. Numbers above bars indicate sample size. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

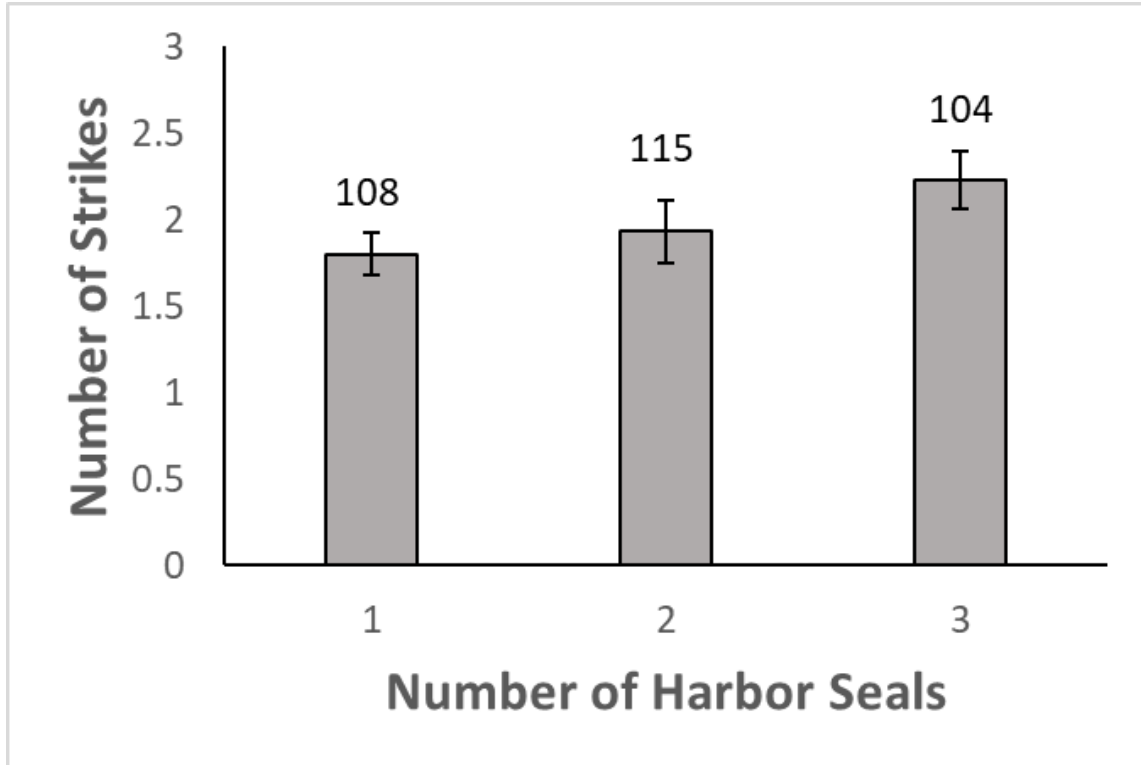


Figure 12: Mean (\pm SE) number of strikes per dive of harbor seals at times when there were one, two, and three harbor seals in the water. Numbers above bars indicate sample size. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.

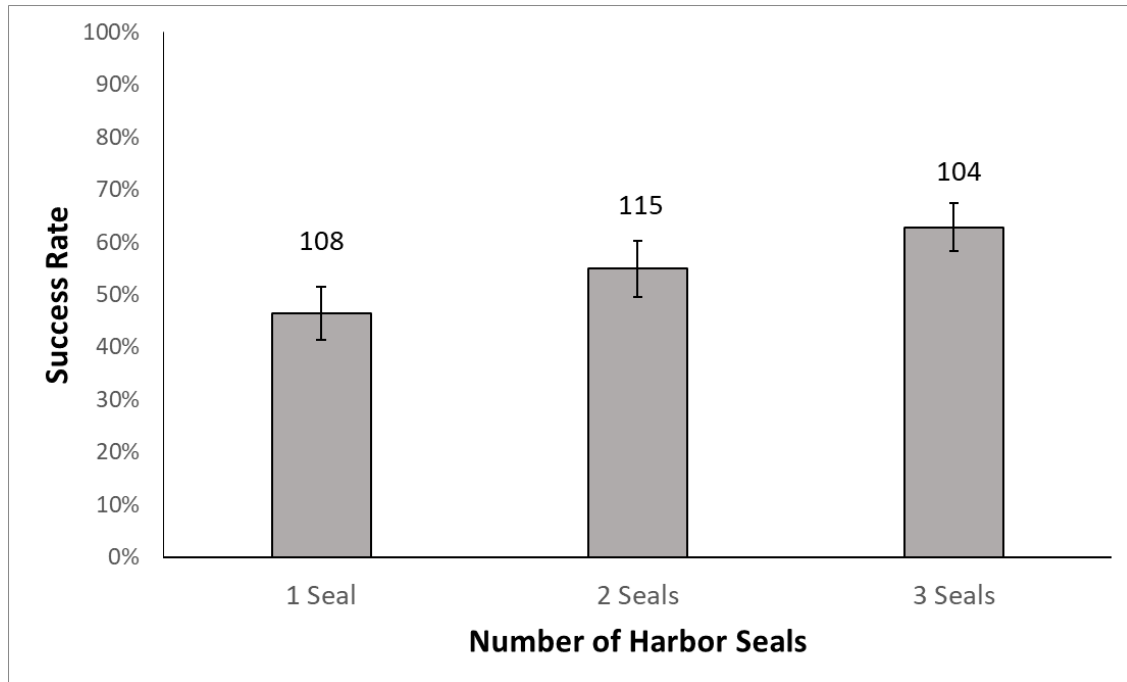


Figure 13: Mean (\pm SE) percent of successful strikes of harbor seals at times when there were one, two, and three harbor seals in the water. Numbers above bars indicate sample size. Successful strikes were recorded when a harbor seal would lunge and catch a fish. Data were collected off the University of Washington Friday Harbor Laboratories dock between 8-12 August 2023 during the night.