Abundance and foraging behavior of pursuit-diving birds in Cattle Pass

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Abstract

Marbled Murrelets (*Brachyramphus marmoratus*), Rhinoceros Auklets (*Cerorhinca monocerata*), and Pelagic Cormorants (*Phalacrocorax pelagicus*) share similar foraging styles, choice of prey, and habitat preference within the San Juan Channel. In this study we used shoreline surveys to compare and contrast the nearshore foraging behavior and abundance of these three pursuit-diving species in Cattle Pass, Washington. We sought to assess tidal and temporal influence on abundance and compare diving behaviors among species, specifically focusing on: dive and rest times, lateral dive movement, and foraging sociality. We found that MAMU abundance peaked in the morning, RHAU were more abundant in the late afternoon, and PECO abundance had a bimodal distribution. Separately, MAMU and PECO were more abundant during fast currents, while RHAU were most abundant nearshore during slack high tide, likely because they were foraging solitarily for their chicks. We observed that the alcid species tended to travel laterally while diving more often than PECO and that among our three target species, foraging sociality was most important in MAMU.

Introduction

Pursuit-diving piscivorous birds are incredibly important to the marine ecosystem in the Salish Sea. When grouped based on foraging style, pursuit divers compose the largest class of tertiary marine birds in the Salish Sea, and their numbers can be enormous during periods of strong current in Cattle Pass, Washington (Vilchis et al. 2014). Their abundance and key role in all marine ecosystems makes understanding their behaviors a crucial part of developing a well-rounded understanding of the Salish Sea ecosystem. Some species of diving birds have faced significant declines due to anthropogenic stressors like climate change, so developing a thorough understanding of their behavior is necessary to ensure accurate species monitoring (Vilchis et al. 2014).

The waters surrounding San Juan Island in the Salish Sea are affected by oceanic influences, resulting in complex changes in tide heights, current speeds, and nutrient availability. Cattle Pass is at the narrowest point of the San Juan channel, serving as an excellent location to observe foraging activity in marine birds. Located between the southern tip of San Juan and Lopez Island, waters flood north into the pass and south into the Strait of Juan de Fuca during ebb. Cattle Pass has strong tidal currents due to its narrow width, steep sides, and position between these two bodies of water (Zamon 2000). The tidal coupling hypothesis suggests that turbulence during fast currents stirs up copepods from the bottom of the pass, causing aggregations of forage fish and, in turn, piscivorous seabirds (Zamon 2003).

Marbled Murrelets are one species of seabird that rely upon Cattle Pass as a feeding site. Their diet consists mainly of small forage fish like sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea* spp.), capelin (*Mallotus* spp.), and shiner perch (*Cymatogaster aggregata*; Strachan et al. 1995). They are deeply connected to the Salish Sea, feeding in the cold, productive waters and nesting in old growth forests along Washington’s coast (Strachan et al. 1995). However, population sizes of these small alcids have declined dramatically and they are now listed as Endangered on the IUCN Red List of Threatened Species (BirdLife International 2020). Blame for this decline is usually attributed to old-growth logging. Most scientific literature investigates the terrestrial factors that are causing declines in this flagship species, however little is known about marine factors that could be influencing their decline. Our study aims to add to the breadth of knowledge of Marbled Murrelets by investigating differences in foraging behavior between them and other piscivorous diving birds, namely Rhinoceros Auklets (*Cerorhinca monocerata*) and Pelagic Cormorants (*Phalacrocorax pelagicus*). We chose our species of interest by identifying the most abundant pursuit-diving seabirds in nearshore waters in Cattle Pass.

Specifically, we collected data on relative abundance throughout different times of day and tidal phases, social elements to diving bouts, dive and rest times, and distance travelled during dives. In this study, we demonstrate correlations between seabird abundance, tides, and time of day. We also display a strong relationship between the physiology of diving birds and their lateral dive profiles. In addition, we compared Rhinoceros Auklet (RHAU) dive times before and after 16:00 because during the breeding season, RHAU self-feed before 16:00 and then forage for larger fish while provisioning (gathering food for their chicks) after 16:00 (Davoren and Burger 1999). We hypothesized that this difference in prey selection might lead to differences in dive times before and after 16:00. Lastly, we identify patterns in foraging sociality among our three species of interest.

Methods

Study Area

This study was conducted at two sites along Cattle Pass on the Southeast end of San Juan Island, Washington (Fig. 1). Cattle Pass has fast moving tidal currents, and a semidiurnal tidal system. Both sites extended to an area about 0.5 km^2 from the shore. Both Hunt Point (48.4643, -122.9596), and Cattle Point (48.4505, -122.9631) provide clear views into the San Juan channel. Both study sites have similar habitats and current features, so we chose to lump our data from each site with one exception - we only analyzed our abundance data from Site 1, because that was the only location where we found Marbled Murrelets.

The area of each study site was determined by shoreline landmarks used to identify north and south bounds. The eastern bound of each site was constrained by the farthest distance we could clearly locate, identify, and follow individual birds with our binoculars.

Field Surveys

To determine differences in abundance and foraging behavior of diving birds, we conducted land-based surveys of Rhinoceros Auklets, Pelagic Cormorants (PECO), and Marbled Murrelets (MAMU) over a period of seven days (August 7-13, 2021). When needed, we used 10x24 binoculars to observe birds further in the channel. Focal surveys were conducted in 10 minute periods with two observers and one recorder. Using a stopwatch, we recorded dive and resurfacing times, to determine the length of dive and rest times within a dive bout. In between dive surveys, we conducted brief point count surveys of total seabird abundance within the study site. A total of 49 dive surveys and 53 abundance surveys were conducted. During dives, we recorded lateral travel distance, and sociality (whether individuals were diving solo, in pairs, or in groups). Sociality was defined as members of the same species, and we did not record larger mixed species flocks that occurred further in the channel. To determine lateral travel distance, we used visual estimates and topographic features to gauge whether the individual resurfaced in the same spot or traveled sideways from its initial location. To improve accuracy, one observer maintained their focus on the original dive spot, while the other observer noted where the individual resurfaced.

Over the seven days of data collection, our surveys were conducted over all tidal phases. We divided the cycle into eight phases: slack low, flood 1, fast flood, flood 2, slack high, ebb 1, fast ebb, and ebb 2 (Fig. 2), all eight of which occur each day (Fig. 3). Tidal phases were determined using Cattle Point Lighthouse, San Juan Island using WillyWeather.

Data Analysis

For the relative abundance analysis, we only used abundance counts from Site 1 (n = 34), because we did not observe any MAMU at Site 2. We calculated the mean relative abundance (number of individuals) of each species for each of the following two hour periods: 09:00-10:59 (n = 9), 13:00-14:59 (n = 9), 15:00-16:59 (n = 9), 17:00-18:59 (n = 2), and 19:00-21:00 (n = 5). We also calculated the mean relative abundance of each species for each of the eight tidal phases (ebb 1: n = 3, fast ebb: n = 2, ebb 2: n = 2, slack low: n = 5, flood 1: n = 8, fast flood: n = 4, flood 2: n = 3, slack high: n = 7).

Several different metrics were used to assess diving behaviors. Data from Site 1 and Site 2 were combined for this analysis. For each species, we calculated mean dive (MAMU: n = 67, RHAU: n = 110, PECO: n = 83) and rest times (MAMU: n = 56, RHAU: n = 104, PECO: n = 70). We also calculated the mean dive times of RHAU before (n = 65) and after (n = 45) 16:00. For each species, we also calculated the percentages of dives (MAMU: n = 67, RHAU: n = 102, PECO: n = 83) for which the lateral distance traveled from dive point to resurfacing point was estimated to be less than or equal to five meters and greater than five meters. Lastly, we calculated the percentages of focal individuals of each species (MAMU: n = 10, RHAU: n = 14, PECO: n = 18) that dove alone, in pairs, and in groups.

We calculated 95% confidence intervals for all mean values using the equation for the standard normal distribution: $CI = \underline{x} \pm 1.96\frac{s}{\sqrt{n}}$, where $\underline{x}$ is the sample mean, $s$is the sample standard deviation, and n is the sample size. We considered mean values to be significantly different if the 95% confidence intervals did not overlap.

Results

Relative Abundance by Time of Day

We found that the relative abundance of each species varied by time of day (Fig. 4). MAMU mean abundance was significantly greater from 9:00-10:59 (5.2 ± 1.6 individuals) than it was for all other time periods. Mean RHAU abundance increased throughout the day. The latest time period was significantly greater than the earliest two, with a mean of 2.6 ± 1.3 individuals. Mean PECO abundance followed a bimodal pattern, peaking in the morning from 9:00-10:59 (1.8 ± 1.5 individuals) and again in the afternoon from 17:00-18:59 (3.5 ± 1.0 individuals).

Relative Abundance by Tidal Phase

Relative abundance of each species also varied by tidal phase (Fig. 5). MAMU mean abundance followed a roughly bimodal pattern, with a larger peak during fast ebb (7.0 ± 3.9 individuals) through ebb 2 (5.5 ± 0.98 individuals) and smaller peaks during fast flood and slack high. PECO mean abundance followed a stronger bimodal pattern with one peak during fast ebb (5.5 ± 2.9 individuals) and another during fast flood (4.8 ± 2.2 individuals) through flood 2 (4.0 ± 1.1 individuals). Mean abundances during these three tidal phases were significantly greater than those of all other phases. Mean RHAU abundance was zero during ebb phases. Mean abundance increased slightly throughout the flood phases and was greatest at slack high (2.3 ± 1.0 individuals).

Dive and Rest Times

Mean dive times (Fig. 6) were not significantly different among species, but there were some significant differences among mean rest times. Also, each species' mean dive time was significantly longer than its mean rest time. MAMU mean dive time was 44 ± 5 sec. and mean rest time was 29 ± 5 sec. The mean dive time for PECO was 49 ± 6 sec. and mean rest time was 32 ± 8 sec. RHAU mean dive time was 42 ± 7 sec. The RHAU mean rest time of 14 ± 3 sec. was significantly shorter than those of the other species. We found no significant difference between RHAU mean dive times before and after 16:00 (Fig. 7).

Lateral Dive Distances

We found that MAMU and RHAU travelled laterally during dives more often than PECO, which had a more vertical dive profile (Fig. 8). MAMU traveled greater than five meters during 72% of dives, RHAU during 67% of dives, and PECO during 48% of dives.

Foraging Sociality

The majority of MAMU focal individuals foraged in pairs or groups, while the majority of PECO and RHAU foraged alone (Fig. 9). 50% of MAMU focal individuals foraged in pairs, 20% foraged in groups, and 30% foraged alone. In contrast, 79% of RHAU individuals foraged alone, 21% foraged in pairs, and none foraged in groups. 72% of PECO focal individuals foraged alone, 11% foraged in pairs, and 17% foraged in groups.

Discussion

We found that the abundance of pursuit-diving birds in Cattle Pass varied with both time of day and tidal phase. Diving times were consistent among species, but lateral dive movements and foraging sociality varied among species. Both MAMU and RHAU were more likely to resurface greater than five meters from their initial diving spot, while PECO were more likely to resurface in the same location. RHAU and PECO usually foraged alone, while about half of MAMU focal individuals foraged in pairs. Our findings align with literature that suggest RHAU forage solitarily close to shore after 16:00 (Davoren and Burger 1999). The data was also in agreement with literature stating that MAMU are highly social divers that often dive synchronously in pairs (Strachan et al. 1995). Additionally, our study supports the finding that seabird abundance in Cattle Pass is affected by tidal coupling (Zamon 2000, 2003).

Although we observed trends in abundance with both time of day and tidal phase, we were unable to conclude which factor had a greater influence on abundance. This is because there was little variation in the timing of tidal phases within our week-long study period. The tidal coupling hypothesis suggests that fast currents create turbulence in the direction of the tide, bringing prey to the surface (Zamon 2000, 2003). At Site 1, we should expect to see the highest seabird abundance during fast flood tides, when currents are flowing north. Though both PECO and MAMU had higher abundances during fast flood periods, they also had high abundances during fast ebb tides. This could be explained by the physical features of Hunt Point. A combination of the topography and the surrounding bathymetry create strong nearshore eddies during fast tides, which likely aggregate prey. It was visually observed that both PECO and MAMU favored foraging in these nearshore eddies. RHAU abundance did not follow the same bimodal pattern. They were the most abundant in the evening during flooding and high tides.

This is likely due to adults provisioning near shore during the evening and tidal coupling aggregating prey during flood tides.

Our analysis aligns with literature suggesting that diving birds forage in bouts. During a dive bout, they dive multiple times in succession and usually spend less time resting at the surface than they do diving (Butler and Jones 1997). Longer rest periods between dive bouts are needed to replenish oxygen stores and potentially to reduce the buildup of lactic acid, a byproduct of anaerobic respiration (Butler and Jones 1997). We found that dive times were similar among species, but rest times were significantly shorter than dive times for each species. These differences are explained by our sampling methods. We only recorded rest times within active diving periods. All observed species had longer inactive periods between dive bouts that were not recorded. Taking this into account, RHAU had significantly shorter rest times during dive bouts than the other species. This could potentially suggest that RHAU employ a different diving strategy than PECO and MAMU, in which rest periods within dive bouts are shorter, but rest periods between bouts are longer.

Interestingly, our data did not indicate differences in dive times for RHAU before and after 16:00. We assumed a difference in prey selection between provisioning and non-provisioning adults would impact dive times, but did not observe this difference. While there could, in reality, be no difference in dive times between provisioning and non-provisioning adults, our findings could also be explained by limitations in our study design. We did not distinguish between provisioning vs. non-provisioning individuals, which could explain why no differences were detected. We also only focused on nearshore individuals, who may have different diving behaviors than self-feeding RHAU that forage in mixed-species flocks farther offshore.

Differences in lateral dive distances likely have a physiological explanation. RHAU and MAMU are part of the family Alcidae, who are wing-propelled divers. Being able to use their wings underwater makes them fast and agile swimmers who are able to chase prey underwater and swim laterally (Watanuki et al. 2006). On the other hand, PECO are foot-propelled divers, who forage on fish and often feed benthically (Kato et al. 2006). However, due to the bathymetry of our study sites, we can assume that PECO individuals were not feeding benthically. Both sites had deep water that dropped off where individuals were diving (Fig. 10). This means that PECO likely fed on similar prey species to RHAU and MAMU. Despite this similarity, PECO more frequently surfaced in the same area that they dove. This indicates that they could have a more vertical diving profile. Being restricted to only foot-propelled diving limits mobility, especially in strong currents (Kato et al. 2006). We observed PECO periodically dipping their heads in the water prior to diving. It seems that individuals were timing their dives, rather than chasing their prey laterally, like MAMU and RHAU. This physiological difference between foot-propelled and wing-propelled birds may be what influences these variances in lateral dive distance between species.

Sociality is commonly observed in all of our focal species, but varies during dive bouts. As expected, MAMU had the highest sociality. They often dove and resurfaced synchronously, maintaining pairs for multiple dives. This suggests that MAMU watch their partner underwater and time their dives together. Literature indicates that not all diving pairs are breeding pairs, which suggests that pair diving may be more related to collaborative hunting than maintaining social bonds (Strachan et al. 1995). However, literature on pair foraging is limited and the purpose of this behavior is still unknown (Strachan et al. 1995).

Results must be interpreted with caution, due to a limited study period and potential bias in our data. There may be greater tidal or temporal influences that we were unable to detect with our short data collection period. Additionally, limiting our study site to only nearshore surveys eliminates individuals that feed in the channel and in flocks. A longer study over the period of a season may help reduce these biases. Using a viewfinder to better estimate distance and more observers may additionally improve accuracy for future studies. Clarifying studies may be conducted to better understand pursuit-diving behavior such as: assessing social foraging strategies in MAMU and comparing provisioning and non-provisioning dive patterns in RHAU.

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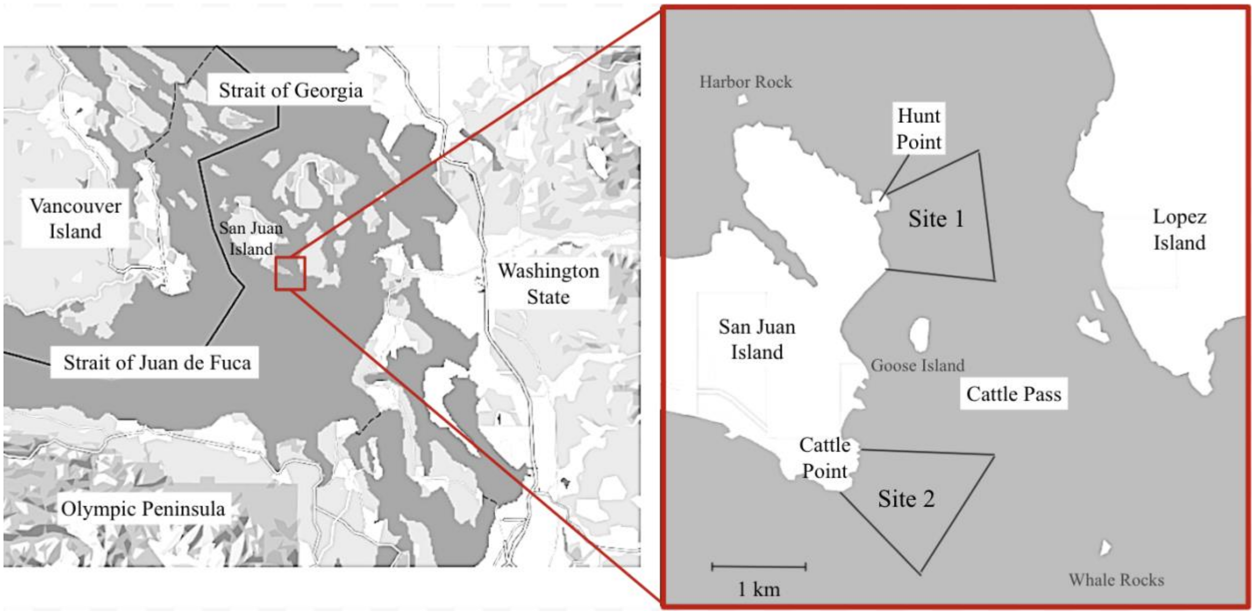

Figure 1. Map of study sites. North/south bounds of each site were defined by shoreline topography and total site area was constrained by the farthest distance we could locate and accurately identify individual birds on the water (Modified from Google Maps).

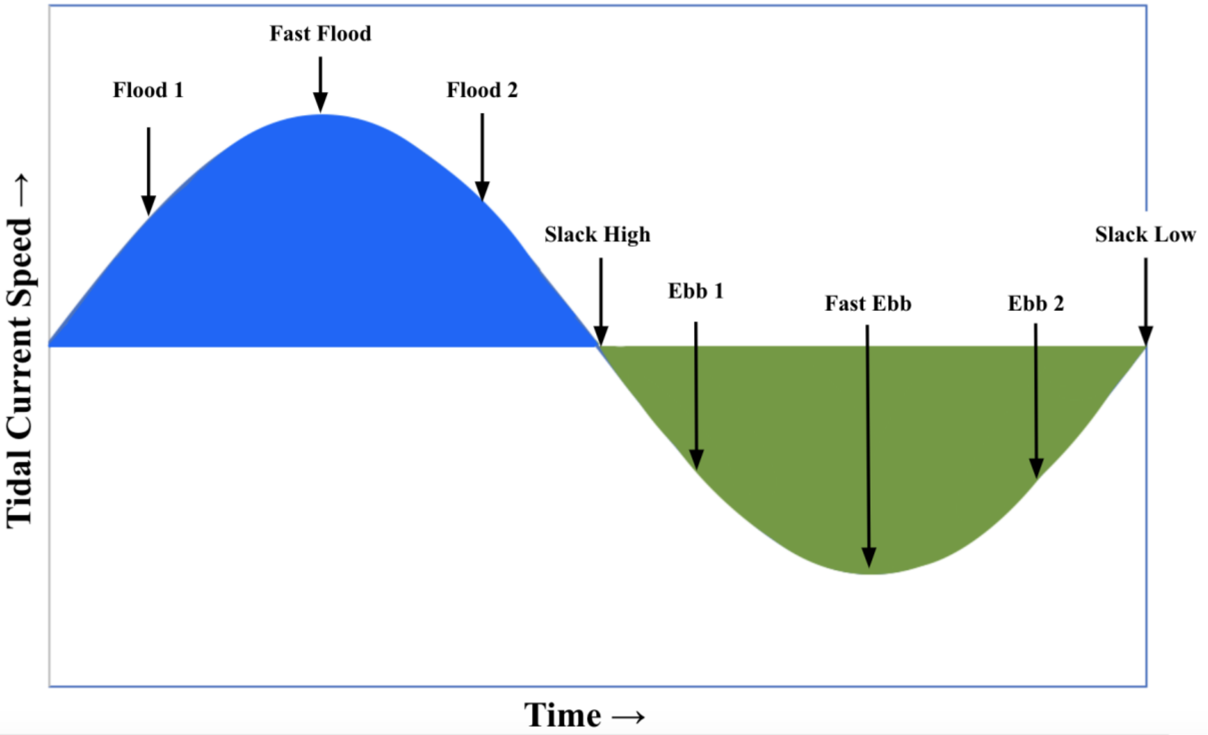

Figure 2. Approximate visual representation of changes in tidal current speed as time progresses through all eight tidal phases.

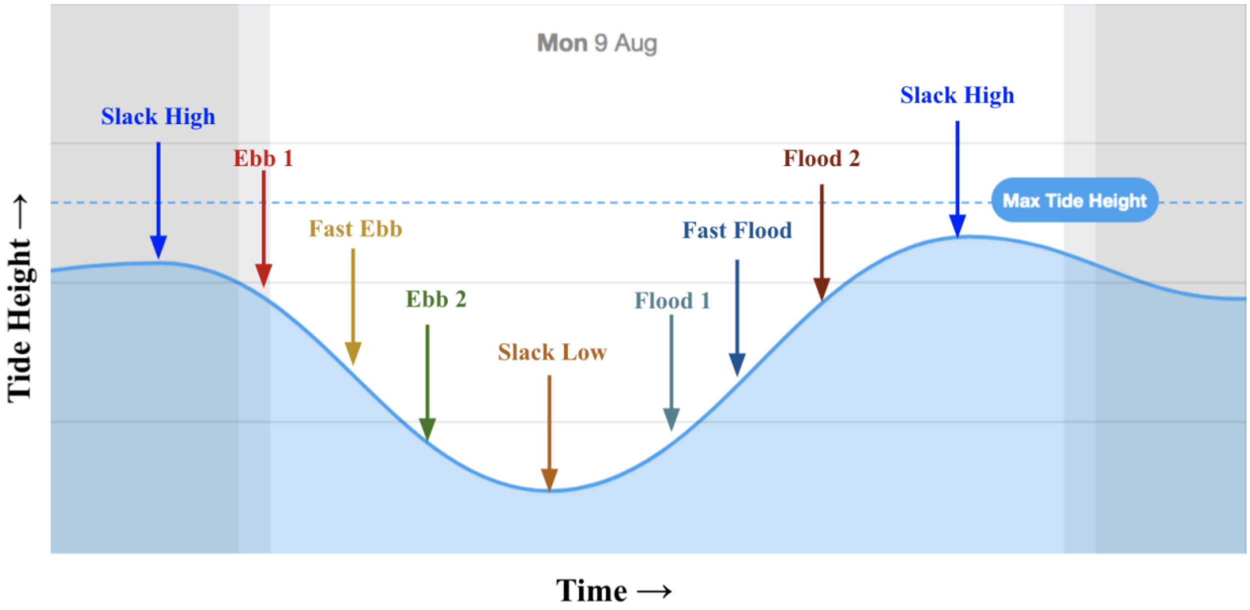

Figure 3. Tide height graph representing a full tidal phase over the daylight hours of 9 August, 2021, one of our data collection days. (Modified from WillyWeather)

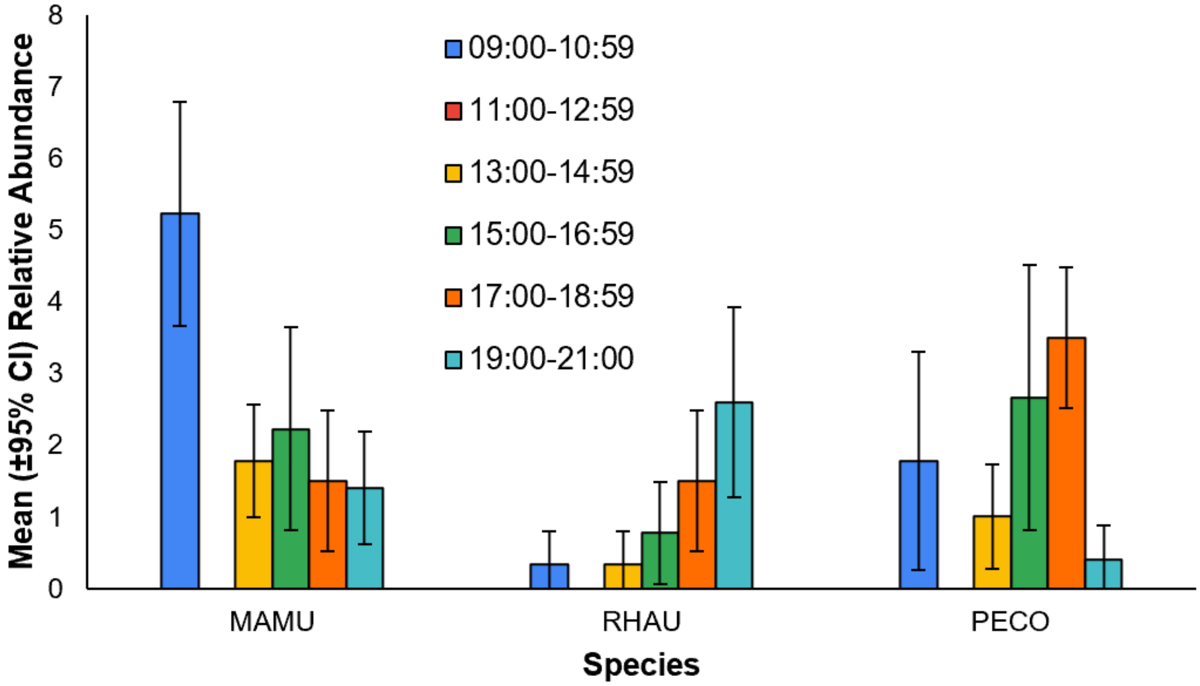

Figure 4. Mean (± 95% confidence interval) relative abundance of MAMU, RHAU, and PECO at Site 1 by time of day. We divided time of day into two hour periods ranging from 09:00 to 21:00. Data was not available for the 11:00-12:59 period.

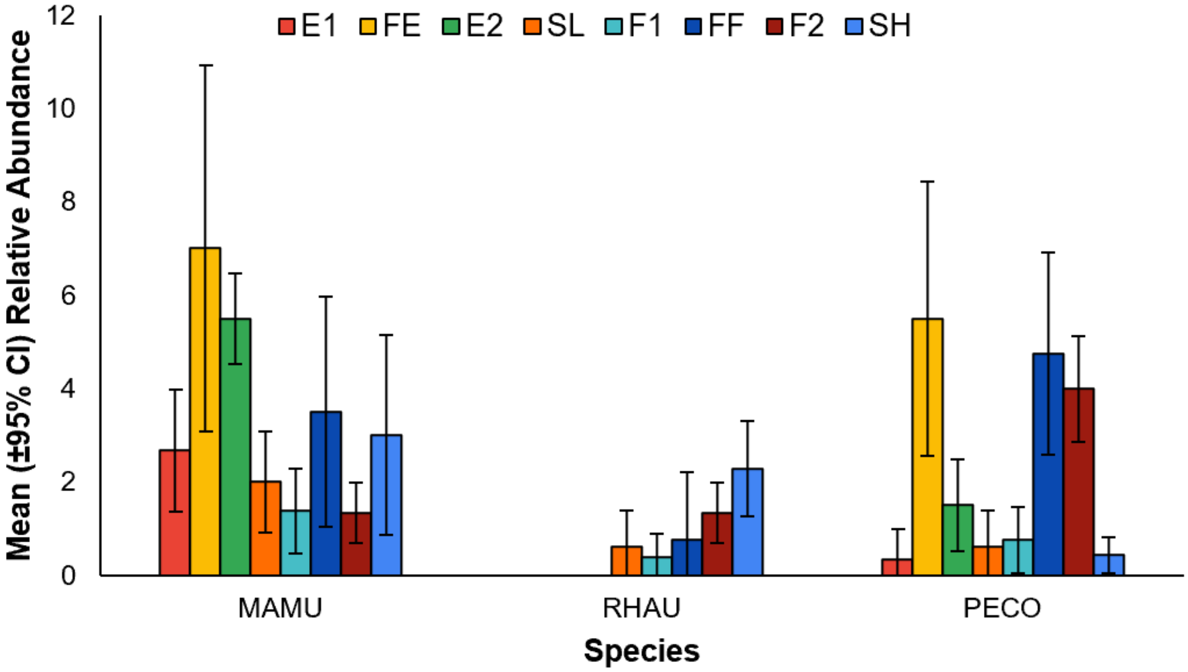

Figure 5. Mean (± 95% confidence interval) relative abundance of MAMU, RHAU, and PECO at Site 1 by tidal phase. Tidal phases were denoted as ebb 1 (E1), fast ebb (FE), ebb 2 (E2), slack low (SL), flood 1 (F1), fast flood (FF), flood 2 (F2), and slack high (SH).

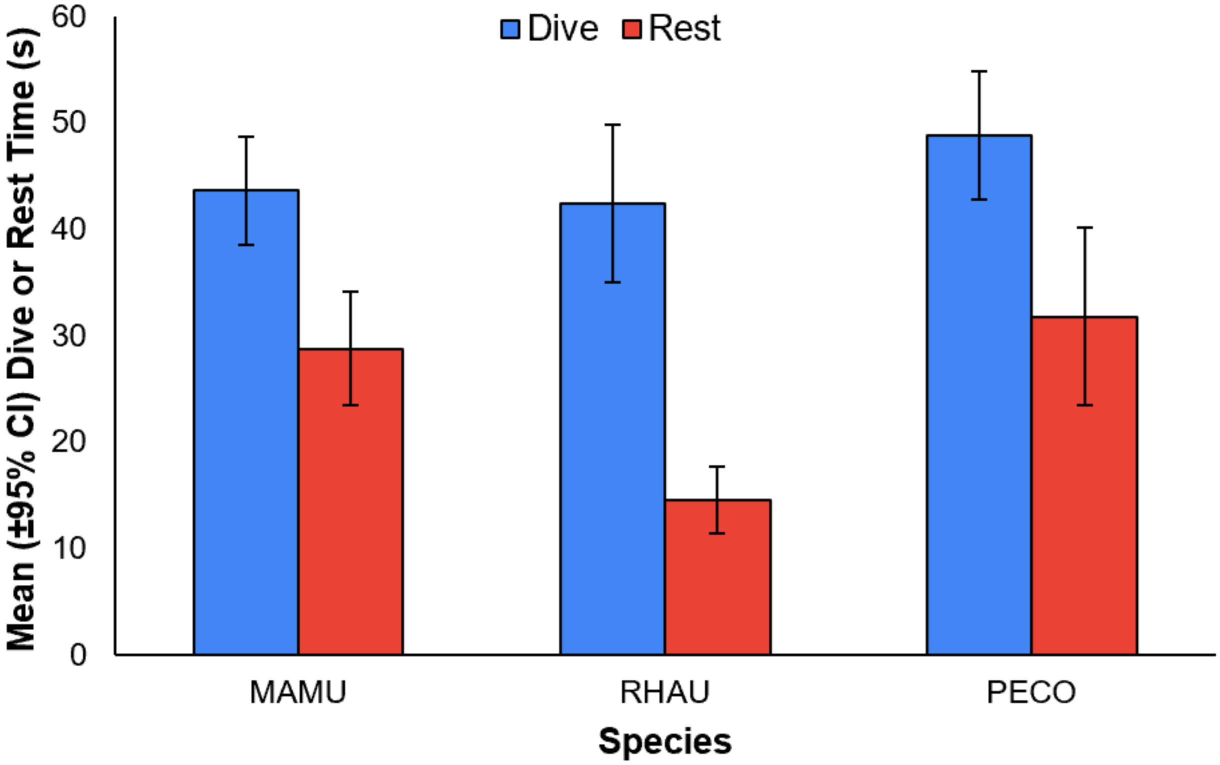

Figure 6. Mean (± 95% confidence interval) dive times (blue) and between-dive rest times (red) in seconds for MAMU, RHAU, and PECO.

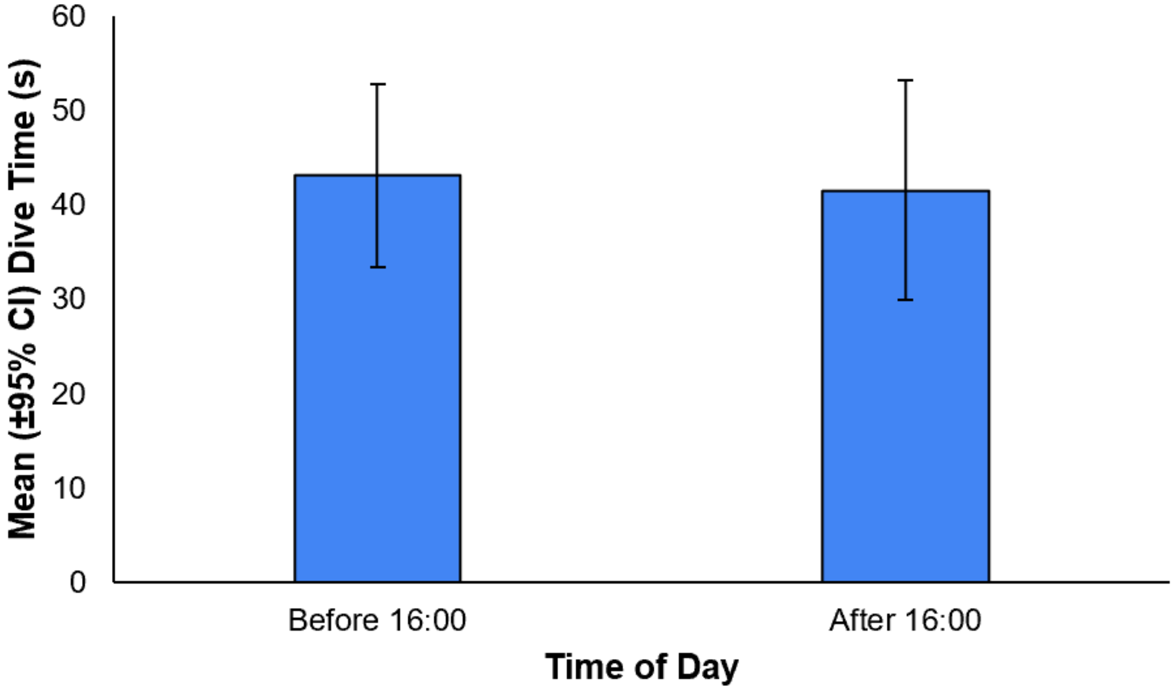

Figure 7. Mean (± 95% confidence interval) RHAU dive times in seconds before and after 16:00.

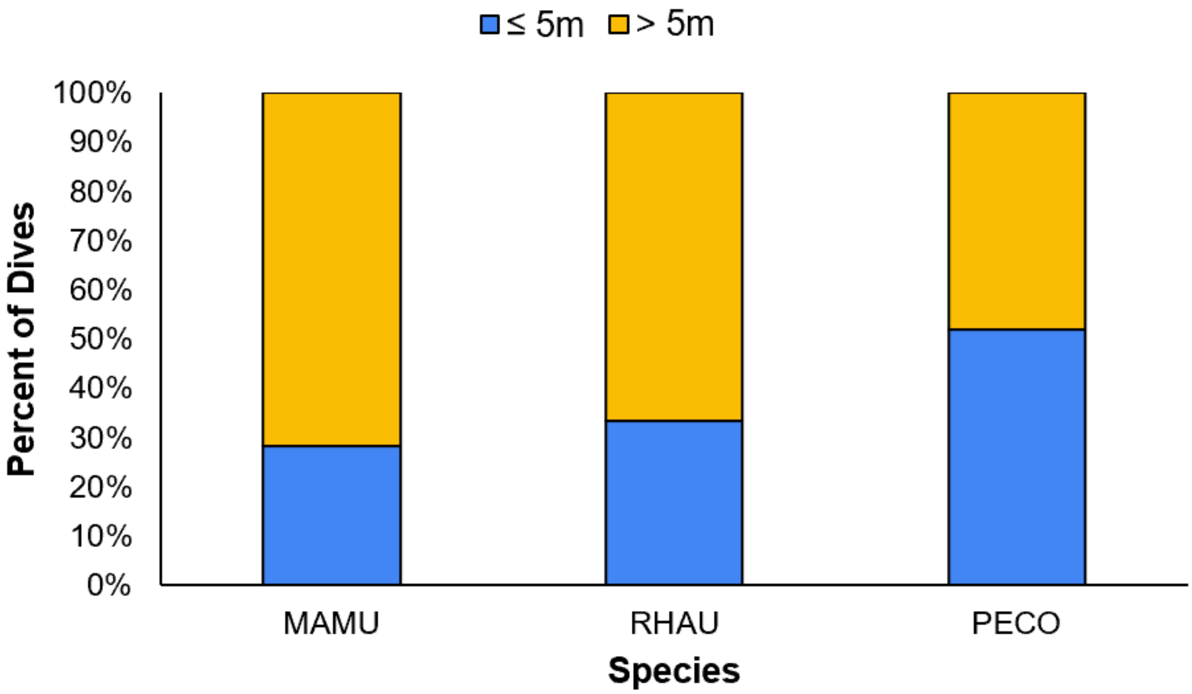

Figure 8. Percentage of dives for which lateral distance traveled was less than or equal to five meters (blue) or greater than five meters (yellow). Lateral distance was defined as the estimated distance between the initial diving location and the resurfacing location.

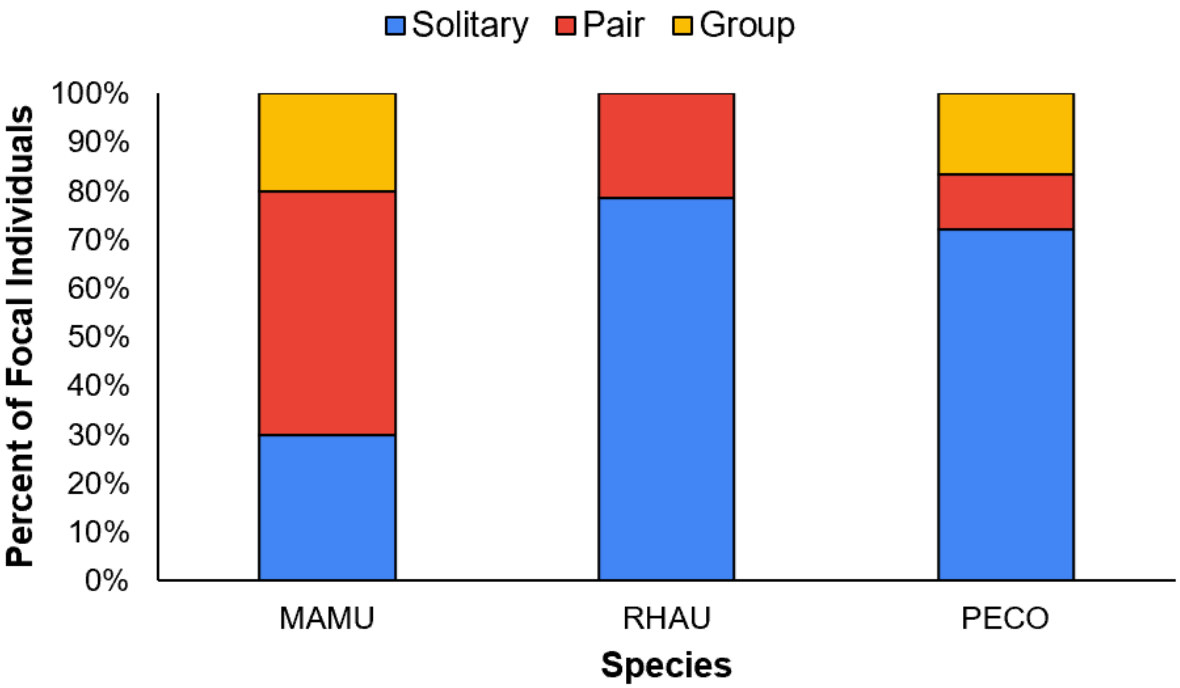

Figure 9. Percentages of focal individuals who foraged solitarily and in intraspecific pairs and groups.

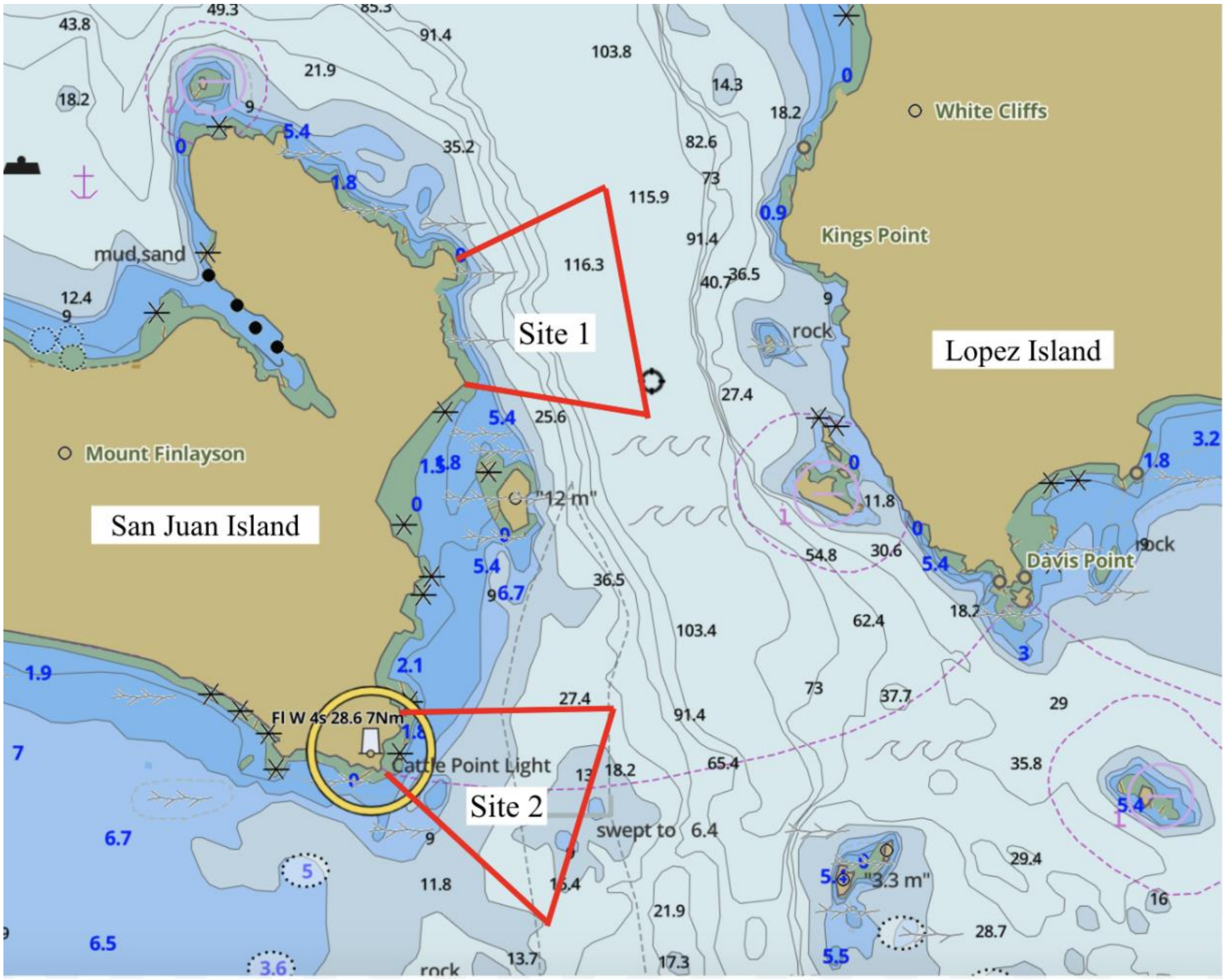

Figure 10. Bathymetric map of Cattle Pass, WA. Showing both study sites and rapid decline in the depth of the ocean floor off the shore of both sites (Modified from GPS Nautical Charts).