TIDAL INFLUENCE ON THE HAUL-OUT BEHAVIOR OF HARBOR SEALS (*PHOCA VITULINA*) AT A SITE AVAILABLE AT ALL TIDE LEVELS

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ABSTRACT—Harbor Seals (*Phoca vitulina*) are the most abundant and widespread seal species in Washington State. Most seal haul-out sites are unavailable at high tide, hence abundance estimates are conducted at low tide when it is commonly accepted that most seals are hauled-out. On sites unaffected by tides, however, it is less clear whether tide level has an effect on seal abundance. We counted hauled-out Harbor Seals from sunrise to sunset on floating water-breakers at Semiahmoo Marina, Washington, to examine the effect of tides on haul-out behavior. Because haul-out behavior is affected by several factors, we conducted mixed-factor analyses that included tide level, tidal current, time of season, and time of day as fixed factors, and several meteorological variables as random factors. The number of hauled-out Harbor Seals was significantly associated with tide level, time of season, and time of day. Results suggest that seal counts in Semiahmoo Marina should be made late in the pupping season and early in the afternoon at moderately positive tide levels to achieve the highest counts. They also indicate that tide was associated with seal numbers unrelated to site availability because seal numbers were positively related to tide height, a finding opposite to studies at tidal haul-out sites.

Key words: *Phoca vitulina,* Harbor Seal, haul-out behavior, tides, environmental influence, Drayton Harbor, Washington State

Harbor Seals (*Phoca vitulina*) are one of the most widespread and common pinniped species worldwide (Burns 2002). Abundance estimates of this species are typically derived from counts of seals hauled-out on land (Eberhardt and others 1979; Thompson and Harwood 1990). The factors influencing when seals haul-out appear to be site-specific but include season, time of day, tide, air temperature, wind speed, and precipitation (Pauli and Terhune 1987; Huber and others 2001; Reder and others 2003; Hayward and others 2005). Harbor Seals haul-out primarily during daylight (Scheffer and Slipp 1944; Boulva and McLaren 1979; Thompson and Rothery 1987), with the highest numbers usually recorded in the pupping and molting seasons at low tide during midday or the afternoon (Pauli and Terhune 1987; Thompson and others 1989; Watts 1996; Reder and other 2003). Due to the effect of tide on haul-out behavior, surveys are performed at low tides to determine how other variables affect hauled-out seal numbers (Grellier and others 1996). However, many haul-out sites, such as floating docks and boom logs, are available at all tide levels. Hence, one might expect use of these sites to be unrelated to tides. To our knowledge, no study has examined the factors influencing haul-out abundance at sites available at all tide levels.

In Washington State, Harbor Seals are the most abundant pinniped species (Jeffries and others 2000) and commonly haul-out on beaches, rock outcroppings, and docks. Abundance surveys are conducted during the pupping season at low tide (Jeffries and others 2003). In the Puget Sound region, 62 of the 117 known haul-out sites (53%) are available at all tide levels. In the remainder of the state, this number is 3.7% (14 of the 364 sites) (Jeffries and others 2000). This study was conducted to determine if non-tidally influenced haul-out sites in Puget Sound also hold maximum seal numbers at low tide. We examined the influence of tide and other environmental factors on the haul-out behavior of Harbor Seals at a site available at all tide levels.

TABLE 1. The best 3 mixed-effect models fitting number of seals hauled-out with the random factors of average wind speed, air temperature, relative humidity, and cloud cover, and different combinations of the fixed factors of season, time of day, tide level, and tidal current. [a]indicates the significant model.

Model	df	AIC	BIC	logLik	Test	L.ratio	*P*
1- Season × Time	19	2280.196	2360.43	−1121.10			
2- Season + Time + Tide	15	2271.903	2335.24	−1120.95	1 vs 2	0.2926	0.9903
3- Season + Time + Tide + Current	17	2268.919	2340.70	−1117.46	2 vs 3	6.9839	0.0304[a]

Methods

We collected data from 21 June to 23 September 2006, at Semiahmoo Marina (48°59.11′N, 122°46.42′W) in Drayton Harbor, Washington. Observations were made from a 6-m-high bluff facing 3 floating water breakers protecting the marina and located 100 to 300 m away. Harbor Seals haul-out on the water breakers, which are exposed at all tide levels. Each week we randomly selected 3 days to count seals. During those days we observed the seals from sunrise to sunset with a 20–60× spotting scope mounted on a tripod or 7 × 50 binoculars. We were unable to distinguish among adult males, adult females, and immature seals on land or in the water; hence, we classified all 3 classes as adults. However, we were able to distinguish adults and recently born pups (about a few weeks old) by the much larger relative size of the adults.

We counted the number of adults and pups hauled out at 60-min intervals. After each 60-min interval, we recorded the following environmental variables with a hand-held weather station (Speedtech SM-28 Skymaster Windmeter): average wind speed (m/s, ± 3%, taken at 7.7 m above the water), ambient temperature (°C, in shade, ± 1°C), and relative humidity (%, ± 3%). We also recorded date, time of day, tide level (cm above mean sea level), tidal current (ebb, slack, and flood), and cloud cover (% of covered sky). Tide levels and tidal current were obtained from the software ''Tides and Currents'', version 2.5b (Nautical Software Inc.).

Mixed-effects models were used to explore whether numbers of seals hauled-out were influenced by tide level. Mixed-effects analyses allow separate estimation of fixed and random effects, independent inclusion of associated error terms in the model, correlation between observations, and unbalanced data sets (Cnaan and others 1997; Faraway 2005). We developed models with all possible combinations of fixed factors as well as the interactions between 2 fixed factors to determine the best model with maximum likelihood (ML) estimation (Faraway 2005). These models allowed us to test for the effects of fixed factors after controlling for the effects of the random factors. Akaike Information Criterion (AIC) scores were used to choose the most parsimonious model (Burnham and Anderson 2001). The final mixed-model was fit using restricted maximum likelihood and ANOVA was used to indicate significant associations. We included the total number of seals hauled-out (adults and pups) as a dependent variable. We entered time of season, time of day, tide level, and tidal current as fixed factors, and meteorological parameters as random factors. We divided the summer season into 3 time periods: early pupping (21 June to 13 July, average of 0.72 pups per hourly count), primary pupping (16 July to 23 August, 4.92 pups per hourly count), and late pupping (26 August to 21 September, 1.54 pups per hourly count). We classified time of day as <9:00, 9:00–12:00, 12:00–15:00, 15:00–19:00, and >19:00. Tide level was classified as <0 cm, 0–75 cm, 75–150 cm, 150–225 cm, and >225 cm above mean sea level. On 24 occasions seals were disturbed and flushed into the water. We recorded the source of disturbance and excluded those counts from the mixed-effect models. Seal numbers were square-root transformed to correct for heterogeneous variances (Zar 1999). The mixed-effects model analyses were performed using the linear and nonlinear mixed-effects models (nlme) package of R, ver. 2.4.1 (R Development Core Team 2006).

Results

We tested 22 models with different combinations of fixed factors after controlling for the effects of random factors and, for brevity, presented the 3 most parsimonious models (Table 1). The model that best fit the number of seals

TABLE 2. ANOVA table for the most parsimonious mixed-effects model explaining number of seals hauled-out (Season + Time + Tide + Current). [a]indicates significant factors.

Parameter	Numerator df	Denominator df	F value	P
Intercept	1	387	6427.52	<0.0001[a]
Season	2	387	282.71	<0.0001[a]
Time of day	4	387	81.06	<0.0001[a]
Tide level	4	387	5.62	0.0002[a]
Tidal current	2	387	1.35	0.261

hauled out included all 4 fixed factors with no interaction: time of season, time of day, tide level, tidal current (AIC = 2268.919; $P = 0.030$, Table 1). Time of season, time of day, and tide level were significant descriptors for model fit (ANOVA, $P < 0.001$, Table 2). Numbers of seals hauled-out were lowest at negative tide levels (Fig. 1; $F_{4,387} = 5.62$, $P = 0.0002$, Table 2). Seal numbers increased from June through September (Fig. 2; $F_{2,387} = 282.71$, $P < 0.0001$, Table 2); they also increased throughout the day until 19:00, and began to decline in the hours immediately before sunset (Fig. 3; $F_{4,387} = 81.06$, $P < 0.0001$, Table 2). Pups were 1st observed on 23 June and their numbers peaked on 28 July (Fig. 4).

DISCUSSION

The abundance of Harbor Seals hauled-out at Semiahmoo Marina was related to the fixed factors of time of season, time of day, and tide level (Table 2) when taking into consideration the random factors of air temperature, wind speed, cloud cover, and humidity. The most parsimonious model also included tidal current (Table 1), suggesting that although not a significant factor per se (Table 2) it provided information to improve the fit of the model.

Studies from tidally-influenced locations show that the number of Harbor Seals hauled-out is related to tide level. Because the largest numbers of hauled-out seals are typically observed at the lowest tide levels (Schneider and Paine 1983; Pauli and Terhune 1987; Reder and others 2003), population surveys are usually done at low tides (Olesiuk and others 1990; Jeffries and others 2003). However, our results indicate an opposite association between tide level and number of seals hauled-out in a site available at all tide levels. The lowest numbers

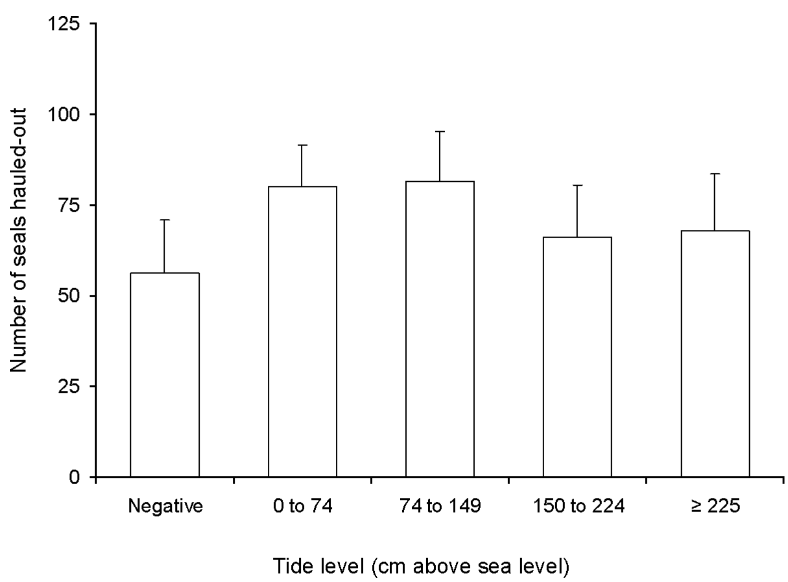

FIGURE 1. Mean number and standard deviation of hauled-out Harbor Seals at Semiahmoo Marina relative to tide level during the summer of 2006.

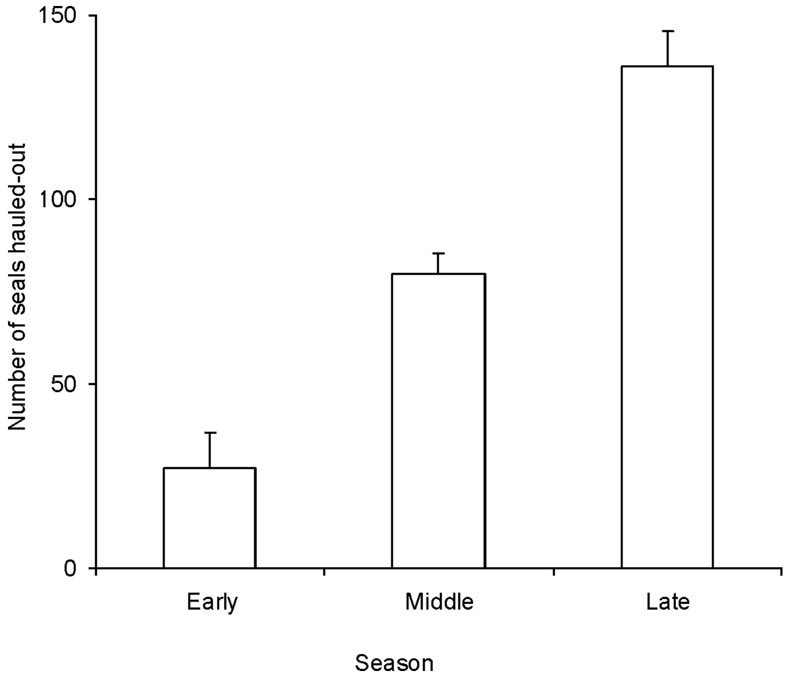

FIGURE 2. Mean number and standard deviation of hauled-out Harbor Seals at Semiahmoo Marina relative to season during the summer of 2006. Early is early pupping (21 June–13 July), Middle is primary pupping (16 July–23 August), and Late is late pupping (26 August–21 September).

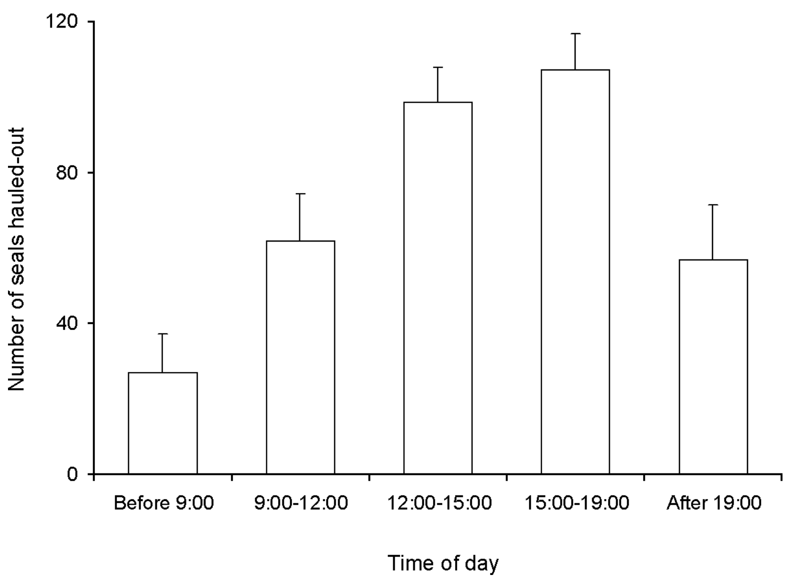

FIGURE 3. Mean number and standard deviation of hauled-out Harbor Seals at Semiahmoo Marina relative to time of day during the summer of 2006. Before 9:00 is sunrise to 8:59; after 19:00 is 19:00 to sunset (Pacific Daylight Savings Time).

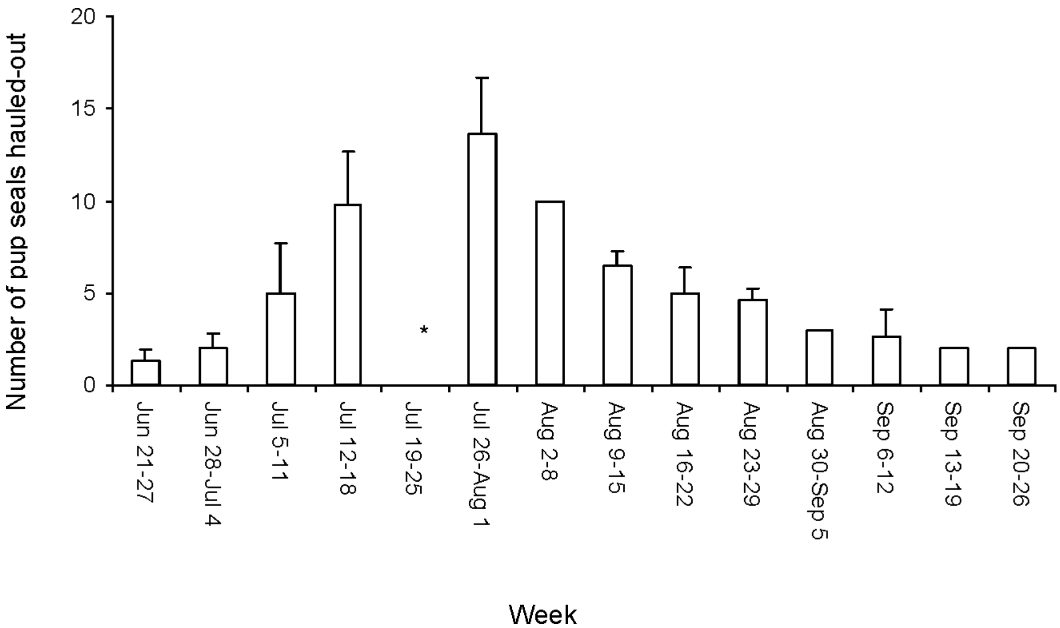

FIGURE 4. Mean weekly number and standard deviation of Harbor Seal pups at Semiahmoo Marina relative to date, 2006. We chose the highest count from each day of observation. * = no counts made between 19–25 July.

of seals hauled-out were observed at negative tide levels and the highest numbers at moderately positive tide levels. The floating water breakers at Semiahmoo Marina, unlike the haul-out sites observed in other studies, are available at all hours of the day and at all tide levels. The breakers are separated from land by water at all tide levels, which, combined with the heavy human presence in the marina, makes it unlikely that terrestrial predators walk on them at low tide levels as occurs in other areas (Cottrell 1995). Hence, the relationship between Harbor Seal numbers and tide level must be explained in terms other than haul-out site availability. One such explanation may be prey availability. Under this scenario, the prey of Harbor Seals may be most available at low tide and one would expect to find more seals in the water and fewer seals on land. However, no data on seal diet or prey distribution are currently available for Semiahmoo Marina to examine this hypothesis.

Numbers of Harbor Seals hauled-out also are related to time of season, time of day and weather at places that do not have haul-out sites available all the time (Schneider and Payne 1983; Grellier and others 1996; Reder and others 2003). In this study, time of season and time of day also were associated with numbers of seals hauled-out. Increased seal numbers at Semiahmoo Marina in the later summer months may be due either to an influx of seals into the area or to seasonal shifts in the proportion of time that seals spend in the water (Huber and others 2001). Increased seal numbers during the late afternoon hours may be related to diurnal haul-out cycles (Stewart 1984; Pauli and Terhune 1987) or to higher air temperatures at that time of day (Reder and others 2003). Pupping, breeding, and molting seasons also may contribute to seasonal variation in the abundance of hauled-out Harbor Seals (Huber and others 2001; Reder and others 2003). The number of Semiahmoo Marina pups peaked between 26 July and 1 August, which coincided with the pupping season of other inland waters in Washington (Huber and others 2001). Likewise, the number of seals hauled-out at Semiahmoo Marina peaked late in the pupping season, which coincided with the beginning of the molting season in other inland waters of Washington (Huber and others 2001). Hence, the seasonal variation observed in Semiahmoo Marina can be attributed, in part, to pupping and molting seasons.

The results of this study indicate that several factors are associated with the numbers of seals hauled-out, thus suggesting and supporting previous findings that haul-out behavior is site- and condition-specific (Huber and others 2001; Hayward and others 2005). The mixed-effects model suggests that counts of hauled-out seals in the marina should be made late in the pupping season, in the afternoon, and at positive tide levels to achieve the highest counts. This is a slight modification of the protocol currently employed to count Harbor Seals throughout the state of Washington (Jeffries and others 2003). Future studies are needed to determine the mechanisms whereby tide level affects Harbor Seal haul-out abundance in sites available at all tide levels.

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