

Short Note

Harbor Seal (*Phoca vitulina*) Tolerance to Vessels Under Different Levels of Boat Traffic

Kelly Cates and Alejandro Acevedo-Gutiérrez

Department of Biology, Western Washington University, 516 High Street, Bellingham, WA 98225-9160, USA
E-mail: kacates@alaska.edu

Disturbance can be defined as any stimulus that, either as a result of natural or human-derived sources, causes a deviation in an animal's typical behavior (Suryan & Harvey, 1999; Jansen et al., 2010). Vessel traffic is an extensive source of anthropogenic disturbance to marine mammals as it can influence reproductive success, alter social communication and behavior, change feeding strategies, and cause displacement (Johnson & Tyack, 2003; Williams et al., 2006; Wright et al., 2007; Bejder et al., 2009; French et al., 2011; Atkinson et al., 2015). Given that over 41% of the world's human population lives within 100 km of the sea coast (Martinez et al., 2007) and that activities such as shipping and recreational boating are likely to increase (Kakoyannis & Stankey, 2002; Tournadre, 2014), coastal marine mammals, such as pinnipeds, are particularly susceptible to disturbances in regions where vessel traffic overlaps with productive coastal waters (Jefferson et al., 1993; Robards et al., 2016). Hence, studying how pinnipeds respond to the expected increase in coastal human activities is important to the conservation and management of these populations.

When disturbed by humans, pinnipeds that are hauled-out typically flush into the water (e.g., Terhune & Almon, 1983; Johnson & Acevedo-Gutiérrez, 2007). Such a response could be more detrimental during pupping season since flushing animals may trample over pups or cause the separation of mother-pup pairs. Another potential issue of additional flushing events is energy loss, which can be especially costly during pupping or molting seasons (Suryan & Harvey, 1999). However, with repeated exposure to stimulus over time, animals may become less responsive to disturbances that would have previously initiated a flight response (Frid & Dill, 2002; Bejder et al., 2009). There can be consequences to a lack of response to disturbances: behavioral habituation can be harmful in the long run and lead to

decreased wariness to human presence or natural predators (Boren et al., 2002; Olson, 2013) or, in the case of primates interacting with humans, exposure to diseases (Woodford et al., 2002). Unfortunately, we know little about how pinniped flushing response to vessel traffic is related to different levels of human activity.

Harbor seals (*Phoca vitulina*) are the most abundant marine mammal in Puget Sound, Washington, with a year-round presence and haul-out sites distributed throughout the region (Jeffries et al., 2000). Puget Sound is a rapidly growing region. By 2030, the population is expected to reach 4.5 million people along with a concomitant increase in commercial and recreational vessel traffic (Puget Sound Regional Council [PSRC], 2015). Vessel traffic is a common source of disturbance to harbor seals in this region (Suryan & Harvey, 1999; Johnson & Acevedo-Gutiérrez, 2007). Over time, disturbance may result in seals hauling-out at times of the day when disturbance is low (Grigg et al., 2002), avoiding areas with increased human activity (Montgomery et al., 2007), or abandoning a haul-out site altogether (Newby, 1973). Although harbor seals appear to tolerate closer vessel approaches in areas of high vessel traffic (Suryan & Harvey, 1999), little is known about how exposure to different levels of vessel activity affects the flushing behavior of harbor seals. To determine the influence of vessel disturbance on the behavior of harbor seals in Puget Sound, we measured the flushing behavior of harbor seals at three haul-out sites exposed to varying types and distances of vessel traffic. It was predicted that seals hauling-out in areas of high vessel disturbance will flush into the water less frequently than those seals that haul-out in areas of lower vessel disturbance.

Data were collected from June through August, 2011 at three haul-out locations in Puget Sound (Figure 1). The haul-out sites were located in

Poulsbo, Port Ludlow, and Brinnon, Washington. The haul-out in Poulsbo (47° 43' N, 122° 38' W) was located on a floating log boom situated in the Liberty Bay Marina 250 m and 870 m from the east and west shores of the bay, respectively, and exposed to constant vessel traffic. Observations were made 60 m away from a floating dock that was level with the haul-out site. The dock was selected because it had an unobstructed view of the haul-out, unlike vantage points at higher elevations. The Port Ludlow haul-out was composed of four closely situated islands (center at 47° 56' N, 122° 40' W) 3.15 km north of the Port Ludlow Marina. Because harbor seal movement was observed between the four low-lying islands, we considered this cluster of islands as one haul-out site and labeled it Port Ludlow. Observations at Port Ludlow were taken from a bluff located approximately 1 km from the four islands, 7.58 m above mean sea level, with a clear view of the entire coastline of the islands. The third haul-out was a slough at the mouth of the Dosewallips River (47° 41' N, 122° 53' W), near Brinnon, Washington. Observations were taken from a fixed, long-term observation platform 550 m away from the slough, 6.29 m above mean sea level, and to the northwest of the slough. At all sites, vessels could approach haul-outs to a distance of < 1 m, depending on the tide.

At each haul-out location, harbor seals were observed in 4-h intervals at times when the number of hauled-out individuals was deemed greatest based on preliminary observations. Observations were made 5 d/wk, cycling through the three sites, with one site visited per day. The days that each site was visited were determined using a random number generator, with observations split randomly between weekdays and weekends. The Poulsbo, Port Ludlow, and Brinnon haul-out sites were observed for 15, 14, and 12 periods, respectively.

Similar to Johnson & Acevedo-Gutiérrez (2007), harbor seals were constantly observed during the study period by two rotating observers using Commander Military 7 × 50 C binoculars and a 20 to 60X spotting Fujinon Field Scope Super ED 80. The two observers practiced with equipment and in estimating sighting distances before the start of the study so as to minimize observer bias. No disturbances resulting from observer presence occurred. Non-pup seals were counted at 15-min intervals over the 4-h period. Pup presence or absence was recorded but was not included in the total count. The counts were used to quantify seal numbers and determine how many seals were disturbed by passing vessel traffic. A disturbance was defined as any event related to a passing vessel that resulted in ≥ 1 harbor seal flushing into the water. Three distance

measurements were made for each passing vessel, and the closest distance at which a vessel passed the haul-out site was used for analysis. Hauled-out harbor seals were recorded immediately after the disturbance and for 2, 5, and 10 min after. Distance was determined using a Leica TC605L theodolite (± 1.5 mm at 100 m accuracy). Corrections for tide were made using the program *Tides and Currents*, Version 2.5B (Nautical Software, Inc., Jeppesen Marine, Portland, OR, USA). A Leica Rangemaster CRF 1000 (± 1 m up to 500 m) laser range finder was used at the Poulsbo site because there was no elevation difference between the haul-out site and the observation point, rendering the use of a theodolite impossible. The laser range finder was first tested at the Poulsbo dock with known distances to determine accuracy.

Every vessel that passed by the haul-out sites was recorded; however, because the sole interest was in vessels that had a likelihood of disturbing the hauled-out harbor seals, only those vessels that were within the longest distance at which seals were observed to be disturbed (800 m) were included in analyses. To determine if there were any significant differences in vessel activity among sites, a Kruskal-Wallis test was used given the non-normal distribution of the data.

Vessels were classified into three categories: (1) non-motorized boats (NMBs) were vessels such as kayaks, paddleboards, and rowboats that were human-propelled; (2) all motorized vessels and sailboats that were 1 to 10 m in length were categorized as medium-sized motorboats (MMBs); and (3) all motorized boats and sailboats >10 m long were categorized as large-sized motor boats (LMBs). The 10-m cutoff point was estimated visually, based on previous practice by the two observers with vessels moored in marinas.

To determine which variables affected the flushing behavior of harbor seals, a generalized linear mixed model (GLMM) was utilized. A GLMM was run using the *lme4* package, Version 2.13.1 (Bates & Maechler, 2009) in the program *R*, Version 3.2.2, where variables were added or removed to determine the most parsimonious model. The model tested the effects of three fixed variables: (1) vessel frequency (number of boats/h), (2) vessel type, and (3) distance of vessel from haul-out. Random effects (Bolker et al., 2009) were included such as the number of seals hauled-out and the Julian date. The effect of each single fixed factor as well as different combinations of fixed factors were examined. Given that the response variable was harbor seals either flushing or not flushing, a binomial distribution to model flushing behavior of hauled-out harbor seals was used (Zuur et al., 2009). Model fit was compared using Akaike Information Criterion

(AIC), and the model with the lowest AIC value was reported. We also ran an ANOVA to examine the distance at which boats passed from the haul-outs relative to the type boat and the haul-out site. All values are given as $\bar{x} \pm SD$.

Overall, Port Ludlow had greater numbers of harbor seals, with 20 ± 19 seals observed per

period ($n = 14$ periods). Fewer harbor seals were recorded in Brinnon and Poulsbo, with 9 ± 8 seals ($n = 12$) and 5 ± 5 seals ($n = 15$) observed per period, respectively. The greatest number of seals observed hauled-out was 94 individuals at Port Ludlow, 48 individuals at Brinnon, and 22 individuals at Poulsbo.

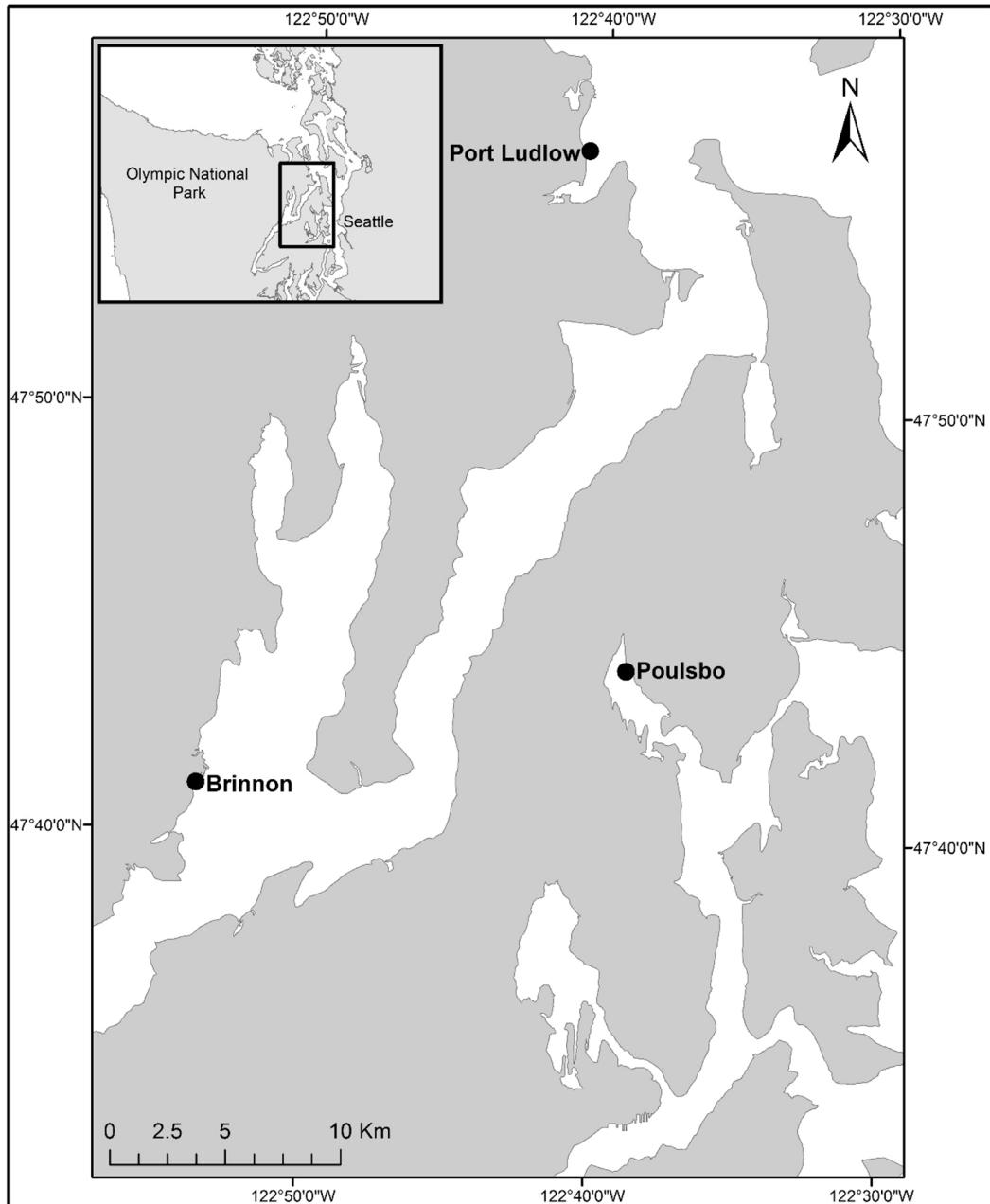


Figure 1. Map of the Puget Sound in Washington State, USA, and haul-out locations of the three sample sites

A total of 541 vessels were recorded within 800 m of each haul-out site: 429 at Poulsbo, 74 at Port Ludlow, and 38 at Brinnon. Medium-sized vessels were the most common boat type in all sites. LMBs and NMBs were present at all sites but less common. All recorded events were single vessels, with the exception of kayaks and paddle boards. Kayaks and paddleboards passed haul-outs with an average of 1 ± 2 vessels per event (maximum of 15 kayakers at Brinnon).

There was a significant difference in the frequency of total vessel traffic among sites (Kruskall-Wallis ANOVA: $H_2 = 23.00$, $p = 0.00001$). The frequency of vessel traffic was 13.7 ± 7.0 boats·h⁻¹ at Poulsbo, 2.6 ± 1.5 boats·h⁻¹ at Port Ludlow, and 2.1 ± 1.8 boats·h⁻¹ at Brinnon. *Post-hoc* contrasts indicated that vessel frequency at Poulsbo was significantly different than both Brinnon and Port Ludlow (Difference = -22.69, $t_1 = 7.55$, $p = 0.000$) but that Brinnon and Port Ludlow were not significantly different from each other (Difference = -0.43, $t_1 = 0.23$, $p = 0.818$). When broken down by vessel class, Poulsbo had the highest frequency of all vessel types, whereas Port Ludlow and Brinnon had similar frequencies (Figure 2).

The distance at which vessels passed was related to the interaction of boat type and haul-out site (Two-way ANOVA: boat type $F_{2,532} = 10.91$, $p < 0.0001$; haul-out site $F_{2,532} = 748.97$, $p < 0.0001$; interaction $F_{4,532} = 17.58$, $p < 0.0001$). NMBs passed haul-outs at the closest distances: 25.7 ± 26.6 m ($n = 91$) at Poulsbo, 184 ± 193.8 m ($n = 5$) at Brinnon, and 66 ± 0 m ($n = 1$) at Port Ludlow. LMBs and MMBs passed at roughly equal distances within each site: 55.4 ± 50.7 m ($n = 40$ vessels) and 46.4 ± 34.6 m ($n = 298$) for LMBs and MMBs, respectively, at Poulsbo; 591.5 ± 113.8 m ($n = 2$) and 493.3 ± 152.3 m ($n = 31$) for LMBs and MMBs, respectively, at Brinnon; and 330.8 ± 78.1 m ($n = 13$) and 323.9 ± 167.7 m ($n = 59$) for LMBs and MMBs, respectively, at Port Ludlow (Figure 3).

Seal flushing behavior was neither affected by Julian date or number of harbor seals (random factors) nor by boat type, vessel frequency, or distance to haul-out site on their own. Rather, flushing behavior was best explained by a combination of the three fixed factors: (1) number of boats per hour, (2) boat type, and (3) boat distance from the haul-out site, as well as their interaction (Table 1). The percentage of harbor seals flushing was

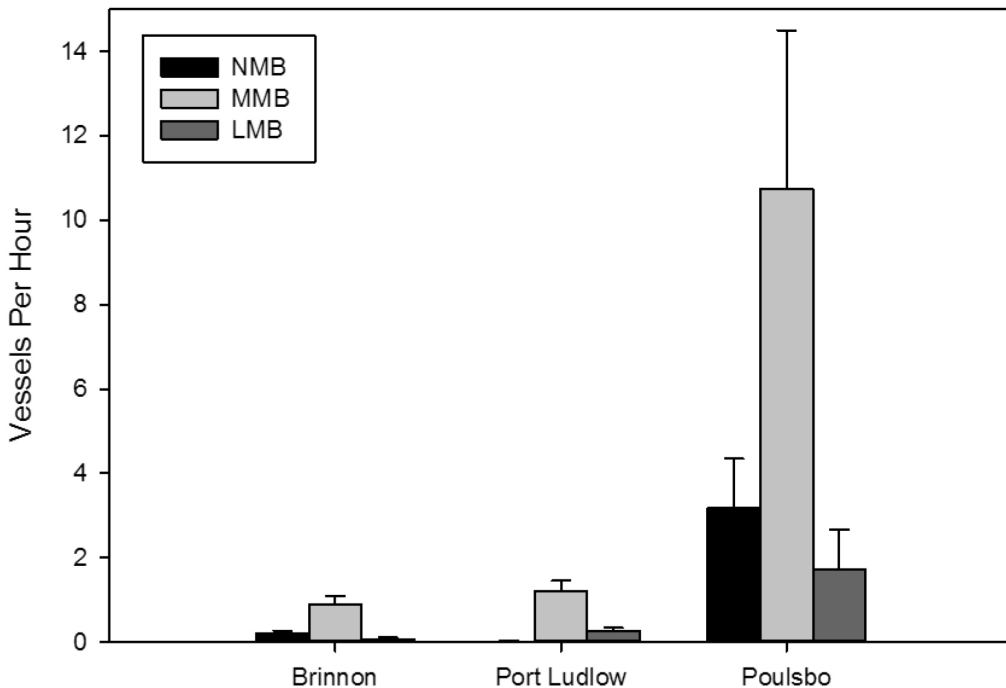


Figure 2. Frequency of vessels · h⁻¹ relative to haul-out site and boat type; error bars indicate SD. NMBs = non-motorized boats, MMBs = vessels 1 to 10 m in length, and LMBs = vessels > 10 m in length.

greater at sites with low vessel activity (Brinnon: 11.1%, $n = 36$; Port Ludlow: 9.2%, $n = 76$) than at Poulsbo (2.3%, $n = 429$), the site with the highest vessel activity. NMBs elicited the highest percentage of flushing, for which 9.2% of passing vessels resulted in a flushing event ($n = 98$); while LMBs and MMBs caused fewer flushing events: 5.5% ($n = 55$) and 2.3% ($n = 388$), respectively.

These results indicate that the event of a passing boat appeared to be relatively infrequent at low activity haul-out sites, and harbor seals tended to respond by flushing more readily than at high activity sites. As such, harbor seals located in areas of low vessel activity were less tolerant to passing vessels than harbor seals located in areas of high vessel activity. Harbor seals located at high

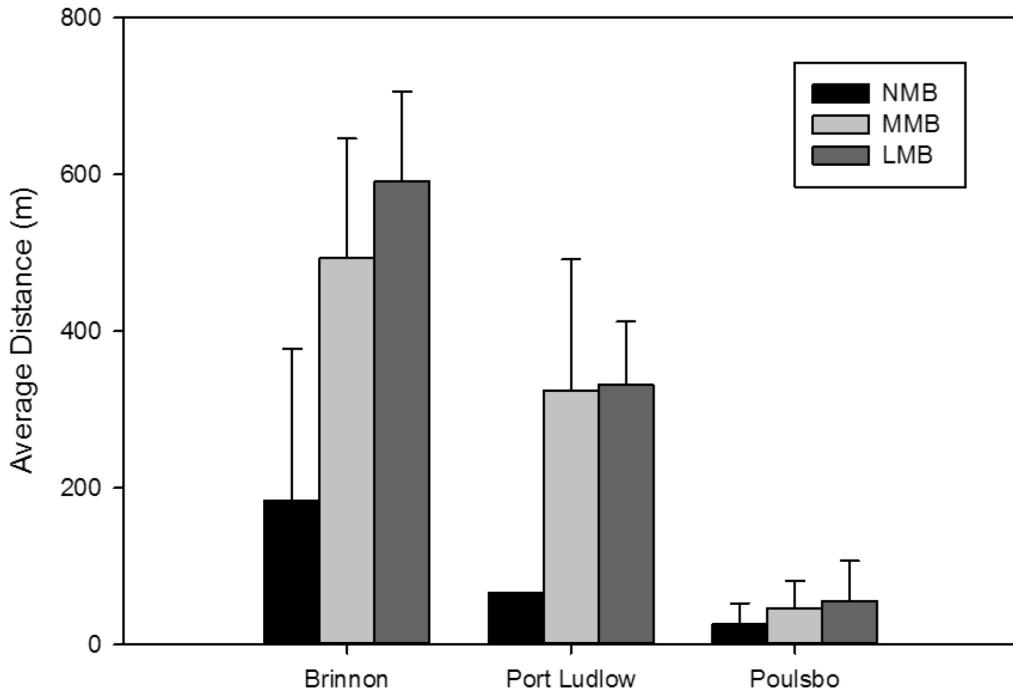


Figure 3. Average distance that each boat type passed haul-out sites; error bars indicate SD. NMBs = non-motorized boats, MMBs = vessels 1 to 10 m in length, and LMBs = vessels > 10 m in length.

Table 1. Results of a generalized linear mixed model (GLMM) for flushing of harbor seals (*Phoca vitulina*) relative to vessel frequency, boat type, and distance from haul-out site. For clarity, not all tested models are shown. Bold font indicates the selected model (lowest AIC of all examined models).

Model	df	AIC	Δ AIC	logLik
Frequency + Type + Distance + Frequency \times Type \times Distance + [Seals + Date]	14	155.62	0.00	-63.81
Frequency + Type + [Seals + Date]	6	158.48	2.86	-73.24
Frequency + [Seals + Date]	4	170.68	15.06	-81.34
Type + [Seals + Date]	4	171.30	15.68	-80.65
Type + Distance + Type \times Distance + [Seals + Date]	8	174.04	18.42	-79.02
[Seals + Date]	3	178.05	22.43	-86.03
Frequency \times Type \times Distance + [Seals + Date]	6	178.57	22.95	-83.28
Distance + [Seals + Date]	4	180.38	24.76	-86.19
Null model	2	180.82	25.20	-88.41

vessel activity sites appeared to have developed a tolerance to disturbances and were more likely to ignore passing vessels, unless closely approached. However, because vessel frequency, distance, and boat type were correlated, each variable was tested to see how it affected flushing behavior. GLMM results showed that boat type and vessel frequency on its own explained the data much better than the null model. However, the additive and interactive combination of the three variables greatly improved the overall model. Hence, despite the correlation among the fixed factors, the data indicate that vessel frequency and boat type, and to a lesser extent distance to haul-out site, affected the flushing behavior of harbor seals.

To our knowledge, no published studies exist that specifically examine the flushing behavior of harbor seals relative to varying levels of human exposure. Prior studies have measured harbor seal tolerance to disturbance using scanning behavior as a variable or, like this study, used flushing relative to boat type (Terhune, 1985; Suryan & Harvey, 1999; Young et al., 2014). In New Brunswick, Canada, seals scanned when disturbed more often than in northern California, an observation hypothesized to be related to the recent bounty on the Canadian seals relative to the protected California seals (Terhune, 1985). In the San Juan Islands, Washington State (USA), harbor seals showed increased tolerance—measured as distance at which a vessel caused flushing—toward repeated disturbance by NMBs (Suryan & Harvey, 1999). The heightened response of harbor seals to NMBs relative to other vessel types observed in this study has been described elsewhere (e.g., Henry & Hammill, 2001; Johnson & Acevedo-Gutiérrez, 2007; Young et al., 2014). In Metis Beach, Canada, flushing response was greatest to kayaks and canoes compared with that of motor vessels and sailboats (Henry & Hammill, 2001). At Yellow Island, Washington State, harbor seals flushed only to kayaks and stopped motorboats, even at distances from the haul-out site larger than those kept by moving powerboats (Johnson & Acevedo-Gutiérrez, 2007). As previously hypothesized, this study supports the notion that the larger flushing response of seals toward non-motorized vessels than toward motorized vessels was related to the tendency of the former to surprise harbor seals by their approach: slow, quiet, and low to the water (Henry & Hammill, 2001). The results of this study support our hypothesis of increased tolerance shown by harbor seals in areas of high disturbance and, in addition, supports the notion that seals are more sensitive to NMBs. It could be argued that vessels transiting the marina at Poulsbo were less disturbing to seals because of their slower speeds due to no wake zones than vessels passing the other two haul-out sites. However, slow-moving

vessels mimic predatory behaviors and, thus, may be perceived as threatening (Henry & Hammill, 2001).

While it was possible that harbor seals moved between haul-out locations during the study, it was unlikely. From Port Ludlow, via transit corridors, Brinnon and the Poulsbo Marina are 40 km and 48 km away, respectively; whereas Brinnon and Poulsbo are located 88 km from each other. Although observations suggest that there is some level of interchange among haul-out sites in the Puget Sound (London et al., 2012), most harbor seals in this region move < 50 km during the summer and are faithful to their haul-out site (Hardee, 2008; Peterson et al., 2012). Hence, it was assumed that the overall haul-out response to vessel traffic was not affected by the potential experience of individual seals at other haul-out sites.

Guidelines established by the National Oceanic and Atmospheric Administration (NOAA) for managing marine mammals and preventing their harassment prohibit the intentional approach by humans and vessels within a certain distance of hauled-out harbor seals. In most cases, the extent of this buffer zone is 100 yd (91 m). These results indicate that flushing by harbor seals was related to level of human activity (measured as vessel frequency), type of vessel, and vessel distance to the haul-out site. In the area where harbor seals were less tolerant to vessel traffic (i.e., the sites with low vessel traffic), NMBs elicited a disturbance response from seals at distances greater than the currently recommended buffer zone. The opposite was true in areas of high vessel traffic; NMBs came within 100 yds from the harbor seals without generating a flushing response. These findings support the suggestion, already posited by other studies (Johnson & Acevedo-Gutiérrez, 2007; Jansen et al., 2010), that the 100-yd buffer zone needs to be revisited. In this regard, the suggestion of Johnson & Acevedo-Gutiérrez (2007) could be modified such that a flexible buffer zone could be created that varies according to a few classes of vessel activity. Ideally, buffers should consider vessel type and be at greater distances in areas where harbor seals are exposed to less vessel traffic. Although difficult to implement, there are already a few flexible buffer zones in the United States. NOAA Fisheries is divided into geographic regions, some of which have delineated different buffer zones for marine mammals, depending on the species (National Marine Fisheries Service [NMFS], 2014). Unfortunately, many studies indicate that humans do not always respect unenforced regulations (e.g., Rowcliffe et al., 2004; Acevedo-Gutiérrez et al., 2011a), even if they are aware of the regulations

(Acevedo-Gutiérrez et al., 2011b). Consequently, to minimize seal disturbance, regulations need to be consistently enforced.

Despite the influence of humans (e.g., boat type, vessel frequency, and distance to haul-out site) on the flushing behavior of harbor seals, the number of flushing events was rare. As such, it is unclear what effect this level of disturbance may have on the harbor seal population in Puget Sound. Unfortunately, because the frequency of vessel–seal interactions is increasing globally (e.g., Jansen et al., 2015), flushing events will likely become more common, making the results and conservation implications found in this study applicable to other regions. These findings support the recommendation of developing and enforcing flexible buffer zones relative to the level of human activity, and ideally to vessel type as well.

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