EFFECTS OF VESSELS ON HARBOR SEALS
IN GLACIER BAY NATIONAL PARK

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We evaluated the effectiveness of harbor seal (Phoca vitulina)-related vessel regulations in Glacier Bay National Park. We observed 100% compliance with area closures intended to minimize disturbance to dependent pups, yet dependent pups were still present in the inlet after the area was opened to vessels. Compliance with the 463 meter (m) minimum approach distance regulation by vessels was low (22%), although 33% of vessel–seal encounters resulted in disturbance when vessels were still >463 m from seals. Ice cover was the best predictor of disturbance. Our results indicated that vessel regulations might be variably effective due to biological irrelevance, noncompliance, or environmental factors. MPA regulations should be evaluated to ensure achievement of conservation objectives.

Key words: Disturbance; Harbor seal; Vessel regulations; Compliance

Introduction

Marine protected areas (MPAs) historically have served as a tool for rebuilding fishery yield or conserving sensitive ecosystems (Leslie, 2005; Lubchenco, Palumbi, Gaines, & Andelman, 2003; Selig & Bruno, 2010) but are increasingly being established to meet conservation goals for higher trophic organisms such as marine mammals (Hooker & Gerber, 2004; Hooker, Whitehead, & Gowans, 2002). Although marine mammal protected areas are established to mitigate a myriad of threats (Gerrodette & Rojas-Bracho, 2011), one common objective is to address detrimental effects from ecotourism (Hoyt, 2011). Many studies have documented that disturbances, including those related to tourism activities, may affect marine mammal behavior (Constantine, Brunton, & Dennis, 2004; Henry & Hammill, 2003; Selig & Bruno, 2010; Williams, 2006), sometimes resulting in decreased reproductive success, population declines, or movement of individuals to other areas (Becker, Press, & Allen, 2011; Bejder et al., 2006; French, González-Suárez, Young, Durham, & Gerber, 2011).

To minimize disturbance potential, MPAs commonly implement fixed spatial or temporal closures,
and/or specific operating conditions, such as minimum approach distances to marine mammals (National Oceanic and Atmospheric Administration [NOAA], 2006). These regulations are necessary because tour operators often believe that visitor experience is best when proximity to marine mammals is closest (Duffus & Dearden, 1993; Zeppelin & Muloin, 2008; but see Orams, 2000), providing an incentive for visitors and tour operators to get as close as possible (Schänzel & McIntosh, 2000). Yet proximity often is a good index of whether animals are disturbed (Blumstein, Anthony, Harcourt, & Ross, 2003; Jansen, Boveng, Dahle, & Bengston, 2010), with the magnitude of change in behavior of the marine mammal often related to approach distance. For example, surface activity of killer whales (Orcinus orca) is greater for closer approaching boats than others that stay at greater distances (Noren, Johnson, Rehder, & Larson, 2009), and slight changes in pinniped behavior occur when vessels approach at greater distances whereas close approaches may elicit energetically costly flights into the water (Jansen et al., 2010; Shaughnessy, Nicholls, & Briggs, 2008).

To meet conservation goals, it is important to consider the effectiveness of regulations, which is a function of both their relevance (i.e., regulations accurately reflect the response of marine mammals to visitor presence) and compliance (i.e., visitors comply with the biologically relevant regulations) (Johnston & Acevedo-Gutiérrez, 2007). For example, if regulations for minimum approach distances are intended to reduce disturbance, the specified distances should reflect how marine mammals respond to approaching vessels. Specifying approach distances too close results in ineffective regulations because animals are disturbed, whereas overly conservative approach distances may keep visitors from viewing marine mammals, potentially affecting public acceptance and, ultimately, the success of the MPA.

Glacier Bay National Park and Preserve, Alaska (hereafter Glacier Bay) represents one of the largest marine protected areas in the northern hemisphere, and historically was the location of the largest aggregation of breeding harbor seals in Alaska, numbering nearly 5,000 individuals in the early 1990s (Mathews & Pendleton, 2006). Because there are no roads that connect Glacier Bay to outside areas of Alaska, visitation occurs almost exclusively by vessels, including kayaks, private and tour vessels, and large cruise ships. Visitors come to Glacier Bay seeking opportunities to view wildlife and tidewater glaciers, which is why Johns Hopkins Inlet (JHI) is a common destination for vessels; it provides an opportunity to see a large, advancing, active tidewater glacier and large numbers of Pacific harbor seals (Phoca vitulina richardii), which aggregate on icebergs calved from the glacier.

There is significant conservation concern about harbor seals in Glacier Bay because the population has decreased by up to 75% since 1992 (Womble et al., 2010) and the National Marine Fishery Service (NMFS) has recently designated this population as a unique stock in Alaska (Allen & Angliss, 2011). Decreases have occurred despite the phase-out of commercial fishing in the park [US Code of Federal Regulations (CFR); 36 CFR 13.65] and the prohibition of hunting seals in Glacier Bay since 1974 (Catton, 1995). Prey resources do not seem to be limiting, as seals that breed in Glacier Bay have similar body mass and body condition compared with seals in stable or increasing populations, and isotopic signatures indicate that seals in Glacier Bay have a diet of high-fat forage fish (Blundell et al., 2011). In addition, recent serological surveys indicated that contaminants and disease have not likely contributed to the population decrease (Hueffer et al., 2011). While reduced ice availability for haul-out substrate might be contributing to the harbor seal decrease, population declines also have been documented at “terrestrial” breeding areas (e.g., island beaches and reefs) (Womble et al., 2010), where ice availability is not a factor.

Disturbance also has been proposed as a factor contributing to the decrease. In other areas, vessel activity near seal aggregations has produced acute disturbance events (Becker et al., 2011; Hoover-Miller, Conlon, & Armato, 2003; Jansen et al., 2010; Johnson & Acevedo-Gutiérrez, 2007; Suryan & Harvey, 1999), and small pilot studies in Glacier Bay have demonstrated that seals are regularly disturbed (Mathews, 1996). Disturbance that results in seals vacating the ice and flushing into cold glacial waters is energetically taxing (Jansen et al., 2010), particularly during critical reproductive periods, when seals already are energetically stressed due to pupping, nursing, and molting (Brasseur, Creuwels,
EFFECTS OF VESSELS ON HARBOR SEALS

Werf, & Reijnders, 1996; Hoover-Miller, 2004; Suryan & Harvey, 1999). In addition, seals that use JHI forage mostly at night (Blundell et al., 2011) thus, disruptions to critical resting periods during the day, when vessels visit the inlet, may have a significant impact on time–energy budgets.

The objective of this study was to examine the frequency and severity of disturbance of harbor seals in JHI with the goal of gaining insight into the potential impacts that visitation and disturbance may have on this regionally important seal population. Similar to many other MPAs, Glacier Bay has regulations to reduce the probability of vessel disturbance, including limitations when vessels can enter JHI to protect mother–pup pairs, and regulations on minimum approach distances (0.25 nautical mile = 463 m). Thus, we sought to understand the effectiveness of these existing regulations in terms of biological relevance (i.e., whether the approach distance accurately protects seals based on their responses) and rates of compliance by vessel operators. Our study reflects a common need for designating regulations in MPAs that achieve conservation objectives, while allowing for high-quality marine mammal viewing by visitors.

The Study

Study Area and Vessel Regulations

Harbor seals haul out and breed at a number of sites around Glacier Bay (Womble et al., 2010) including at reefs and island/islet beaches (“terrestrial haul-outs”) mostly in the southern parts of the park near the mouth of the bay, and in a few glacial inlets where they use icebergs calved from tidewater glaciers (“glacial ice haul-outs”) at the head of Glacier Bay. Our study occurred in JHI (58°53’N, 137°5’W) (Fig. 1) where approximately 66% of all seals in Glacier Bay haul out (Womble et al., 2010). JHI is a steep-walled fjord, approximately 10 km long, 1.6 km wide, and located ca. 93 km from the park entrance.

Given the importance of the inlet for harbor seal reproduction and molting, a number of regulations exist for vessels including a 0.25 nautical mile (463 m) minimum approach distance (36 CFR 13.65; May 1–August 31), a distance far greater than what is commonly recommended by NOAA (100 yards; 91 m; NOAA, 2006). There also are temporal restrictions in JHI. Vessels are not allowed to enter JHI in May and June with the objective of minimizing disturbance to mother–pup pairs. Beginning in July, all vessels except cruise ships are allowed in JHI but must maintain the minimum approach distance, except when safe navigation requires otherwise (36 CFR 13.65). Cruise ships are allowed into the inlet beginning September 1. Additionally, the U.S. Marine Mammal Protection Act (MMPA) (National Marine Fisheries Service [NMFS], 1992) prohibits “take,” which includes disturbance, of any marine mammal without a permit, so any disturbance to harbor seals in Glacier Bay is a violation of the MMPA, regardless of approach distance.

During the summers of 2007 and 2008, we established a semipermanent field camp near the head of JHI from which observations were made. The field camp and observation points were not easily visible by vessels and the camp presence was not communicated to visitors when they entered the park. Thus, it is unlikely that most vessels were aware of the camp’s presence and purpose and we assume that the poor compliance (Table 1) with regulations recorded during our study further indicates vessels operators were unaware of the field camp or the study. The observation site elevation was approximately ~35 m above sea level (Mathews & Pendleton, 2006), and was at sufficient elevation to make observations of seals and vessels throughout the inlet using spotting scopes. This site was situated about 1 km from the densest aggregation of seals near the face of Johns Hopkins glacier at the head of the inlet, although seals were regularly distributed throughout the inlet, sometimes within 200 m of the observation site.

Observations occurred for 2–4-week periods during June–September when harbor seals were most abundant, and also covered a range of vessel activity levels. During each time period, we recorded information about all vessels observed from the observation site including vessels that approached but did not enter JHI. Vessel type was defined based on the Glacier Bay National Park Vessel Quotas and Operating Requirements Final Environmental Impact Statement (VQOR FEIS) including cruise ships, tour vessels, private vessels, and kayaks. Cruise ships are defined as any motor vessel at or greater than 100 tons gross (US) or 2,000 tons gross (International Convention)
Figure 1. Location of Glacier Bay National Park in southeastern Alaska, and Johns Hopkins Inlet, where observations of vessel–seal encounters were observed.

Table 1
Rates of Compliance in Johns Hopkins Inlet, Glacier Bay National Park

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Independent of Whether Seal Flushed</th>
<th>Seal Flushed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vessel in Compliance (CPA &gt; 463 m)</td>
<td>Vessel Noncompliant (CPA ≤ 463 m)</td>
</tr>
<tr>
<td>Kayak</td>
<td>24% (15)</td>
<td>76% (48)</td>
</tr>
<tr>
<td>Private</td>
<td>19% (59)</td>
<td>81% (257)</td>
</tr>
<tr>
<td>Tour</td>
<td>16% (72)</td>
<td>84% (385)</td>
</tr>
<tr>
<td>Cruise ship</td>
<td>33% (97)</td>
<td>67% (196)</td>
</tr>
<tr>
<td>All vessels</td>
<td>22% (243)</td>
<td>78% (886)</td>
</tr>
</tbody>
</table>

Rates of compliance by different vessel types in Johns Hopkins Inlet, Glacier Bay National Park, 2007–2008 relative to the regulation requiring vessels stay greater than 463 m (closest point of approach; CPA) from seals hauled out on the ice. The table also shows the proportion of all approaches that resulted in a seal flushing relative to whether or not the vessel was in compliance to the 463 m CPA. Numbers in parentheses indicate the number of approaches observed.
carrying passengers for hire. Most cruise ships that enter Glacier Bay are large, ranging in length from 181 to 294 m (mean ± SE: 251 ± 9.3 m) and generally carry 1,500–3,000 passengers. Tour vessels are defined as any motor vessel under 100 tons gross (US; under 2000 tons gross International Convention) that is rated to carry more than 49 passengers or any smaller vessel that conducts tours or provides transportation at regularly scheduled times along a regularly scheduled route (36 CFR 13.65). Private vessels are defined as any motor vessel used for recreation that is not engaged in commercial transport of passengers, commercial fishing, or official government business. Thus, vessels are defined by a suite of characteristics and functions, and size of vessels may vary significantly within each vessel type. The park’s daily entry quota is 25 private vessels, 3 tour vessels, and 2 cruise ships. Vessel traffic into JHI was largely unknown prior to this study, given that JHI is ~93 km from the park entrance and no vessel monitoring effort is in place.

**Seal Abundance**

To determine the number of seals that could potentially be disturbed by vessels, we conducted systematic counts one to three times daily, dispersed throughout the day, in accordance with historical monitoring protocols (Mathews & Pendleton, 2006; Womble et al., 2010). Two individuals conducted each count simultaneously and the average was used as the abundance estimate for that count. Similar to established monitoring protocols (Womble et al., 2010), we also recorded covariates that influence the probability that a seal is hauled out (thus available for counting). Modeled results incorporating covariates and details on methods for adjusting raw counts can be found in Womble et al. (2010). All data used for analysis used the adjusted (modeled) counts.

During each count, we also recorded the number of dependent pups present, which were identified by nursing behavior or by size difference (pups were approximately half the length of non-pups). Separation of mother–pup pairs due to disturbance can have detrimental effects on pup survival (Gazo, Aparicio, Cedenilla, Layna, & Gonzalez, 2000; Kenyon, 1972); thus, park management has closed JHI to all vessel traffic until July 1 with the specific goal of minimizing disturbance to mother–pup pairs. Following July 1, all vessel types, except cruise ships, are allowed in JHI with the assumption the pupping season has finished and no dependent pups are present.

For most days when counts occurred, we also recorded ice cover. Ice cover in the inlet is dynamic, driven by myriad factors including local climatic and tidal cycles (Post, O’Neill, Motyka, & Streveler, 2011), and may affect both the number of seals and vessel movements. Daily remote sensing photos of ice cover, used in habitat studies for other ice-associated phocids (Friedlaender, Johnston, & Halpin, 2010; Johnston, Bowers, Friedlaender, & Lavigne, 2012) were not available on a temporal (daily) or a spatial scale (JHI) relative to our study objectives. We thus developed an index of ice cover to capture changes that may occur from day to day. The index was calculated by dividing the inlet into three sections and assigning values for percent ice cover (1 = 0–25%; 2 = 26–50%; 3 = 51–75%; 4 = 76–100%) and ice density values (1 = no ice, 2 = sparse, widely spaced icebergs, 3 = mixed dense and sparse icebergs, 4 = dense ice) for each section using the equation:

\[
\text{Ice index} = (\%\text{cover}_{\text{section}1} \times \text{ice density}_{\text{section}1}) + (\%\text{cover}_{\text{section}2} \times \text{ice density}_{\text{section}2}) + (\%\text{cover}_{\text{section}3} \times \text{ice density}_{\text{section}3})
\]

Although the ice index values could theoretically vary between 3 and 48, there were never days when ice was absent (or nearly absent) nor were there days when dense ice essentially covered the entire inlet. Thus, the index ranged between 6 and 33. Although our ice index is coarse, it reflects other published attempts to understand ice–seal relationships by generating indices of ice concentration (%) based on a range of metric values such as cover and size of ice floes (e.g., Bajzak, Hammill, Stenson, & Prinsenberg, 2011; Johnston et al., 2012). We feel confident that our index captured the variation in daily ice cover reflected in the large range in index values within months (Fig. 2).

**Seal Focal Follows**

To understand the rates of vessel disturbance on seals and other factors (including ice cover) that influenced the probability of a seal being flushed, we used a digital theodolite (Sokkia D510) to obtain vertical and horizontal bearings on vessels...
Ortiz, 2000). Although vessel approaches to seals can have myriad effects ranging from no effect, to slight changes in behavior (e.g., lifting head), to internal physiological changes, such as heart rate and metabolic rate, vacating the ice (flushing) is the most obvious and easiest metric to record (Tarlow & Blumstein, 2007), and likely results in the greatest energetic cost (Jansen et al., 2010). Each focal follow thus resulted in a dichotomous result: either the seal flushed into the water or it did not.

For each focal follow we recorded the CPA, ice cover in the inlet, average number of seals in the inlet that day, and vessel type as explanatory factors. We did not record the approach angle by the vessel because of difficulty in obtaining accurate measures of angles, which varied depending upon distance of the field site to the vessel–seal encounter. Because the existing regulation for Glacier Bay identifies distance (and not approach angle), we focused on this metric. Group size also may influence the probability of flushing but it was difficult to ascertain, particularly when multiple, presumably independent, seals were on adjacent icebergs. Thus, we did not use group size as an explanatory variable.

While the objective of our observational study was to understand the probability of flushing in response to approaching vessels, we recognize that seals flush into the water for reasons other than anthropogenic disturbances (initiate foraging bouts, social interactions, etc.). Thus, there is a chance that during a focal follow we may have spuriously attributed a flushing event to an approaching vessel when in fact the seal may have flushed for other reasons. To understand the probability of observing a “natural” flushing event during a focal follow (as vessels approached), we also conducted focal follows on seals when no vessels were in the inlet. Using the same protocol as for focal follows in the presence of vessels, seals were followed until they flushed or until some certain criteria were met, which varied among years. In 2007 attempts were made to follow seals until they flushed but observer fatigue was significant as individual seals were followed for up to 8 hours with no flushing event. Thus, in 2008 we truncated follows to 30 minutes or until they flushed, whichever came first. To understand the probability of a seal flushing “naturally,” we then calculated the average elapsed time during

and randomly selected seals hauled out on icebergs. When a vessel was observed entering the inlet, we selected individual seals and conducted focal follows (Altmann, 1974) as the vessel approached. We randomly selected seals that were ahead and in the general path of the vessels. We felt this was an appropriate sampling method because we used these data to infer distance–disturbance relationships (with covariates) rather than to estimate of the total number of seals in the inlet (which would require systematic sampling). Thus, in some cases vessels ultimately passed very close to the focal seal (<100 m) while in other instances the closest point of approach (CPA) was 1 km or more. New seals were selected when the previous focal seal flushed or the vessel passed it without flushing it, resulting in multiple focal follows per vessel entry. Bearings were recorded electronically and subsequently used to calculate distances between vessels and seals using the program Pythagoras (Gailey & Ortega-
a focal follow while a vessel approached with the probability of observing a flushing event during the same amount of time in the absence of vessels.

**Results**

**Seal Abundance**

During 2007, 166 counts of harbor seals were conducted during 44 days in JHI, whereas 222 counts were conducted during 53 days during 2008. The total number of seals using JHI varied significantly among months ($F(7)=14.62, p<0.0001$) (Fig. 3), with peaks in June (mean ± SE: 1233 ± 47), concomitant with pupping, and in August (1144 ± 54), concomitant with molting. Seal abundance (pups + non-pups) was significantly correlated to ice cover when all months and years were combined (Pearson’s product moment correlation; $r=0.53, t=20.06, p<0.0001$) and for each month separately during July ($r=0.86, t=14.98, p<0.0001$), August ($r=0.71, t=22.71, p<0.0001$), and September ($r=0.54, t=13.26, p<0.0001$) (Fig. 4).

In 2007 and 2008, mother–pup pairs were observed after July 1, when vessels were allowed into JHI, although the number of pairs varied among years (Fig. 5). In 2007, the last June count of pups occurred on June 24, when nearly 500 mother–pup pairs were recorded. The observation camp was reestablished on July 7, when more than 100 mother–pups pairs were counted each day through the end of the observation period on July 12. In 2008, counts occurred continuously from June 24 until July 13. On July 1, greater than 350 mother–pup pairs were counted, although the number rapidly decreased until July 13, when only 20 mother–pup pairs were seen (Fig. 5).

**Vessel Use of JHI**

Vessel use of JHI varied among months and vessel type. Averaged across both years, nearly two groups of kayaks entered the inlet per day in July (1.8 ± 0.8) and August (1.9 ± 0.7) but were absent in June and September each year. The average number of private vessels recorded per day was the least of all vessel classes (July = 0.6 ± 0.2; August = 0.5 ± 0.1; September = 0.4 ± 0.1). Tour vessels entered the inlet at approximately the same rate in July (0.6 ± 0.2 per day) and September (0.6 ± 0.1 per day), but peaked in August (1.2 ± 0.2 per day). No cruise ships entered JHI June–August, and averaged only one per day in September (1.1 ± 0.2). During 2007 and 2008, 178 vessels (counting individual kayaks) entered JHI on observation days after July 1. Of the
Figure 3. Mean number of seals counted in Johns Hopkins Inlet, Glacier Bay National Park, June–September 2007–2008. Data are corrected for significant covariates found to affect the probability of a seal hauling out (see Womble et al., 2010). The boundary of the box indicates the 25th and 75th percentile and the line within the box marks the median. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles and dots are outlying observations.

Figure 4. Relationship between the log daily numbers of seals counted in Johns Hopkins Inlet, Glacier Bay National Park, relative to index of ice cover.
total approaches resulted in a seal flushing from the ice, including a sizeable fraction of disturbances that occurred when vessels were still in compliance. For example, 44% of approaches by cruise ships ultimately resulted in a seal flushing from the ice despite the ship being more than 463 m from the seal (i.e., consistent with compliance distances), with a nearly identical proportion (43%) of approaches resulting in a disturbance when the ship CPA was <463 m. The CPA regulation was most effective for kayaks: 50% of all approaches within 463 m resulted in a seal flushing but no seals flushed when kayaks remained compliant (Table 1). Plotting the cumulative proportion of flushed seals as a function of distance demonstrated that 18–38% (depending on vessel type) of seals that ultimately flushed did so while the vessel was still in compliance with the minimum approach distance (Fig. 6, Table 1).

Factors Influencing the Probability of Disturbance

To understand the natural rate of flushing (i.e., the probability of observing a seal flushing for reasons other than a vessel approach), we standardized the length of our vessel-absent focal follows to match

Figure 5. Counts of dependent pups (identified by nursing behavior or by size difference) in Johns Hopkins Inlet (JHI), Glacier Bay National Park, 2007–2008. Surveys ended on July 12 in 2007 and on July 13 in 2008, and resumed in early August during both years. The vertical line corresponds to the July 1 regulation when all vessels except cruise ships are allowed into JHI.
Thus, the probability of a seal flushing into the water owing to causes other than a vessel approach, was small (0.067). Therefore, for our models of flushing probability, we assumed that our error of attributing a flushing event to a vessel when in fact the seal was flushing for other reasons was low.

The most parsimonious logistic regression model for understanding factors that influenced the probability of disturbance included only the first-order terms of approach distance, vessel type, number of seals present, and ice cover (Table 2). Inclusion

The average duration we followed seals as vessels approached. The average elapsed time during focal follows as a vessel approached was 8 minutes 7 seconds (range: 1–88 minutes) and thus we calculated the probability of a seal flushing during any 8-minute period. We conducted 461 focal follows that lasted at least 8 minutes 7 seconds when vessels were absent from the inlet including follows during June \( (n = 161) \), and July–September \( (n = 300) \). Twenty-nine of 461 vessel-absent focal follows ended when the seal flushed in the water within 8 minutes 7 seconds.

Thus, the probability of a seal flushing into the water owing to causes other than a vessel approach, was small (0.067). Therefore, for our models of flushing probability, we assumed that our error of attributing a flushing event to a vessel when in fact the seal was flushing for other reasons was low.

The most parsimonious logistic regression model for understanding factors that influenced the probability of disturbance included only the first-order terms of approach distance, vessel type, number of seals present, and ice cover (Table 2). Inclusion

The number of disturbance events recorded per vessel type in Johns Hopkins Inlet, June–September 2007–2008 for vessels that encountered seals within 1,000 m.

Table 2
Results of Logistic Regression Models to Predict the Probability of Disturbance

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>AIC</th>
<th>ΔAIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance + vessel type + seal count</td>
<td>1071.4</td>
<td>54.2</td>
</tr>
<tr>
<td>Distance + vessel type + ice cover</td>
<td>1026.3</td>
<td>9.1</td>
</tr>
<tr>
<td>Vessel type + seal count + ice cover</td>
<td>1024.9</td>
<td>7.7</td>
</tr>
<tr>
<td>Distance + seal count + ice cover</td>
<td>1019.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Vessel type + distance + seal count + ice cover</td>
<td>1017.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Vessel type + distance + seal count + ice cover + all interactions</td>
<td>1021.5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

The number of disturbance events recorded per vessel type in Johns Hopkins Inlet, June–September 2007–2008 for vessels that encountered seals within 1,000 m.
of interaction terms did not significantly improve model fit (residual deviance, i.e., the difference in the −2log likelihood, with interaction terms = 1005.5 and without = 1007.2; *p* = 0.633). Ice cover and approach distance contributed most to the model fit (Table 2), with ice cover positively associated with the probability of a seal flushing (coefficient = 0.11; odds = 1.12; 95% CI of odds = 1.08–1.15). In contrast, the expected change in the log odds of flushing a seal increased with every unit (m) decrease in distance (coefficient = −0.001; 95% CI of odds = 0.998 and 0.999) holding ice cover, seal count, and vessel type constant. The relationship between probability of flushing and the

number of seals in the inlet (seal count) also was negative (coefficient = −0.001; 95% CI of odds = 0.998 and 0.999).

Plotting the relationship between CPA and predicted probability of flushing at average values of seals in the inlet exemplifies how different conditions of ice cover influenced the probability of flushing (Fig. 7). For example, the probability of a seal flushing was always greater for each vessel type, regardless of distance, when ice cover was at its maximum index value compared to ice cover at its minimum index value. This also had implications for the effectiveness of the 463 m CPA regulation. When JHI had greater ice cover, the probability of

![Graph showing predicted probabilities of flushing](image)

*Figure 7. Predicted probabilities of a seal being flushed from the ice as a function of approach distance (m) in conditions of greater ice cover (top graph) and lesser ice cover (lower graph) in Johns Hopkins Inlet, Glacier Bay National Park 2007–2008. Dotted line indicates the maximum approach distance regulation (463 m). Note the difference in scale between the two graphs.*
while minimizing impacts from disturbance. While managers use temporal and spatial regulations intended to reflect this tradeoff, the effectiveness of these regulations rarely are tested. Our results indicate that regulations may be variably effective due to poor compliance or because the regulations lack biological relevance (i.e., inaccurate reflection of marine mammal biology or behavior). We also found that effectiveness can vary dramatically depending upon environmental conditions, which may change daily. We thus emphasize the importance of understanding the suite of factors and conditions that may influence regulation effectiveness in order to craft strategies to meet conservation goals.

Having an easily understood regulation is important for compliance (Briggs, 2006). Using a set date (July 1) to open the waters of JHI to vessel traffic, which is intended to minimize disturbance-induced mother–pup separation during pupping, meets this criterion. This regulation also is easily communicated because all mariners are required to stop at the Visitor Information Station near the mouth of the park to receive guidance on vessel operating regulations (including approach distances) before traveling into the bay. Consequently, we found 100% compliance to this regulation; vessels often approached the inlet but never entered JHI prior to July 1.

Nevertheless, this regulation for protecting mother–pup pairs from disturbance provides a good example of how a regulation can be ineffective because it was not biologically relevant, despite perfect compliance. Substantial numbers of dependent pups were recorded in JHI up to several weeks after vessels were allowed into the inlet and these vessels were observed disturbing seals. Although it was beyond the scope of this study to test if pupping phenology has shifted to later dates since regulation inception, populations of harbor seals in Alaska and elsewhere (e.g., Sable Island, Canada) have demonstrated dramatic shifts in pupping phenology depending upon their population trajectory, with parturition occurring later during periods of population decreases (Bowen, Ellis, Iverson, & Boness, 2003; Jemison & Kelly, 2001). Given that the population of seals in JHI has decreased precipitously since the early 1990s (Womble et al., 2010), parturition, and thus the presence of dependent pups, may be occurring

**Magnitude of Disturbance**

We recorded the minimum number of seals disturbed per entry during vessel follows. Of 52 observation days during July–September of both years when vessels entered the inlet, there were 6 days when the seal population in JHI was undisturbed despite vessel presence. On the days when vessels flushed seals, an average of 17.7 (±2.4) seals were flushed (range 1–63). Including the days when no seals were flushed, the average number of seals flushed per day dropped to 15.3 (±2.27). Cruise ships flushed an average of 11.5 (±3.1) seals per entry into JHI, followed by private vessels (7.7 ± 2.6), tour vessels (4.1 ± 0.6), and kayak groups (2.9 ± 1.3). Relative to the total number of seals present in JHI, on average, 2.6% of all seals in JHI were disturbed per day (range 0.1–12%). Including the 6 days when no seals were flushed, the average was only slightly less (2.2%).

**Discussion**

MPAs are increasingly being used to achieve conservation objectives for marine mammals, including mitigating anthropogenic threats (Hooker & Gerber, 2004). Thus, a common issue is balancing the opportunities for marine mammal viewing and Figure 8. A cruise ship closely approaching several seals on an iceberg during sparse ice conditions in Johns Hopkins Inlet, Glacier Bay National Park (photo by Jamie Womble).
The effectiveness of the 463 m CPA regulation was variable, mainly because compliance was poor and because the regulation may not be biologically relevant. For example, compliance to the 463 m CPA regulation for all vessels was only 22%, with some vessel types, such as tour vessels, in compliance on only 16% of approaches. One possible reason for the poor compliance is that mariners in Glacier Bay rely primarily on Global Positioning System (GPS) for navigation, which accurately depicts distances to shore, but does not provide information for distance to icebergs supporting seals. Yet compliance to approach distance regulations for harbor seals was poor even for areas where harbor seals haul out on shore (Johnson & Acevedo-Gutiérrez, 2007). Thus, it is unlikely that poor compliance is solely a function of lack of detection or errors in estimating distance.

An alternative explanation for poor compliance is that mariners may use the reactions of seals to gauge whether or not they are too close. Regulations in Glacier Bay are clearly communicated as a means (regulation) to an end (minimizing seal disturbance). Ultimately, however, seals remained on the ice during most (72%) approaches; thus, mariners may feel they are not disturbing seals even if they are not complying with park regulations. Also, the proportion of seals that flushed in response to vessels was comparable when the vessel was in compliance (33%, i.e., >463 m from the seal) versus out of compliance (26%), thus further muddling the distinction between the CPA regulation and disturbing seals.

Perhaps most surprising was our result indicating the strong influence of ice cover on probability of flushing. In conditions of sparse ice cover, the probability of a seal flushing from the ice was less across all approach distances compared with conditions of greater ice cover. We propose several explanations for this relationship.

One possibility is that the results presented are an artifact of unmeasured vessel behavior, such as course, which covaried with ice cover. Vessels navigating in the inlet during sparse ice conditions may be able to maintain a more consistent speed or course compared with conditions of greater ice, which may result in a more erratic, unpredictable course to avoid icebergs. Vessels stopping or moving erratically near other seal haul-outs have elicited greater levels of disturbance (Henry & Hammill, 2001; Johnson & Acevedo-Gutiérrez, 2007) but measuring this vessel activity was difficult in JHI. Another possibility is that in conditions of greater ice coverage, seals flushed into the water at greater distances because they were reacting to increased vigilance by other seals in the presence of vessels. Our results indicated that seal density in the inlet was generally greater on days of more ice and thus, by definition, there were more opportunities for our focal seal to react to other seals that were first reacting to the approaching vessel.

It also is possible that seals make state-dependent decisions based on known or perceived resource availability, such as alternative sources of ice for haul-out. There is growing theoretical and empirical evidence that animals respond to human disturbance based on the state of resources available to them, including habitat quality (e.g., Gill, Norris, & Sutherland, 2001). For example, Beale and Monaghan (2004) demonstrated experimentally that individual birds that had better foraging opportunities flushed at greater distances in response to human disturbance compared with birds with lesser quality forage. This indicated that the resources available to birds (internally or externally) strongly influenced the probability of flushing distance. They concluded that protected area managers are likely to make erroneous conclusions if they base regulations solely on flush distances without also considering the state of available resources to the animals subject to disturbance. By extension, harbor seals in JHI may be less likely to flush from an iceberg in response to a vessel approach when there are fewer icebergs (a resource state that can be readily and rapidly assessed using visual cues) available for hauling out. The 463 m distance regulation thus may be more effective during periods of sparse ice but less effective on days when ice availability is greater.

Finally, we recognize that our estimates of disturbance rate represent minimum levels because some flushing events were inevitably missed, and our metric for disturbance (flushing from the ice) does not encompass the suite of other possible reactions
remains at the discretion of park managers whether the level of disturbance experienced by seals in JHI is deemed acceptable. All national parks in the US are guided by a mandate outlined in the National Park Service Organic Act of 1916, which states that wildlife shall be preserved for enjoyment of future generations, and viewing harbor seals in their natural glacial habitat is clearly a means of enjoyment by visitors. Yet we hold that reducing the level of disturbance to zero would likely result in a significant reduction in the amount of vessel traffic in the inlet. Seals were often seen reacting to vessels at distances of over 2 km or more and thus it would be difficult to allow vessels in the inlet without some level of disturbance occurring. One option is to increase the level of outreach to mariners, particularly cruise ships entering JHI in September. Regardless of approach, our study highlights the need to evaluate regulation effectiveness to achieve conservation objectives in marine protected areas.

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EFFECTS OF VESSELS ON HARBOR SEALS

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