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Haul-out patterns and effects of vessel disturbance on harbor seals (*Phoca vitulina*) on glacial ice in Tracy Arm, Alaska

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Abstract—Tidewater glacial fjords provide important habitat for breeding harbor seals (*Phoca vitulina*) that rest, give birth, and nurse pups on icebergs. These fjords also attract tourist vessels that potentially disturb seals. In May and June during 2001–2006, we documented seal abundance, pupping phenology, and seal–vessel interactions in Tracy Arm, a glacial fjord in southeastern Alaska. We used randomized observations to determine the frequency at which seals entered the water in the presence and absence of vessels, and we estimated the reaction distances of seals to approaching vessels. Mean daily vessel counts varied from 10.2 (2001) to 2.0 (2006) (range: 1–33). Tour and power vessels were the most common types of vessels, but seals were most sensitive to cruise ships and kayaks. The odds of a seal entering the water were higher when vessels were present (>2 times) or within 100 m (3.7 times), and when a pup was present (1.3 times). The baseline, undisturbed, rate of seals entering the water was 0.06 (95% CI: 0.05–0.08) per 10 min. Seal births occurred during 30 May–25 June and peaked (4–8 per day) during 7–13 June. The maximum pup count (408) was observed on 24 June. Harbor seal fitness in Tracy Arm may be reduced by vessel disturbances during breeding and pupping.

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Harbor seals (*Phoca vitulina*) are widespread throughout the temperate and subarctic waters of the North Pacific and North Atlantic and primarily inhabit coastal waters where they haul out on land or ice to rest, give birth, and molt (Hoover, 1983). In Alaska, tidewater glacial fjords provide important habitat for pupping and molting harbor seals (Bishop, 1967; Calambokidis et al., 1987; Mathews and Pendleton, 2006; Jansen et al., 2010; Hoover-Miller et al., 2011). The number of harbor seals that use glacial ice increases in the late spring and summer, when they give birth and molt on drifting ice (Calambokidis et al., 1987; Mathews and Kelly, 1996; Herreman et al., 2009; Blundell et al., 2011; Womble and Gende, 2013). Glacial ice may be preferable to terrestrial haul-out sites because of the reduced risk of terrestrial or marine predation and the availability of ice throughout the tidal cycle (Fay, 1974; Hoover, 1983; Calambokidis et al., 1987; Mathews and Adkison, 2010). Up to 73% of the several thousand seals in Glacier Bay National Park (GBNP), Alaska, use glacial habitat rather than land haul outs during breeding (Mathews and Pendleton, 2006).

Glacial fjords in Alaska also attract substantial numbers of tourists, most of whom visit these sites by boat during the summer. These visits introduce the potential for the disturbance of seals and other wildlife in these fjords. With dramatic increases in tourism in Alaska and worldwide over the past 2 decades, and the coincident high use of glacial fjords during summer by both harbor seals and tourists, the possibility for unintended harassment of seals increases—harassment that is in violation of the Marine Mammal Protection Act (Calambokidis et al.[1]; Allen[2]; Suryan and Harvey, 1999; Henry and Hammill, 2001; Johnson and Acevedo-Gutiérrez, 2007; Jezierski, 2009; Young, 2009; Jansen et al., 2010; Hoover-Miller et al., 2013). From May through September, approximately 850 cruise ship trips carrying a total of nearly 1 million passengers visit southeastern Alaska each year (Nuka Research and Planning Group[3]). Commercial and private vessels with overnight accommodations bring thousands of additional passengers into Alaskan fjords throughout the summer months (Nuka Research and Planning Group[3]).

Frequent exposure of harbor seals to vessel traffic, especially during the critical stages of pupping and nursing (May–July) and molting (July–September), can alter seal behavior (Allen et al., 1984) (e.g., increased vigilance, premature entry into the water). Such alterations might affect seal fitness and pup survival (Johnson, 1977; Renouf et al., 1983; Jemison, 1997; Osinga et al., 2012). Captive seals deprived of haulout access compensated later by hauling out to rest for longer periods, indicating a physiological need for resting out of water even when they were not molting or breeding (Brasseur et al., 1996). Before weaning, pups remain almost constantly with their mothers, especially when hauling out on moving glacial ice (Hoover, 1983). The first few hours after a pup is born are the most important for establishing the mother-pup bond (Johnson, 1977; Lawson and Renouf, 1987), and separation of mother and pup during the first 2–3 weeks after birth can result in permanent abandonment and starvation of a pup (Johnson, 1977; Renouf et al., 1983; Osinga et al., 2012).

Even disturbances that do not cause permanent separation may have negative consequences for pup survival, as seen with gray seals (*Halichoerus grypus*) (Robinson, 2014). In addition, harbor seal pups are born with a relatively thin insulative-blubber layer (Bigg, 1969; Newby, 1973; Pitcher, 1986; Hoover-Miller[4]). Given the cold surface-water temperatures in glacial fjords, repeated disturbances that cause pups to spend >50% of their time in frigid glacial waters could be detrimental; the energy deficit incurred by increased metabolism could reduce blubber deposition in pups and overall fitness (Jansen et al. 2010) or possibly increase energetic costs for lactating females to compensate for increased pup energy requirements.

Steep declines in harbor seal counts have been documented at 2 glacial sites in Alaska (Hoover-Miller[4]; Mathews and Pendleton, 2006; Womble et al., 2010; Hoover-Miller, 2011), highlighting the need for a better understanding of 1) the basic ecology of seals that use glacial habitat and 2) the potential benefits and costs of using glacial ice to give birth, breed, or molt (Blundell et al., 2011). In the 1980s, GBNP began partial and complete vessel closures in John Hopkins Inlet, a tidewater glacial fjord, in response to concerns about the disturbance of harbor seal pups (Calambokidis et al.[1]); those regulations remain in place (Glacier, 2006).

Research on harbor seals in glacial fjords in Alaska has been concentrated in GBNP (Streveler[5]; Calambokidis et al.[1]; Mathews and Kelly, 1996; Mathews and Pendleton, 2006; Young, 2009; Womble et al., 2010; Blundell et al., 2011; Womble and Gende, 2013), Kenai Fjords National Park (KFNP) (Hoover, 1983; Jezierski, 2009; Hoover-Miller et al., 2011, 2013), and Disenchantment Bay (Jansen et al., 2010, 2015). Tracy Arm is a glacial fjord that is used by more than 1000 harbor seals during the summer and that has high tourist visitation. However, other than aerial population assessment surveys and preliminary telemetry tagging (results not available), there has been no research before this study on harbor seals in Tracy Arm (Withrow and Jansen[6]). Blundell and Pendleton (2015) studied haul-out patterns by tracking harbor seals equipped with VHF-transmitters in Tracy Arm and neighboring Endicott Arm, but that study was conducted after the collection of data for this study.

The objectives of this study were 1) to determine the patterns of abundance of nonpup and pup harbor seals during the pupping season and investigate the potential effects of environmental factors and number of vessels on seal counts, 2) to document vessel traffic (numbers and type) in Tracy Arm during early–mid summer, and 3) to determine the effects of the presence, type (e.g., cruise ship, tour vessel), proximity of vessels, and environmental variables on the probability that hauled-out seals would enter the water.

Materials and methods

Study area

Tracy Arm–Fords Terror Wilderness within the Tongass National Forest comprises 2 deep and narrow fjords: Tracy Arm and Endicott Arm (Fig. 1; each fjord is >48 km long). The Sawyer and South Sawyer glaciers, located at the end of Tracy Arm, flow into tidewater, which creates icebergs; both glaciers are rapidly

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[1] Calambokidis, J., L. E. Healy, and G. H. Steiger. 1985. Reaction of harbor seals (*Phoca vitulina*) to boats in Glacier Bay, Alaska, 23 p. [Unpubl. report.] Cascadia Research Collective, Olympia, WA.

[2] Allen, S. 1991. Harbor seal habitat restoration at Strawberry Spit, San Francisco Bay, 44 p. Final report for U.S. Marine Mammal Commission contract MM2910890-9, NTIS PB91-212332, Marine Mammal Commission, Bethesda, MD.

[3] Nuka Research and Planning Group. 2012. Southeast Alaska vessel traffic study, 21 p. Nuka Research and Planning Group, Seldovia, AK. [Available at website.]

[4] Hoover-Miller, A. A. 1994. Harbor seals (*Phoca vitulina*): biology and management in Alaska, 45 p. Report to the Marine Mammal Commission, Washington, D.C.

[5] Streveler, G. P. 1979. Distribution, population ecology and impact susceptibility of the harbor seal in Glacier Bay, Alaska, 49 p. [Available from Glacier Bay National Park and Preserve, P.O. Box 140, Gustavus, AK.]

[6] Withrow, D. E., and J. K. Jansen. 2015. Personal commun. Natl. Mar. Mamm. Lab., Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115-6349.

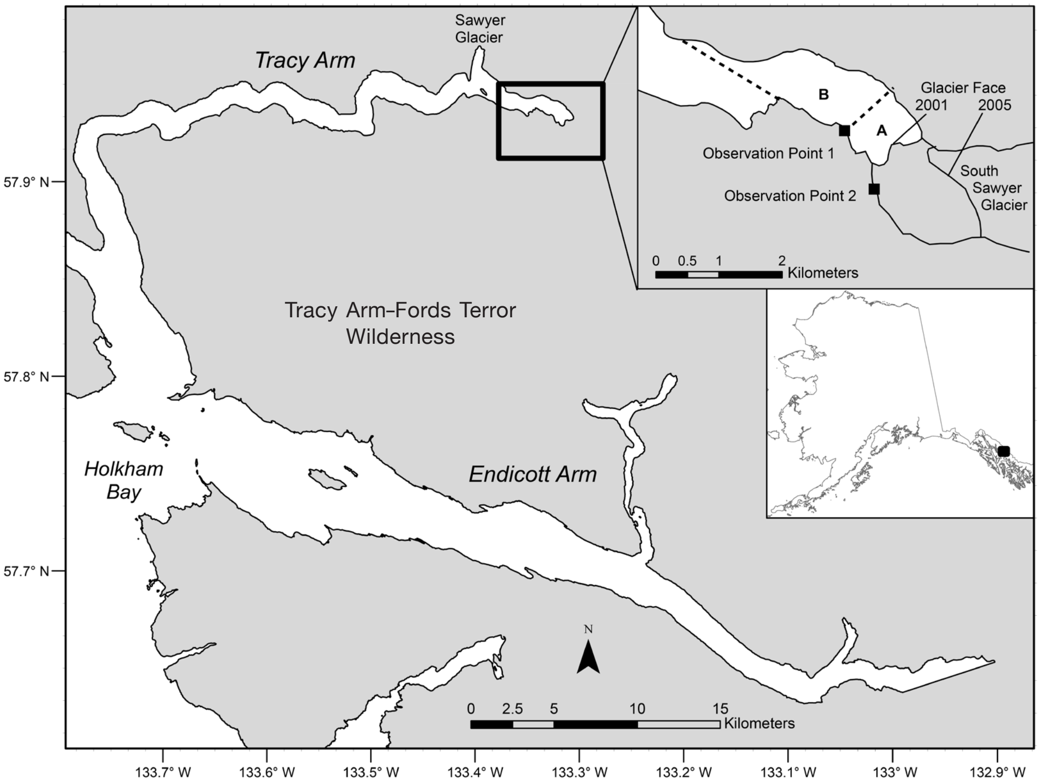

Figure 1

Map of the study area and its location within the Tracy Arm–Fords Terror Wilderness area in southeastern Alaska where harbor seals *(Phoca vitulina)* rest and nurse their pups on ice calved from glaciers. Observation point 1 (upper inset), from which seals were studied, is located at 57.857°N, 133.135°W. We recorded the time when boats entered and left sections A and B (upper inset). Observation point 2 was used beginning in 2005 after the South Sawyer Glacier had receded so far that observation point 1 no longer provided a good view of the seals.

thinning and retreating (Larson et al., 2007). Endicott Arm also has tidewater glaciers. Tracy Arm is 72 km south of Juneau, a major cruise ship port (CLAA[7]) and the capital of Alaska. The proximity of this fjord to Juneau results in hundreds of cruise ships (7 visits/week on average; Nuka Research and Planning Group[3]), tour boats, other commercial vessels, and private vessels visiting Tracy Arm each year. Unlike vessel traffic in GBNP, where numbers and speed are restricted, vessel traffic is currently unregulated in Tracy Arm.

We conducted our study in Tracy Arm from 2001 to 2006 and conducted more intensive sampling (e.g., more days of sampling and more types of data collected) in 2001 than in later years. We monitored seals and vessels from an elevated observation point (OP1) initially ~500 m from the face of the South Sawyer Glacier (Fig. 1). Tracy Arm is approximately 1 km wide at OP1, which afforded an unobstructed view of the areas of greatest seal and ice concentration (Fig. 1). From July 2004 through August 2005, the South Sawyer Glacier receded dramatically such that the face of the glacier was >1.6 km farther from OP1. Because of that change, a second observation point (OP2) was used late in the 2006 season (Fig. 1), but the use of OP2 had little direct effect on the type of data collected (i.e., counts from shore and from behavioral sampling) during this period. We refer to the area visible from OP1 and OP2 as “the study site” or “the inlet.”

Seal counts

From 27 May through 30 June 2001, harbor seals were counted from OP1 with tripod-mounted 10×42 binoculars. Whenever possible, 2 observers counted simultaneously. Each day between 0700 and 2000 h, 3–6 counts (1–4 of which were paired counts) were made; the median time interval for conducting a count was 22 min (range: 7–39 min). Each day, we attempted to obtain at least 1 count before vessel disturbance (i.e., before vessels entered the study site).

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[7] CLAA (Cruise Line Agencies of Alaska). 2015. Cruise ship calendar for 2016. CLAA, Ketchikan, AK. Available at website.]

Seals were categorized as nonpups or pups and as hauled out or in the water. We identified seals as pups by several criteria, including their small size, close association and positioning with an adult (presumed to be the mother), behavior (e.g., suckling, nuzzling), overall body shape, and pelage. In late June as pups approach or cease weaning, they typically are larger and more likely to be left unattended (Boness et al., 1994). Therefore, we distinguished pups and yearlings in late June by pelage differences if they were close enough for pelage to be seen clearly. It is likely that we underestimated pup abundance in late June because of difficulty in seeing pelage on unattended pups and yearlings far from our observation point, and that difficulty may have slightly reduced peak pup counts, slightly increased peak nonpup counts, and possibly caused a slight underestimate in the date of the peak pup count. In contrast, the estimated date of onset of pupping would not have been affected by these factors.

We recorded percent ice cover (visually estimated in 10% increments), weather variables, the number of vessels present, and incidences of disturbance (i.e., seals entering the water in response to vessel activity) during each count. Weather variables included sky condition (i.e., clear, partly cloudy, overcast), temperature, precipitation (i.e., none, mist or light rain, heavy rain), wind speed (Beaufort scale), and wind direction (i.e., up, down, or across the fjord). When there were 2 observers, we used the average of the estimates of ice cover. For 13 counts with ice cover recorded in 25% increments, we used the mid-point of each category for our estimate.

During each count, we also recorded the number of icebergs with evidence of fresh blood or the presence of bald eagles *(Haliaeetus leucocephalus)*, which we used as a proxy for the number of recent seal births. Bald eagles are attracted to fjords during seal pupping because they eat the seal afterbirth and stillborn pups (Calambokidis and Steiger, 1985). At the end of a count, each observer rated the quality of his or her count on a scale of 1–7, with 1 being excellent and 7 being poor. Counts with a quality rating of 7 were excluded from analyses.

We used generalized linear models (GLMs; Poisson error, log link) to estimate the relationships between seal counts (i.e., nonpups, pups, and all seals) and the following explanatory variables: count quality, day of year (DOY), time of day (TOD), percent ice cover, sky conditions, temperature, precipitation, wind speed and direction, and the presence of vessels in the count area. We included vessels as a variable in 1 of 2 forms: 1) presence or absence or 2) the number of vessels in the inlet; only 1 of these vessel-related variables was used in a single model. For this and all subsequent analyses, DOY was centered on the median DOY of all counts, and TOD was centered on solar noon. Centering predictors eliminates the correlation between linear and quadratic terms, facilitating model fitting (Draper and Smith, 1981). Quadratic terms for DOY and TOD were also included in initial models.

To account for over-dispersion, we included a scale parameter estimated as the Pearson chi-square value divided by the degrees of freedom. All variables were included in the initial model and deleted one at a time until all remaining variables had Wald chi-square-based P-values of approximately <0.05. Mean counts adjusted for the other variables in the model (i.e., least-squares means; Littell et al., 2006) were computed for the levels of categorical variables that remained in the final models.

Vessel traffic

We recorded all vessels that entered the inlet from the start of observations in the morning to the end of observations for that day. We recorded the time that each vessel entered (came into view) and departed (disappeared from view) from the inlet. Vessels that approached the glacier face were likely to have had greater effects on seals than vessels that did not; therefore, in 2001, we divided the study area into 2 sections (Fig. 1, inset map, A and B) by drawing a line between our observation point and a large waterfall across the inlet, and we recorded if and when a vessel entered and left section A. Because the South Sawyer Glacier was receding, the A and B section categorization was not used after 2001.

We categorized vessels into 6 types: 1) cruise ships (large, oceangoing vessels of 91 metric tons gross or more that carry passengers for hire; 2) tour boats (commercial vessels less than 91 metric tons gross that operate on a daily or weekly schedule); 3) power boats (chartered vessels and private vessels, including sailboats under power and nonskiff auxiliary vessels from cruise ships [these subcategories were pooled because it was not always possible to distinguish among them]); 4) inflatables (inflatable skiffs with an outboard motor), 5) skiffs (hard-hulled skiffs with an outboard motor), or 6) kayaks. For groups of inflatables, skiffs, or kayaks traveling together, the lead vessel was tracked if the group was monitored for seal disturbance, but each boat in the group was counted separately for vessel summaries. Because observations were concentrated during the day and vessels may have entered the inlet before or after observations, vessel counts were minimums; counts of tour boats likely were the most accurate because their times of daily entry and departure usually were within our observation periods.

Seal–vessel interactions

Randomized observations We conducted randomized observations of focal groups (Altmann, 1974) of seals to determine the rate at which seals entered the water—a rate that we modeled as a function of predictor variables, including the presence of vessels. We conducted 2–14 observations (median: 6 observations) of 10 min each per monitoring session. To spread sampling proportionately, the study site was divided into 10 zones. We used a computer-generated list to randomly select 1 zone for monitoring during each 10-min period. At the start of each 10-min period, the observer chose a general area within the selected zone as the initial search area for scans. We tried to vary the ice type (i.e., either dense, with icebergs packed together, or scattered, with much open space among icebergs) and the position of the initial search area in subsequent samples.

Once an initial search area was selected, the observer used binoculars or a spotting scope and the first seals to come into view became the focal seals for that period. If possible, we added additional seals in the immediate vicinity to try to bring the total number of focal seals to between 6 and 10. We recorded the size of the seal group, number of mother–pup pairs in each group, ice type, the position of the seals in relation to an overall patch of icebergs (e.g., interior versus near an edge next to a section with open water or less ice), and weather (i.e., sky condition, precipitation, and wind speed). During each 10-min observation period, we recorded the number of seals that entered the water and the number of vessels in the inlet. In 2001, we also recorded the vessel type of the nearest vessel and the closest approach (in the categories 0–50 m, 51–100 m, 101–300 m, >300 m) of that vessel to the focal seals. Observations were terminated early if any of the focal seals drifted out of view; these rare, incomplete observations were not used.

We used a generalized linear mixed model (GLMM; binomial error, logit link) to model how the probability of a seal entering the water was affected by external factors. The response variable was the number of seals that entered the water in the 10-min observation period in relation to the number of seals under observation. The predictors were DOY, TOD, seal position on the ice, number of mother–pup pairs, ice type, sky condition, precipitation, wind speed, number of vessels, vessel type, and distance to vessels. We included quadratic terms for DOY and TOD to allow for nonmonotonic associations. For several variables (e.g., sky condition, precipitation, wind speed, vessel distance), categories with few observations were combined with adjacent categories. The predictors mother-pup pairs and vessels were, in separate models, fitted as either continuous predictors (counts) or binary predictors (presence or absence). Vessel type was fitted as a single, multicategory predictor to determine whether responses differed by vessel type; then we fitted models for the presence of each vessel type separately to produce individually estimated odds ratios for each vessel type.

Initially, models included DOY, TOD, their quadratic terms, seal position on the ice, and all weather variables. Wald chi-square statistics (P>~0.05) were used to eliminate unimportant variables one at a time (Hosmer and Lemeshow, 2000). After this model fitting (i.e., after we determined useful environmental predictors), mother–pup pairs and vessel predictors were included and evaluated in the same way.

Vessel approaches To estimate the effect of vessel type and distance more directly on seal behavior (i.e., the probability that a seal will enter the water), in 2001 we observed a subset of the vessels entering Tracy Arm as they approached seals hauled out on icebergs. When seals are hauled out, they are in a temporary state that ends when the seal enters the water. As such, external factors, including the presence of boats, can only affect the timing of when a hauled-out seal enters the water, not the fact that the entry will occur. We used entry into the water as our response because it is an easily observed and unambiguous behavior with energetic and predator-exposure consequences, and it has been used as a measured response in most comparable studies (Calambokidis et al.[1]; Mathews, 1995; Jansen et al., 2010; Young et al., 2014).

Once a vessel was selected for observations of seal–vessel interaction, the observer selected one or more focal icebergs in the vessel's path and recorded the number of nonpups and pups on each iceberg. We estimated the distance between the vessel and seals and classified it into 1 of 4 distance classes: 0–50 m, 51–100 m, 101–300 m, and ≥300 m. When possible, we selected icebergs that were >300 m from the vessel at the start of an observation, but not all distance classes were observed for every vessel–iceberg combination. For each distance class transited by a vessel, we recorded the number of pups and nonpups that entered the water (which could be zero). We continued to monitor icebergs until shortly after the vessel made its closest approach to the seals, at which point observations were terminated and a new iceberg was selected for focus. We attempted to monitor a vessel during its entire inbound and outbound track, and we recorded both seal behavior and vessel activity (i.e., vessel moving or not moving) during these observations. Most observations were made within 1 km of the observation point.

We evaluated our visual distance estimates by comparing them with measurements made with laser rangefinder binoculars (Leica Vector IV[8], Vectronix, Inc., Bedford, NH), which allowed us to measure the distances to the vessel and to the seal(s) and the angle between them, automatically calculating the distance between the vessel and the seal(s); the rangefinder was calibrated according to the manufacturer's recommendations. For this effort, 2 observers simultaneously recorded distances between selected icebergs or an iceberg and a vessel; 1 observer estimated the distance visually, using the seal–vessel distance classes, and the other observer measured the distance with the laser rangefinder. The distance measurements made with the rangefinders were then converted to distance classes, and the visual estimates of distance were scored into 3 bins: classified correctly, overestimated by 1 or 2 classes, or underestimated by 1 or 2 classes.

Although we did not systematically monitor such behavior, we occasionally observed seals entering the water after the vessel had passed its point of closest

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[8] Mention of trades names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

approach to a seal or seal group because of wake effects or for other reasons (also reported by Calambokidis et al.[1]). If the seal entered the water when the vessel was still in the same distance class as the closest approach, we used the observation in the analyses, assuming that most such disturbances would have been observed. However, we did not use observations of disturbances when vessels had moved beyond the distance class of their closest approach because we were far less likely to observe them. Consequently, our estimates of the probability of disturbance are biased low but are comparable to those of other studies where seals were not tracked after vessels passed them (Jansen et al., 2010; Young et al., 2014) and comparable to counts of "visual reactions" (versus "wake reactions") reported by Calambokidis et al.[1]

We used a GLMM (binomial error, logit link) to estimate the effect of predictor variables on the probability of a seal entering the water. We used the following predictors: distance between the seal and vessel, seal age class (pup, nonpup), DOY, TOD, group size (the number of seals on an iceberg when the vessel entered each distance zone), percent ice cover in the area of the monitored iceberg, if ≥1 pup was on an iceberg when it was first observed, vessel activity (i.e., moving, not moving), sky condition, temperature, and precipitation. Encounter (i.e., individual vessel observed) and iceberg within an encounter were included in the model as random effects because observations within these units were not independent. We included quadratic terms for DOY and TOD to allow for nonlinear (on the logit scale) responses between the predictors and water-entry probability.

We also included the interaction terms *distance class*vessel type* and *distance class*age* to allow the effect of distance class to vary by vessel type or by seal age category. The effect of *age* and *distance class*age* were investigated by using a data set that separated observations of pups and nonpups; a data set that included both pups and nonpups was used to investigate all other predictors. For 2 *distance*vessel* categories (skiff: >300 m; kayak: >300 m), there were no observations of seals entering the water—a situation that prevented successful model fitting and estimation of parameters (Hosmer and Lemeshow, 2000). To overcome this problem and facilitate model fitting, we added 0.1 (i.e., added one-tenth of a water entry) to one observation in each category. Because of this adjustment, the estimates for these 2 categories are slightly positively biased, although they remain essentially zero.

Results

Seal counts and timing of pupping

In 2001, we counted seals in Tracy Arm 193 times on 34 days (range: 3–10 counts per day); 100 of these counts were paired (50 pairs), with counts differing by >10% in 8 of the 50 pairs. All counts were included in the analyses. Total counts (i.e., pups+nonpups) peaked during 24–26 June, with a high count of 1351 seals (Fig. 2A). Separate counts of both pups and nonpups peaked during this period, at ~400 pups and ~1000 nonpups (Fig. 2B). The average numbers of pups seemingly began to level off by about 25 June, with the maximum pup count of 408 observed on June 24; however, it is unclear whether the average nonpup numbers were still increasing or were at a peak on 30 June, the last day that we made observations in 2001 (Fig. 2B). We observed the first evidence of birth (blood on iceberg) on 30 May, the third day of our study, and we recorded the last on 25 June. Peak daily numbers of icebergs with evidence of recent births (4–8) were observed during 7–13 June.

For all 3 groupings of seals (nonpups, pups, and all seals), 6 variables (count quality, DOY, TOD*TOD, percent ice cover, sky condition, and temperature) were retained in the GLMs (Table 1). Mean counts were lowest for high count qualities and highest for intermediate count qualities (Table 1). The number of nonpups peaked at around 1300, whereas the number of pups showed no distinct diurnal pattern (Fig. 3). Seal counts, for both pups and nonpups, were positively related to ice cover (Table 1). More seals were counted under clear skies, more nonpups were counted when there was no precipitation, and more pups were counted when wind speed was intermediate among the conditions we observed (i.e., Beaufort 2) compared with the counts when there was more (i.e., Beaufort 3) or less (i.e., Beaufort 1) wind (Table 1). Counts of nonpups and pups increased with increasing temperatures (Table 1).

Vessel traffic

The mean numbers of vessels observed daily in Tracy Arm varied from 10.2 in 2001 to 2.0 in 2006 (Fig. 4). The maximum number of vessels recorded in a day was 33 on 26 June 2001. Also in 2001, the mean number of vessels per day on weekdays (10.25, n=24) was similar to that observed on weekend days (10.20, n=10); consequently, this factor (i.e., weekday versus weekend day) was not used in other analyses.

Tour boats were the most common type of vessel observed in most years, followed by power boats (Fig. 4), and these 2 types of boats accounted for 57–100% of the vessels observed in a day. The number of sampling days was small during the years 2004–2006, making the ranking of vessel types potentially imprecise for those years. The majority of inflatables, skiffs, and kayaks were launched from larger vessels.

In 2001, most vessels (87%) entered section A, the part of our study area closest to the glacier (Fig. 1, inset map). Individual vessels were in the study area an average of 1.2 h both in 2001 (n=269; 95% confidence interval [CI]: 1.10–1.30) and during 2002–2006 (n=193; 95% CI:1.12–1.30). Some estimates of mean lengths of stay were underestimated when vessels arrived or departed outside of our observation periods. The number of vessels per day in Tracy Arm declined over the period 2001–2006, both in total and for each vessel type

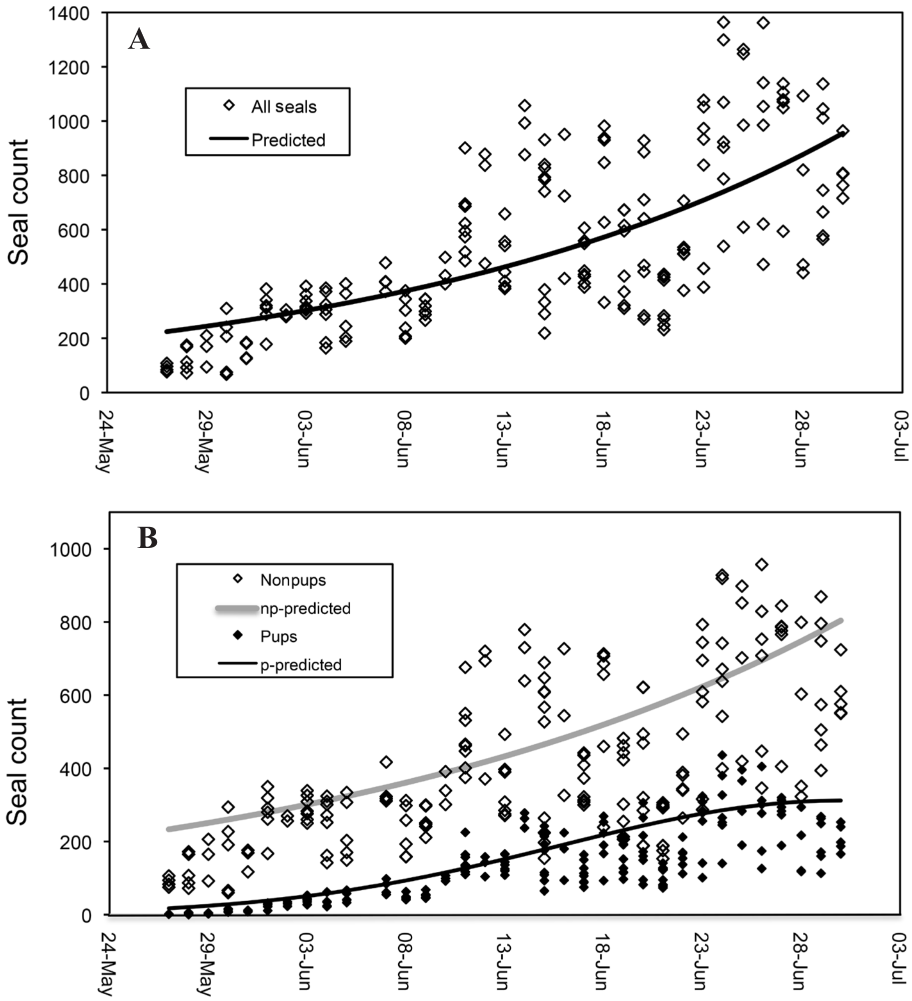

Figure 2

Counts of harbor seals (*Phoca vitulina*) in Tracy Arm, Alaska, including both seals that were hauled out and those in the water. Seals were counted from 27 May–30 June 2001 and are summarized as (**A**) all seals and (**B**) pups and nonpups separately. Lines are the predicted counts based on modeled functions of the mean counts in relation to day of year and are adjusted for other predictors in the models.

(Fig. 4). Although vessel traffic declined in Tracy Arm, the number of vessels counted in nearby Endicott Arm increased (U.S. Forest Service[9]; Fig. 4).

Seal–vessel interactions

Randomized focal observations We made 662 10-min observations of focal seal groups, and recorded the behavior of 3250 seals (group size: 1–24, median 4). The probability of a seal entering the water, during a 10-min period when no vessels were present—an undisturbed baseline level for the entering the water behavior—averaged across all other predictor variables, was 0.06 (95% CI: 0.05–0.08). In other words, every 10 minutes we would expect 6 of 100 undisturbed seals, on average, to enter the water. The odds of a seal entering the water was not related to DOY or TOD (P>0.17), to ice type (dense versus scattered), or to any of the weather predictors (Fig. 5). The presence of a pup, usually indicative of a mother–pup pair, and the number of pups were associated with reduced probability of a seal from those groups entering the water (Fig. 5, pup present).

Vessel type affected the probability of seals entering the water in different ways (Fig. 5, vessel type). The odds of seals entering the water were >2 times higher when vessels were present in the study area

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[9] U.S. Forest Service. 2002–2013. Unpubl. data. Juneau Ranger District Wilderness Program, U.S. Forest Service, Juneau, Alaska 99801.

Table 1

Analyses of counts of harbor seals (*Phoca vitulina*) recorded in Tracy Arm, Alaska in 2001. Means, adjusted for other variables in the model (i.e., least-squares means), are presented for categorical variables. For continuous variables, "%change" is the percentage increase in counts for a 1-unit increase in the predictor. Analyses were conducted separately for nonpups, pups, and total counts. For means and change percentages, 95% confidence intervals are given in parentheses.

	Nonpups		Pups		All seals	
Variable	*P*	Mean or %change	*P*	Mean or %change	*P*	Mean[1] or %change
Count quality	<0.01		<0.01		<0.01	
1.5		350.6 (301.0–408.5)		106.5 (90.8–128.2)		466.1 (401.4–541.2)
2		355.5 (303.4–416.6)		111.0 (94.4–130.6)		477.4 (408.6–557.7)
2.5		399.9 (348.7–458.6)		130.8 (114.0–150.0)		543.2 (474.9–621.4)
3		389.1 (342.3–442.3)		127.5 (113.4–144.4)		524.1 (462.0–594.4)
3.5		486.3 (408.9–578.4)		167.7 (142.5–197.1)		675.6 (570.6–800.0)
4		476.3 (417.7–543.0)		154.2 (136.6–174.0)		645.4 (567.4–723.3)
4.5		466.4 (352.7–616.9)		176.9 (134.3–233.1)		652.7 (497.5–856.3)
5		414.3 (318.9–538.4)		125.4 (92.0–171.6)		528.3 (404.9–689.2)
6		409.2 (301.6–555.2)		125.9 (88.7–179.1)		532.9 (391.2–725.8)
Day of year (DOY)	<0.01	[2]	<0.01	[2]	<0.01	[2]
DOY*DOY	0.28		<0.01	[2]	0.58	
Time of day (TOD)	0.17		0.16		0.19	
TOD*TOD	<0.01	[3]	<0.01	[3]	<0.01	[3]
Ice cover (%)	<0.01	0.80% (0.43–1.18)	<0.01	1.22% (0.80–1.63)	<0.01	0.93% (0.57–1.31)
Sky	<0.01		0.04		<0.01	
Clear		516.8(426.1–626.7)		164.7 (134.0–202.3)		698.9 (577.7–845.5)
Partly cloudy		369.4 (326.2–418.4)		119.1 (104.8–135.6)		492.9 (436.2–556.9)
Overcast		371.0 (335.2–410.7)		123.5 (109.7–139.8)		498.9 (451.7–551.0)
Temperature	0.05	1.27% (-0.01–2.57)	0.01	1.84% (0.45–3.24)	0.03	1.35% (0.08–2.63)
Precipitation	0.01		0.41		0.05	
None		470.5 (435.3–508.5)				612.8 (567.0–662.4)
Mist or light rain		391.6 (337.1–454.9)				523.6 (451.2–607.8)
Heavy rain		384.4 (303.1–487.6)				535.5 (426.7–672.1)
Wind speed	0.16		0.05		0.10	
Beaufort 1				127.6 (114.1–142.8)		
Beaufort 2				147.2 (127.9–169.8)		
Beaufort 3				129.0 (103.9–160.7)		
Wind direction	0.55		0.76		0.66	
Vessels	0.65		0.30		0.55	

[1] Because models were fitted separately for nonpups, pups, and all seals, the effect of the predictors differs, and the means for "all seals" are not the sum of the means for nonpups and pups.
[2] See Figure 2.
[3] See Figure 3.

than when they were not (Fig. 5, vessel type pooled). Randomly selected seals were more likely to enter the water when inflatables or kayaks were present in the study area (Fig. 5, vessel type). However, seals entered the water less often when there was a tour boat in the inlet than when there were none. The estimated effects of other vessel types were imprecise, either because of small sample sizes or variable seal responses for seals on randomly selected patches of ices. When all vessel types were pooled, both the number of vessels and the presence of at least one vessel were associated with an increased probability of a seal entering the water in relation to the probability of entry when no vessels were present (Fig. 5, vessel type pooled).

The odds of a seal from a randomly selected focal group entering the water were 3.7 times (95% CI :2.6–5.4) greater when vessels were in the 2 shortest distance classes (0–50 m or 51–100 m) than when they were within the longest distance class (> 300 m). The estimate for the remaining distance class (101–300 m), although imprecise, also indicated an increased likelihood of a seal entering the water than when boats were >300 m away (Fig. 5, vessel distance).

Vessel approaches In 2001, vessels entered the inlet on all 34 days when vessel entries were tabulated. We monitored 141 vessels (of 348 seen) and 1199 icebergs with 1755 harbor seals for disturbances of seals as ves-

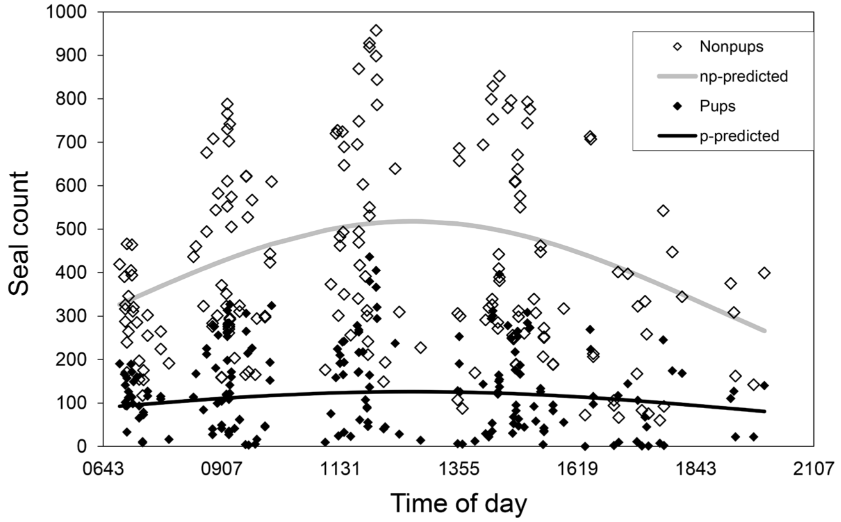

Figure 3

Counts of pup (p) and nonpup (np) harbor seals (*Phoca vitulina*), including seals that were hauled out and those in the water, in Tracy Arm, Alaska, from 27 May–30 June 2001 as a function of time of day (TOD). Lines are the modeled functions of the mean counts in relation to TOD and are adjusted for other predictors in the models.

sels approached. Vessels were observed for an average of 24 min (standard deviation=29 min). Individual icebergs had 1–15 nonpup seals and 1–5 pups; 725 icebergs (~60% of those observed) had at least 1 pup. Disturbances caused by monitored vessels occurred on all of the 32 days we observed vessel approaches.

Overall, 74% of visual estimates of distance were correctly classified by observers. Observers tended to estimate shorter distances more accurately than longer distances (93% of distances <50 m were classified correctly, but only 64% of distances >300 m were correctly categorized). Observers tended to underestimate rather than overestimate distances, and this bias increased with distance. Overall proportions of misclassification were similar for both observers, although variability between observers also increased slightly with distance.

Day of year and TOD were not related to the probability of a seal's entry into water (water entry [P>0.35]), nor were seal age category (including *age*distance class*), temperature, or precipitation (Fig. 6). Predictors associated with the probability of water-entry included seal group size, the presence of a pup at the start of the observation, percent ice cover, sky condition, vessel activity, and vessel distance, the latter 2 of which varied by vessel type (Figs. 6 and 7). Seals were more likely to leave an iceberg as ice cover decreased or under clear versus cloudy skies (Fig. 6). Seals were less likely to leave an iceberg with increasing group size but were much more likely (1.3 times [95% CI :1.0–1.8]) to enter the water if there was at least 1 pup present in the focal group of seals on an ice berg when the observation began (Fig. 6, pup present). However, pups were rarely the first seal in a group to enter the water. In 56 of the 278 (20%) instances when a seal entered the water when a pup was present, we recorded whether a pup or a nonpup entered the water first (in 222 instances, both entered at the same time or the order was not clear from the recorded data). For 43 of the 56 (77%) instances, a nonpup entered the water first.

The odds of a seal entering the water when a vessel was stopped were about 4 times as high as when a vessel was moving (Fig. 6, vessel activity). The probability that a seal entered the water increased dramatically as the distance between a seal and a vessel decreased, but the effect differed depending on vessel type (Table 2, Fig. 7). The probability of a seal responding to a vessel was higher for cruise ships and kayaks than for other vessel types (Fig. 7). The probability of a seal entering the water when vessels were within 50 m was >0.47 for every vessel type and almost 1 for cruise ships and kayaks. For vessel types other than cruise ships and kayaks, the probability of water entry by seals decreased to low levels for distances >100 m. Probabilities of water entry were uniformly low for all vessel types at distances >300 m (Fig. 7).

Discussion

Seal counts

In Tracy Arm in 2001, there were more seals (both nonpups and pups) hauled out with greater ice cover,

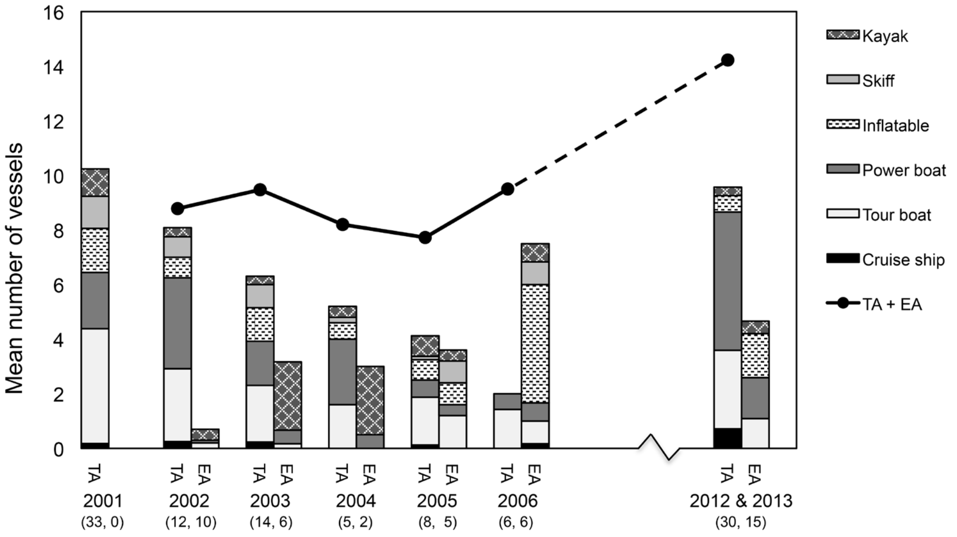

Figure 4

Mean daily counts of vessels, by type, for the period 2001–2006 in Tracy Arm (TA) and Endicott Arm (EA), Alaska, with counts for 2012 and 2013 (average for 2 years) included for comparison. The numbers of survey days in each inlet are listed (in parentheses) below year.

warmer temperatures, and clear skies; more nonpups hauled out when there was no precipitation, and more pups hauled out when wind speed was intermediate. Other studies also have found that harbor seal counts are affected by environmental factors, but such factors can be site specific or might not be detected in a study because of the limited range of conditions under which surveys were conducted (e.g., Boveng et al., 2003; Simpkins et al., 2003; Jemison et al., 2006, Jansen et al., 2015). Although harbor seal haul-out patterns on glacial ice typically are not affected by tide stage (Calambokidis et al., 1987; Boveng et al., 2003; Mathews and Pendleton, 2006; but see Hoover-Miller et al., 2011), they are affected by the availability of floating ice. Calambokidis et al. (1987) and Young et al. (2014), both working in GBNP, found that seal counts were positively related to percent ice cover, the proportion of seals counted in the water was negatively related to percent ice cover, and, when ice cover was low, hauled-out seals were concentrated on the few remaining icebergs. Jansen et al. (2015) reported that seals were most abundant with intermediate ice densities (5–7 tenths coverage).

As with other harbor seal studies in glacial fjords in southeastern Alaska, we found peak pup counts in late June (Mathews and Pendleton, 2006, Jansen et al., 2015). However, Hoover-Miller et al. (2011) reported peak pup counts in Aialik Bay, KFNP, in early- to mid-June, indicating regional variation in pup birth dates. The maximum proportion of pups from our counts (30–36%) was also similar to the high values reported for seals in other tidewater glacial fjords (KFNP: 21–34%, Hoover, 1983, Hoover-Miller et al., 2011; GBNP: 34–40%, Calambokidis et al., 1987, Mathews and Pendleton, 2006), but ~3 times greater than the proportion of pups in Disenchantment Bay (Jansen et al., 2015). Note also that the proportion of pups can be affected by immigration or emigration of nonpups in addition to changes in productivity.

Seal haul-out patterns

The number of nonpups that were hauled out peaked at around 1300 (Fig. 3)—a number similar to patterns seen with other ice-associated harbor seals (Calambokidis et al., 1987; Mathews and Pendleton, 2006; Hoover-Miller et al., 2011, Blundell and Pendleton, 2015). Using telemetry data, Blundell and Pendleton (2015) found that seals in Tracy Arm and Endicott Arm had the highest haul-out probabilities in the middle of the day, especially during the pupping season. Our randomized observations indicated that the probability of a seal entering the water was not related to TOD, but the time span of our observations might have been too narrow to detect a pattern if the afternoon peak was broad. Blundell and Pendleton (2015) found seals more likely to end haul-out bouts (i.e., enter the water) later in the day.

In contrast to the pattern observed for nonpups, the predicted number of pups hauled out in Tracy Arm, after accounting for other predictors, showed no distinct diurnal pattern (Fig. 3), although the observed counts indicate a slight peak. In Aialik Bay, mother-pup pairs also were less influenced by environmental

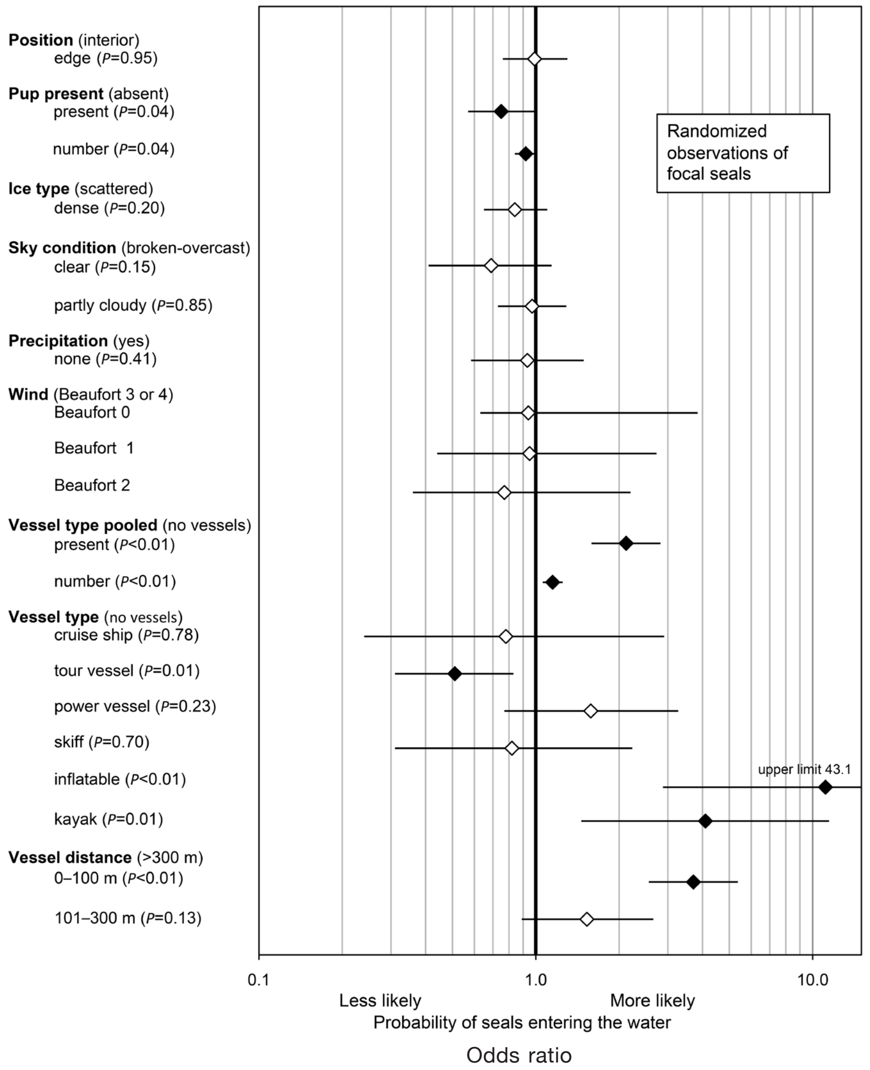

Figure 5

Odds ratios of a harbor seal (*Phoca vitulina*) entering the water during randomized, focal seal observations (2001–2006). Bars indicate 95% confidence intervals (CIs). Solid black symbols indicate factors that were statistically significant (i.e., where the CI does not cross 1). The odds ratios are relative to what we used as the comparison category for each variable (in parentheses). Position=seal's position in relation to the overall patch of ice (e.g., interior versus near an edge next to a section with open water or less ice). Vessel type and vessel distance results are based on 2001 data only. Vessel distance=distance from the focal seal or group.

conditions than nonpups, but they did show a midday peak in counts (Hoover-Miller et al., 2011). Because pups suckle when they are hauled out, the haul-out cycles of lactating females may be influenced by the needs of their pups. We found that, when >1 mother-pup pair was present, seals were less likely to enter the water during a random 10-min observation than were seals in groups without a pup present (Fig. 5), which also suggests longer haul-out bouts by mother-pup pairs. In Johns Hopkins Inlet, GBNP, in June, the TOD also was not associated with counts of either nonpups or pups or with the proportion of hauled-out seals that were pups (Mathews and Pendleton, 2006). Our analyses of our randomized observations did not reveal any relationship between seals entering the water and local ice dispersion (i.e., scattered or dense) (Fig. 5). In contrast, Young et al. (2014) observed a pattern in which seals were more likely to enter the water when an ice cover index (a combination of cover and density) was high.

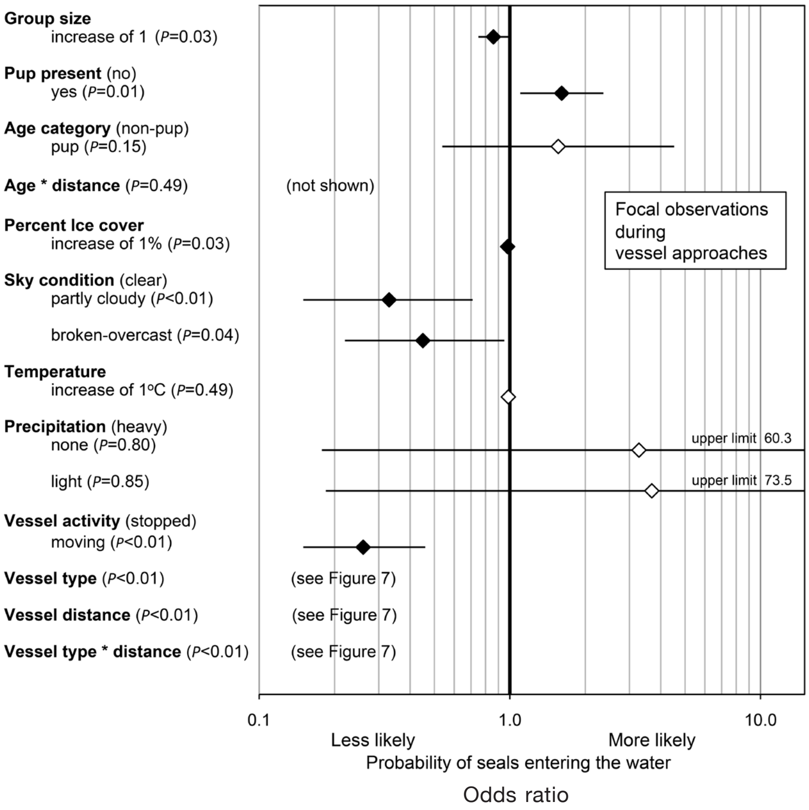

Figure 6

Odds ratios of a harbor seal *(Phoca vitulina)* entering the water in response to vessels approaching or remaining near an iceberg where the seal was hauled out. Bars indicate 95% confidence intervals (CIs). Solid black symbols indicate factors that were statistically significant (i.e., where the CI does not cross 1). The odds ratios are relative to what we used as the comparison category for each variable (in parentheses). Observations were made from 27 May through 30 June 2001.

Vessels and seals

Vessel traffic We documented high levels of vessel activity in Tracy Arm in 2001 (10.2 vessels/day (maximum 33 vessels/day) during 32 days of observation), compared with Johns Hopkins Inlet in GBNP during months when vessels could enter the inlet (3.7 vessels/day, 1994–2001, E. A. Mathews, unpubl. data; 2.8 vessels/day, 178 vessels during 64 days of observation in July 2007 and 2008, Young et al., 2014). After 2001, vessel traffic decreased in Tracy Arm, whereas it increased in nearby Endicott Arm (Fig. 4), likely because of the rapid recession of South Sawyer Glacier that increased the number of icebergs in the water, making maneuvering boats and ships in Tracy Arm more difficult and potentially hazardous. From 2001 through 2013, the combined vessel traffic in Tracy Arm and Endicott Arm remained high and may have increased (Fig. 4).

Seal counts and vessel numbers Higher vessel counts were not associated with reduced seal counts in 2001 (Table 1), a pattern also noted by Jansen et al. (2015) in Disenchantment Bay. However, our total counts included seals in the water, and therefore they were less sensitive to vessel disturbance. Furthermore, there could have been an effect of vessels on seal counts that we were unable to detect because of the constant daily presence of boats. In Muir Inlet in GBNP, peak counts of seals on days with no vessels were, on average, 15% higher than counts when vessels were present (Calambokidis et al.[1]).

Seal–vessel interactions All of our analyses of seal–vessel interactions (i.e., randomized focal observations and direct observations of vessel approaches) revealed increased probabilities that seals would enter the water in response to at least some types of boats (Tables 1, Figs. 5–7). We also found that the probability of a seal

Table 2

Predicted probabilities of a harbor seal (*Phoca vitulina*) entering the water when vessels of various types approached within 4 distance classes. Confidence intervals (95%) are given in parentheses below their associated point estimates. Data were collected during 27 May–30 June 2001; sample sizes are listed in parentheses in the first 2 rows of this table.

Distance class	Cruise ship	Tour boat	Power boat	Skiff	Inflatable	Kayak
No. of vessels	(5)	(77)	(25)	(12)	(14)	(8)
No. of ice bergs	(103)	(694)	(147)	(81)	(110)	(64)
0–50 m	0.99	0.62	0.47	0.66	0.77	0.98
	(0.96–1.00)	(0.50–0.73)	(0.24–0.71)	(0.39–0,85)	(0.54–0.90)	(0.92–1.00)
51–100 m	0.50	0.16	0.10	0.01	0.12	0.62
	(0.23–0.76)	(0.11–0.24)	(0.04–0.23)	(0.00–0.11)	(0.05–0.26)	(0.32–0.85)
101–300 m	0.22	0.05	0.01	0.06	0.02	0.18
	(0.08–0.49)	(0.03–0.08)	(0.00–0.04)	(0.02–0.22)	(0.00–0.10)	(0.06–0.44)
>300 m	0.02	0.02	0.00	0.00	0.11	0.00
	(0.00–0.08)	(0.01–0.04)	(0.00–0.04)	(0.00–0.53)	(0.01–0.70)	(0.00–0.57)

entering the water increases with decreasing seal–vessel distance (Figs. 5 and 7)—a finding that agrees with those of other studies (Calambokidis et al.[1]; Jezierski, 2009; Jansen et al., 2010; Hoover-Miller et al., 2013, Young et al., 2014). However, seals in Tracy Arm during our study appeared to be less responsive to vessels at a given distance than seals in Disenchantment Bay, where only cruise ships were monitored (Jansen et al., 2010), and in Muir Inlet in GBNP where all vessel types were monitored (Calambokidis et al.[1]), and they were far less sensitive than seals in Johns Hopkins Inlet in GBNP (Young et al., 2014), even when accounting for vessel type.

For our visual estimates, we tended to underestimate distances between seals and vessels, especially for longer distances, and we did not adjust assigned distance classes used in other analyses. Our underestimates of distance could possibly explain some of the weaker distance response in Tracy Arm than that in other glacial fjords where seal-to-vessel distances were measured.

Independent of distance, we found that seals were more sensitive to the presence of cruise ships than to other vessel types, except kayaks. Other studies in which multiple vessel types were monitored also reported this pattern (Calambokidis et al.[1]; Calambokidis et al.,1987; Young et al., 2014; Blundell and Pendleton, 2015). Calambokidis et al.[1] found that cruise ships in GBNP disturbed seals on ice at an average distance of 277 m, Jansen et al. (2010) reported seal disturbances by cruise ships at distances of up to 500 m, and Young et al. (2014) reported disturbances by cruise ships at distances >800 m. In contrast, we found the probability of disturbance by cruise ships approached 1 for ships within 50 m of a seal, but the response probability declined rapidly to 0.02 when the distance between the seal and ship was >300 m (Fig. 7)—a more rapid decline in response than was observed by Jansen et al. (2010).

For all of our analyses by vessel type, kayaks also had high probabilities of causing seal disturbance, with a disturbance response pattern similar to that caused by cruise ships (Table 2). Some other studies had also noted that kayaks disturb seals at greater distances than those of motorized vessel types (e.g., power boats) (Jezierski, 2009; Hoover-Miller et al., 2013), but Calambokidis et al.[1] found that harbor seals were equally sensitive to kayaks and tour boats (and less sensitive to pleasure boats [i.e., private vessels in our study]) and Young et al. (2014) found seals were less sensitive to kayaks than any type of power vessel.

It is possible that harbor seals can habituate to the noise of power boats and can determine a boat's approximate location by the sound of its engine. Kayaks, on the other hand, travel more slowly and quietly and may go undetected by seals until they are in close proximity, or until they make a noise, causing the seals to startle and flee into the water. The lower sensitivity to kayaks reported by Young et al. (2014) could be a function of the behavior of kayakers at that specific site, possibly a function of regulations or boater education, which have been shown to reduce kayak-related disturbance elsewhere (Hoover-Miller et al., 2013). Also, kayakers frequently travel in groups, which could account for the higher probabilities of kayaks causing disturbance. Further, differences among sites in the sizes of kayak groups could be a factor in the variability among sites in patterns of harbor seal response to kayaks. We had too few observations of kayak groups to estimate the effect of kayak group size on disturbance probability.

We found responses of seals to tour boats, skiffs, inflatables, and power boats generally similar, although there was some variation in results from our study methods (i.e., randomized focal observations vs. vessel approaches) and analyses (Figs. 5–7). Analyses of the randomized observations indicated that seals were less likely to enter the water when a tour boat was present than when there were no tour boats present in the

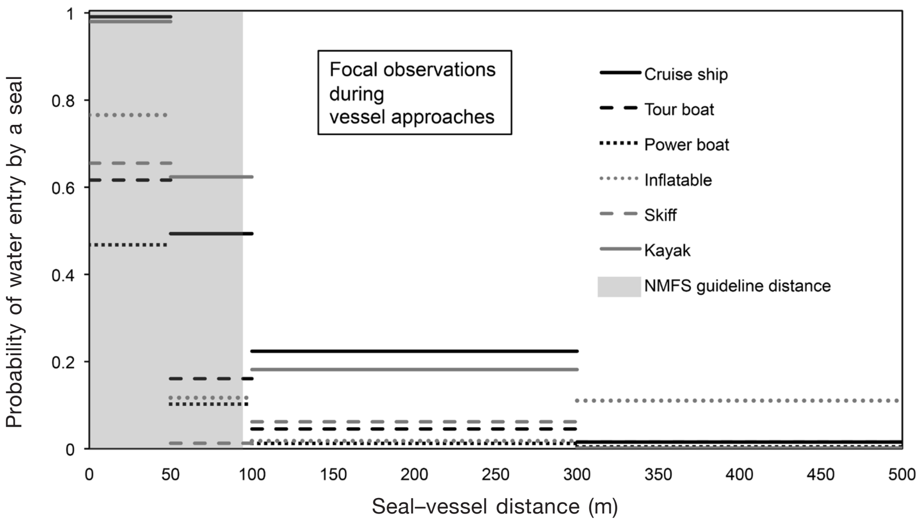

Figure 7

Estimated probabilities of hauled-out harbor seals (*Phoca vitulina*) entering the water when approached by a vessel as a function of seal–vessel distance and vessel type. Bars span the widths of the categorical distance bands used in this study. The National Marine Fisheries Service recommends that vessels remain beyond 100 yds (=91 m) from seals on haulouts (NMFS guideline avoidance area is blocked out in gray). Confidence intervals are presented in Table 2. Data were collected in Tracy Arm fjord in Alaska in 2001.

study area. Although we do not have a direct explanation for this pattern, possibilities include the predictable nature of tour boats in terms of arrival times and vessel maneuvering, the skill of experienced vessel captains, and seal habituation to specific boats. Some tour boats typically approach more slowly than other vessel types and then deploy motorized inflatables or skiffs to dispatch passengers, after which they continue slowly toward the glacier. Thus, another possible explanation is that the auxiliary craft preceding the tour boat may displace seals, functionally buffering the mother ship from producing disturbance. In addition, this could be a spurious result in which there was no actual tour boat effect, but because tour boats were always present at midday when seal haul-out probability was also highest, these two variables could end up being correlated without any cause and effect relationship, as suggested by Blundell and Pendleton (2015) and Jansen et al. (2015).

The number of vessel-caused disturbances is a function of the number of vessels of each type, how they are distributed, and the probability of disturbance at specific distances. Tour and private power vessels were the majority of vessels observed in our study; therefore, they almost certainly caused more of the total disturbances, a function of both disturbance risk and the number of encounters, than did the less commonly observed cruise ships or kayaks, even though the probability that tour and private power vessels caused a disturbance at a given distance was considerably lower. Consistent and predictable vessel speed after vessels pass harbor seals is also important in minimizing disturbance. Hoover-Miller et al. (2013) found that, although vessel captains were careful in approaching and passing seals, once the seals were behind the boat and out of view, some vessels accelerated, alerting the seals and occasionally causing them to flee into the water. We found that vessels that were stopped, often at their closest approach to the glacier—where there are typically lots of icebergs and seals—were more likely to cause disturbance than were vessels in motion. This pattern is consistent with the observations of Johnson and Acevedo-Gutiérrez (2007), where stopped power boats caused disturbances of hauled out harbor seals at distances of up to 10 times those of boats that passed by at steady speeds, even if the speed was fast.

Habituation and tolerance There were no days of our study at Tracy Arm without vessels. We recorded up to 33 vessels in one day and the minimum number of vessels we recorded was close to, or exceeded, the average numbers from other studies in glacial fjords (Calambokidis et al., 1987; Jansen et al., 2010; Young et al, 2014). Tracy Arm is only ~1 km wide (Fig. 1), which is 2–3 times narrower than Disenchantment Bay and Johns Hopkins Inlet, and most seals are clustered near the glacier face where vessels typically stop to view the glacier. Thus, it is likely that most seals in Tracy Arm were exposed to vessel traffic because they would likely have been within the diameter of a potential disturbance swath as boats traversed the inlet. The difference in response distance in our study and the distances at other study sites with less vessel traffic, wider fjords, or both, could, therefore, result from higher levels of seal habituation to vessels. Alternatively, seals less tolerant of vessels might have left Tracy Arm for sites with less disturbance, leaving more tolerant seals or those seals incapable of dispersing (e.g., in poor condition) (Gill et al., 2001; Frid and Dill, 2002; Bejder et al. 2009). Individual habituation and selection for disturbance-tolerant individuals could yield similar patterns of lower levels of seal responses to vessels in Tracy Arm compared with other areas with less vessel traffic. Additional research, however, would be needed to address whether habituation or tolerance is more likely in glacial fjords with higher vessel traffic.

Harbor seal pups in Tracy Arm

The seasonal summer increase in vessel activity in Tracy Arm (Nuka Research and Planning Group[3]) coincides with the harbor seal pupping and nursing periods (late May–mid-July). The timing of harbor seal births in Tracy Arm (peak births occurred during 7–13 June and the maximum pup count occurred in late June) was similar to patterns in other glacial fjords in Alaska (Muir Inlet, Calambokidis et al., 1987; Johns Hopkins Inlet, Mathews and Pendleton, 2006; Aialik Bay Hoover-Miller et al., 2011).

Our analyses of observations of vessels approaching hauled-out seals showed that seal groups on icebergs that included a pup (and presumably its mother) were 1.6 times more likely to have at least 1 seal enter the water in response to the approach of a vessel than a seal in a group that did not include a pup (Fig. 6). The first seal, however, to enter the water usually was not a pup, which also was noted by Calambokidis et al.[1] and is consistent with observations of harbor seal mother–pup pairs at a terrestrial site (Renouf et al., 1983). Similarly, Suryan and Harvey (1999) and Henry and Hammill (2001) found that seal groups at a haul out with the highest proportion of pups were significantly more likely to show disturbance reactions to boats than seals hauled out at 2 other sites with lower proportions of pups.

Disturbances that do not cause permanent separation of the mother and her pup can have negative consequences for pup survival. Harbor seals have short lactation periods (Muelbert and Bowen, 1993; Thompson and Wheeler, 2008), and repeated disruption of nursing bouts could reduce pup growth and, consequently, pup survival (Harding et al., 2005). Repeated disturbances that increase the amount of time a young pup remains in cold glacial waters can increase its metabolism (Jansen et at., 2010), presumably having a negative impact on pup fitness. In addition, oxytocin, an endocrine hormone released during and shortly after birth, has been linked to maternal behavior in mothers (Pedersen and Prange, 1979; Pedersen et al., 1982; Keverne and Kendrick, 1992) and identified as an indicator of maternal success in phocid seals (Robinson, 2014). Gray seal females displaying abnormal maternal behavior were found to have lower plasma oxytocin concentrations than successful mothers that raised their pups to weaning age, and it is hypothesized that one cause of low oxytocin concentrations is disturbance of the mother-pup pair shortly after birth (Robinson, 2014). Because dependent pups are present in Tracy Arm during the summer tourist season, the potential exists for reduced pup fitness.

In 1996, the National Marine Fisheries Service (NMFS[10]), NOAA, published voluntary guidelines for viewing marine mammals in Alaska. These guidelines recommended that viewers stay at least 91 m (100 yards) from pinniped haul-out locations. In 2012, increasing concerns about disturbance to harbor seals in glacial fjords, including specific concerns about high levels of vessel traffic in Tracy Arm, led NMFS to consider regulations that would limit vessel disturbance of seals that use glacial sites (Federal Register, 2013). Because of public comment and other relevant information, NMFS decided to publish new voluntary guidelines that recommend that vessels stay 457 m (500 yards) from seals (NMFS[11]) and to distribute educational materials to vessel operators in 2015 (NMFS[12]).

Limiting access to these glacial habitats during the most critical life history stages of pup birth and nursing could reduce disturbance during critical mother-pup bonding, but it also could make seals more sensitive after closures are lifted because of potentially reduced habituation to vessel traffic. Better education of vessel operators could also help reduce seal disturbance, but the narrow configuration of Tracy Arm and the desire by vessel operators to closely approach the glacier face, and hence the seals, are problematic, especially in regard to the documented increase in marine-mammal–related tourism and the inevitable effect that such tourism will have on seal behavior.

Acknowledgments

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[10] National Marine Fisheries Service (NMFS). 2000 NOAA Fisheries proposes extra protection for humpback whale. [News release available at website, accessed January 2016]

[11] National Marine Fisheries Service (NMFS). 2015. NOAA Fisheries revises approach guidelines for vessels in Alaska glacial fjords, accessed January 2016.

[12] National Marine Fisheries Service (NMFS). 2015. Alaska harbor seal: approach guidelines in glacial fjords. [Available at website.]

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Literature cited

Allen, S. G., D. G. Ainley, G. W. Page, and C. A. Ribic.
1984. The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California. Fish. Bull. 82:493–500.

Altmann, J.
1974. Observational study of behavior: sampling methods. Behaviour 49(3):227–267. [Available at website.]

Bejder, L., A. Samuels, H. Whitehead, H. Finn, and S. Allen.
2009. Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. Mar. Ecol. Prog. Ser. 395:177–185. Article

Bigg, M. A.
1969. The harbour seal in British Columbia. Fish. Res. Board Can., Bull. 172, 33 p.

Bishop, R. H.
1967. Reproduction, age determination and behavior of the harbor seal, *Phoca vitulina* L. in the Gulf of Alaska. M.S. thesis, 121 p. Univ. Alaska Fairbanks, Fairbanks, AK.

Blundell, G. M., J. N. Womble, G. W. Pendleton, S. A. Karpovich, S. M. Gende, and J. K. Herreman.
2011. Use of glacial and terrestrial habitats by harbor seals in Glacier Bay, Alaska: costs and benefits. Mar. Ecol. Prog. Ser. 429:277–290. Article

Blundell, G. M., and G. W. Pendleton.
2015. Factors affecting haul-out behavior of harbor seals (*Phoca vitulina*) in tidewater glacier inlets in Alaska: can tourism vessels and seals coexist? PLoS ONE 10(5): e012486. Article

Boness, D. J., W. D. Bowen and O. T. Oftedal.
1994. Evidence of a maternal foraging cycle resembling that of otariid seals in a small phocid, the harbor seal. Behav. Ecol. Sociobiol. 34:95–104. Article

Boveng, P. L., J. L. Bengtson, D. E. Withrow, J. C. Cesarone, M. A. Simpkins, K. J. Frost, and J. J. Burns.
2003. The abundance of harbor seals in the Gulf of Alaska. Mar. Mamm. Sci. 19:111–127. Article

Brasseur, S., J. Creuwels, B. V. D. Werf, P. Beijnders, and Inst. For. Nat. Res.
1996. Deprivation indicates necessity for haul-out in harbor seals. Mar. Mamm. Sci. 12:619–624. Article

Calambokidis, J., and G. H. Steiger.
1985. Bald eagle (*Haliaeetus leucocephalus*) consumption of harbor seal (*Phoca vitulina*) placenta in Glacier Bay, Alaska. J. Raptor Res. 19:145.

Calambokidis, J., B. L. Taylor, S. D. Carter, G. H. Steiger, P. K. Dawson, and L. D. Antrim.
1987. Distribution and haul-out behavior of harbor seals in Glacier Bay, Alaska. Can. J. Zool. 65:1391–1396. Article

Draper, N. R., and H. Smith.
1981. Applied regression analysis, 2nd ed., 709 p. John Wiley & Sons, New York

Fay, F. H.
1974. The role of ice in the ecology of marine mammals of the Bering Sea. *In* Oceanography of the Bering Sea with emphasis on renewable resources. Occas. Publ. 2 (D. W. Hood and E. J. Kelley, eds.), p 383–399. Alaska Inst. Mar. Sci., Univ. Alaska Fairbanks, Fairbanks, AK.

Federal Register.
2013. Marine mammals: Alaska harbor seal habitats. Federal Register 78:15669–15672. [Available at website.]

Frid, A., and L. Dill.
2002. Human-caused disturbance stimuli as a form of predation risk. Conserv. Ecol. 6:11.

Gill, J. A., K. Norris, and W. J. Sutherland.
2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biol. Conserv. 97:265–268. Article

Glacier Bay National Park and Preserve.
2006. 36 C.F.R. Sect. 13.65 (2006). [Available at website.]

Harding, K. C., M. Fujiwara, Y. Axberg, and T. Härkönen.
2005. Mass-dependent energetics and survival in harbour seal pups. Funct. Ecol. 19:129–135. Article

Henry, E., and M. O. Hammill.
2001. Impact of small boats on the haulout activity of harbour seals (*Phoca vitulina*) in Métis Bay, Saint Lawrence Estuary, Québec, Canada. Aquat. Mamm. 27.2:140–148.

Herreman, J. K., G. M. Blundell, D. B. McDonald, and M. Ben-David.
2009. Asymmetrical male-mediated gene flow between harbor seal (*Phoca vitulina*) populations in Alaska. Can. J. Zool. 87:498–507. Article

Hoover, A. A.
1983. Behavior and ecology of harbor seals (*Phoca vitulina richardsi*) inhabiting glacial ice in Aialik Bay, Alaska. M.S. thesis, 133 p. Univ. Alaska Fairbanks, Fairbanks, AK.

Hoover-Miller, A., S. Atkinson, S. Conlon, J. Prewitt, and P. Armato.
2011. Persistent decline in abundance of harbor seals *Phoca vitulina richardsi* over three decades in Aialik Bay, an Alaskan tidewater glacial fjord. Mar. Ecol. Prog. Ser. 424:259–271. Article

Hoover-Miller, A., A. Bishop, J. Prewitt, S. Conlon, C. Jezierski, and P. Armato.
2013. Efficacy of voluntary mitigation in reducing harbor seal disturbance. J. Wildl. Manage. 77:689–700. Article

Hosmer, D. W., Jr., and S. Lemeshow.
2000. Applied logistic regression, 2nd ed., 375 p. John Wiley & Sons, New York.

Jansen, J. K., P. L. Boveng, S. P. Dahle, and J. L. Bengston.
2010. Reaction of harbor seals to cruise ships. J. Wildl. Manage. 74:1186–1194. Article

Jansen, J. K., P. L. Boveng, J. M. Ver Hoef, S. P. Dahle and J. L. Bengston.
2015. Natural and human effects on harbor seal abundance and spatial distribution in an Alaskan glacial fjord. Mar. Mamm. Sci. 31:66–89. Article

Jemison, L. A.
1997. Recent history and demography of harbor seals on Tugidak Island, Alaska. M.S. thesis, 82 p. Univ. Alaska Fairbanks, Fairbanks, AK.

Jemison, L. A., G. W. Pendleton, C. A. Wilson, and R. J. Small.
2006. Long-term trends in harbor seal numbers at Tugidak Island and Nanvak Bay, Alaska. Mar. Mamm. Sci. 22:339–360. Article

Jezierski, C.
2009. The impact of sea kayak tourism and recreation on harbor seal behavior in Kenai Fjords National Park: integrating research with outreach, education, and tour-

ism. M.S. thesis, 69 p. Univ. Alaska Fairbanks, Fairbanks, AK.

Johnson, B. W.
1977. The effects of human disturbance on a population of harbor seals. *In* Environmental assessment of the Alaskan continental shelf, Annu. Rep. 1:422–432. Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Johnson, A., and A. Acevedo-Gutiérrez.
2007. Regulation compliance by vessels and disturbance of harbour seals (*Phoca vitulina*). Can. J. Zool. 85:290–294. Article

Keverne, E. B., and K. M. Kendrick.
1992. Oxytocin facilitation of maternal behavior in sheep. Ann. N. Y. Acad. Sci. 652:83–101. Article

Larson, C. F., R. J. Motyka, A. A. Arendt, K. A. Echelmeyer, and P. E. Geissler.
2007. Glacier changes in southeast Alaska and northwest British Columbia and contribution to sea level rise. J. Geophys. Res. 112:F01007. Article

Lawson, J. W., and D. Renouf.
1987. Bonding and weaning in harbor seals, *Phoca vitulina*. J. Mamm. 68:445–449. Article

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger, and O. Schabenberger.
2006. SAS for mixed models, 2nd ed., 828 p. SAS Institute, Cary, NC.

Mathews, E. A.
1995. Long-term trends in abundance of harbor seals *(Phoca vitulina richardsi)* and development of monitoring methods in Glacier Bay National Park, southeast Alaska. *In* Proceedings of the Third Glacier Bay Science Symposium; Gustavus, AK, 15–18 September 1993 (D. R. Engstrom, ed.), p. 254–263. U.S. Government Printing Office, Washington, D.C.

Mathews, E. A., and B. P. Kelly.
1996. Extreme temporal variation in harbor seal (*Phoca vitulina richardsi*) numbers in Glacier Bay, a glacial fjord in southeast Alaska. Mar. Mamm. Sci. 12:483–488. Article

Mathews, E. A., and G. W. Pendleton.
2006. Declines in harbor seal (*Phoca vitulina*) numbers in Glacier Bay National Park, Alaska, 1992–2002. Mar. Mamm. Sci. 22:167–189. Article

Mathews, E. A., and M. D. Adkison.
2010. The role of Steller sea lions in a large population decline of harbor seals. Mar. Mamm. Sci. 26:803–836. Article

Muelbert, M. M. C., and W. D. Bowen.
1993. Duration of lactation and postweaning changes in mass and body composition of harbour seal, *Phoca vitulina*, pups. Can. J. Zool. 71:1405–1414. Article

Newby, T. C.
1973. Changes in Washington State harbor seal population, 1942–1972. Murrelet 54:4–6. Article

Osinga, N., S. B. Nussbaum, P. M. Brakefield, and H. A. Udo de Haes.
2012. Response of common seals (*Phoca vitulina*) to human disturbances in the Dollard estuary of the Wadden Sea. Mamm. Biol. 77:281–287. Article

Pedersen, C. A., and A. J. Prange Jr.
1979. Induction of maternal behavior in virgin rats after intracerebroventricular administration of oxytocin. Proc. Natl. Acad. Sci. U.S.A. 76:6661–6665.

Pedersen, C. A., J. A. Ascher, Y. L. Monroe, and A. J. Prange Jr.
1982. Oxytocin induces maternal behavior on virgin female rats. Science 216:648–650.

Pitcher, K. W.
1986. Variation in blubber thickness of harbor seals in southern Alaska. J. Wildl. Manage. 50:463–466. Article

Renouf, D., J. Lawson, and L. Gaborko.
1983. Attachment between harbour seal (*Phoca vitulina*) mothers and pups. J. Zool. 199:179–187. Article

Robinson, K. J.
2014. The role of oxytocin in the maternal behaviour of the grey seal (*Halichoerus grypus*). Ph.D. thesis, 238 p. Univ. St Andrews, St. Andrews, U.K.

Simpkins, M. A., D. E. Withrow, J. C. Cesarone, and P. L. Boveng.
2003. Stability in the proportion of harbor seals hauled out under locally ideal conditions. Mar. Mamm. Sci. 19:791–805. Article

Suryan, R. M., and J. T. Harvey.
1999. Variability in reactions of Pacific harbor seals, *Phoca vitulina richardsi,* to disturbance. Fish. Bull. 97:332–339.

Thompson, P. M., and H. Wheele.
2008. Photo-ID-based estimates of reproductive patterns in female harbor seals. Mar. Mamm. Sci. 24:138–146. Article

Womble, J. N., and S. M. Gende.
2013. Post-breeding season migrations of a top predator, the harbor seal (*Phoca vitulina richardii*), from a marine protected area in Alaska. PLoS ONE 8(2): e55386. Article

Womble, J. N., G. W. Pendleton, E. A. Mathews, G. M. Blundell, N. M. Bool, and S. M. Gende.
2010. Harbor seal (*Phoca vitulina richardii*) decline continues in the rapidly changing landscape of Glacier Bay National Park, Alaska, 1992–2008. Mar. Mamm. Sci. 26:686–697. Article

Young, C.
2009. Disturbance of harbor seals by vessels in John Hopkins Inlet, Glacier Bay, AK. M.S. thesis, 120 p. San Jose State Univ., San Jose, CA.

Young, C., S. M. Gende, and J. T. Harvey.
2014. Effects of vessels on harbor seals in Glacier Bay National Park. Tourism Mar. Environ. 10:5–20. Article