GIS-based analysis of harp and hooded seal sighting locations on shore in the Southern Gulf of Maine

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Abstract

Ice seals (harp and hooded seals) were rarely seen in the Gulf of Maine before 1990 but have been sighted with increased frequency since. To explore these types of sightings, we developed an analysis technique for events that occur at the irregular border between two polygons. We used a geographic information system and non-parametric statistics to analyze 584 ice seal sightings in the southern Gulf of Maine. Compared to harp seals, hooded seals were sighted closer to deep water and were less healthy; sicker animals were more likely than healthy ones to be sighted near high-energy intertidal zones. Using Ordinal Logistic Regression, we also found that high seal sighting densities occurred more often near public land and in the southwest of the study region. Given the opportunistic nature of this data set, and its inherent reporting biases, these correlations should be interpreted carefully; however this technique may be useful to analyze other “border” events.

Keywords: Seal, stranding, border phenomena.

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Introduction

Although they are not closely-related species, harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) are collectively known as “ice seals” because they whelp on the Canadian and Arctic pack ice in early spring. Both species have their most southerly whelping patches in the Gulf of St. Lawrence, north of Prince Edward Island, Canada and on the “Front,” east of Labrador and Newfoundland, Canada where the Labrador and North Atlantic currents meet [5, 31]. After weaning they disperse, generally moving north to feed in arctic waters in the summer and back south in the winter [7, 30].

The Gulf of Maine is an important marine ecosystem that is bordered by the coastlines of Massachusetts, New Hampshire, and Maine, USA on the south and west; New Brunswick and Nova Scotia, Canada on the north; and Georges Bank and the continental shelf on the east [6]. Prior to 1980, the predominate distribution of ice seals in the west Atlantic extended only as far south as northern Nova Scotia, Canada [13]; ice seals were seldom seen on shore in the Gulf of Maine [3]. However, since 1990, both species have been reported on the shore of the Gulf of Maine with increasing frequency [8, 9, 22, 23, 24, 33]. This change may reflect alterations in seal populations, fish stocks, or ocean conditions. Improved reporting, as well other unknown factors could also play a role [21].

Both harp and hooded seals are highly pelagic species. Other than hauling out for several weeks in the early spring to whelp, and then again in the summer to molt, they spend virtually all their time in the water [13, 31]. Because counting highly dispersed species in the water is challenging at best, estimates of population size are generally made from counts of animals in whelping patches; determinations of geographical distribution are often made from on-shore sightings [27].

Past reports of on-shore ice seal sightings in the Gulf of Maine concentrate on temporal analysis of occurrences, and provide only a rudimentary spatial analysis [8, 9, 21, 23, 24, 33]. With the wide dissemination of Geographic Information Systems (GIS), tools are now available to analyze ice seal sighting locations. But because these sightings occur at a shoreline, the irregular border between two polygons (the land and the ocean), their statistical analysis can be challenging. Border phenomena are not unique to onshore seal sightings, however. They are also important in a
wide range of fields including hydrology, human economic development, and whale stranding locations behavior [12, 18, 36]. Thus, it is worthwhile to develop methods to analyze these events.

To provide additional tools for the understanding of border events, we developed a conceptually simple method to analyze the density of onshore ice seal sightings. Here, we describe that method and report its use in a GIS-based analysis of 584 ice seal sighting locations in the southern Gulf of Maine region between 1997 and 2002. These techniques may also be useful for the analysis of other geographical events that, similar to seal sightings on a shoreline, occur exclusively at an irregular border between two polygons.

**Methods**

*Seal sightings:* In the US, the National Marine Fisheries Service administers a network of volunteer organizations that respond to reports of stranded or distressed marine mammals. Since January 1997, the Marine Animal Lifeline (MAL) (Westbrook, Maine) has participated in this network as the primary responder to reports of pinnipeds (seals) between Kittery (43.088°N, 70.737°W) and Rockland, Maine (44.103°N, 69.108°W): MAL maintains a 24-hour hotline for reports of marine animals and dispatches a volunteer to the location of virtually all reported animals to assess their health status. It also maintains files on all reports of pinnipeds it receives. For this study, we reviewed all MAL records from 01/01/1997 to 12/31/2002 for reports of harp and hooded seals in which the seal species was verified by a trained observer.

It is important to emphasize both the strengths and the weaknesses of this dataset. MAL is a well-known organization in its area of geographical responsibility and makes efforts to respond to all reports of on-shore seal sightings [8, 9]. However, this is clearly a completely opportunistic dataset. For a seal to appear in this data set it must come ashore, be observed by a person, be reported by that person, and still be present on shore when the trained observer arrives. If any step in this process fails, the seal will not appear in this data set.

For each verified ice seal sighting we collected the following information: species, date, location, and health status. To describe health status, we placed seals into one of the following categories indicating descending health level:
(1) deemed healthy (i.e. left on the beach),
(2) taken into rehabilitation and successfully rehabilitated,
(3) taken into rehabilitation but either died or was euthanized, and
(4) dead when the observer arrived.

This method makes the assumptions that the decision to take a seal into rehabilitation is made in a consistent manner in all cases, that these decisions are made similarly for both species, and that there is no reporting bias by health status; for at least a small subset of these data, these assumptions may not be met (see discussion of reporting bias and health status below).

The latitude and longitude of seal sighting locations were determined using a commercially available map program (DeLorams, Freeport, Maine) and translated into Universal Transverse Mercator to produce units on a linear scale using a publicly available macro [4]. An assumption of this analysis is that dead seals died at (or at least close to) the location where they were observed on shore, and as discussed below, this may not be the case.

Digital data sets: Because our goal was to analyze seal sighting locations in relationship to other spatially referenced data of our study area, we sought to identify a range of variables that might impact whether or not seals were sighted in a particular location. To do this, we obtained digital data sets from additional sources and manipulated them using the GIS software ArcMap (ESRI, Redlands, CA) to generate variables for statistical analysis.

The coast of Maine exhibits a range of shoreline types from sand beach to rock ledge. Seals may preferentially access or avoid certain shoreline types. To assess the impact of shoreline on seal sightings, we obtained digital maps of subtidal and intertidal shore types for the Maine coast from the Maine Department of Environmental Protection and identified high, medium, and low energy areas in those maps using textbook descriptions of coastal energy levels.

Because reporting bias may influence seal sighting data, we sought maps that might reflect the likelihood of people being present at a particular area of the shore. We reasoned that people were more likely to be present in areas closer to high human population densities and on or near public land, and that seals that came ashore in these areas would
be more likely to be reported. This is an important analysis because it can potentially suggest whether or not areas with low numbers of seal sightings are simply the product of low reporting effort. To perform this analysis, we obtained digital block level 2000 census maps from the Maine Office of GIS website [17]. We also obtained a map of the public land in Maine from the Maine Office of GIS website and removed the military bases because these are not places where civilians recreate. We were forced to ignore the important phenomenon of seasonal population fluctuations along the Maine coast because detailed data are available on permanent residence only.

The Gulf of Maine contains submerged offshore features, including ledges and basins that provide habitat for a range of marine species that are prey items for seals. Ice seals sighted onshore near these features might indicate use of these features for foraging. To determine the impact of proximity to offshore features on seal sightings, we obtained a digital map of bathymetry of the Gulf of Maine at 10 meter resolution from the Massachusetts Office of GIS Website [20] and used this map to identify the following important offshore features of the Gulf of Maine: Cashes Ledge, Jeffreys Ledge, Wilkinson Basin, Georges Basin, and Jordan Basin. The ledges were defined as areas with depth $\leq 60$ m. Wilkinson and Jordan Basins were defined as areas with depth $\geq 200$ m. Because it lies in deeper water, Georges Basin was defined as an area with depth $\geq 300$ m. These definitions produced areas that generally conformed to the contours of the features commonly shown on marine charts. We also defined all ocean areas of 30m and 60m ocean depth and used proximity to these areas as a measure of proximity to deep water.

We obtained a digital 1 : 24,000 scale map of Maine from the Maine Office of GIS website and used it to define the coastline. To do this we selected all map line segments bordering on salt water, and removed both the small uninhabited islands (because seals on these islands are unlikely to be reported) and estuaries that could be accessed only through channels $< 100$ m wide (because seals were unlikely to enter these areas).

GIS construction: We used the maps described above in two types of comparisons: group-wise comparisons and seal sighting density analysis. To allow group-wise comparisons, we constructed a vector GIS from which we determined the following variables in reference to each seal.
sighting location:

1. **map variables** — location on north-south and east-west axes,
2. **human variables** — human population within 30km and distance to non-military public land,
3. **onshore variables** — closest intertidal and subtidal energy shoreline energy type, and
4. **offshore variables** — distance to the important offshore Gulf of Maine features listed above as well as distance to both 30m and 60m depth.

Because the actual location of dwellings within a census block is not available, we used the total population of all census blocks that had a centroid within 30km radius of each sighting location as an approximation of the number of people living in this area. Given the small size of census blocks, and based on an analysis of 20 sighting locations distributed along the coast, we estimated that this method produced at most a 3% error in calculation of population number.

For analysis of seal sighting densities we constructed a vector GIS that divided our study area into 2km grid boxes using a publicly available macro [4]. We selected the grid boxes that contained coastline, and determined the human, map, and offshore variables listed above using the centroid of each grid box as the reference location, with the most northwest grid box in the study area designated (1,1). We also counted the number of ice seal sightings in each grid box. Given the irregular nature of the Maine coast, the length of coastline in each grid box was quite variable. Because seals cannot walk far inland, all sightings are near water and we might reasonably predict that grid boxes with more coast will have more seal sightings as well. To allow us to correct for variability in the amount of coast per grid box, we determined the length of coastline in each grid box by creating nodes where the coast crossed grid box borders, selecting the coast line segments within each grid box, and summing their length. This allowed us to compute the number of seals/km of coastline in each grid box.

**Statistical analysis:** To determine if species or health status were significantly associated with sighting locations, we performed group-wise comparisons based on these variables. Because ice seals are presumed to be moving south in the fall and winter and north in the spring and summer
we also performed a groupwise comparison of animals sighted in the March through August to those sighted in September through February. For the group-wise comparisons, we used a Pearson Chi-Square test for categorical variables and either a Mann Whitney test or a Kruskal Wallis test for numerical variables depending on the number of groups present in the comparison. We used non-parametric methods because the variables of interest were all highly skewed.

To analyze seal sighting densities, we used Ordinal Logistic Regression by categorizing the response variable for each grid box (\# seals/km of coast) into the following six ordinal categories: $X = 0$, $0 < X < 0.25$, $0.25 < X < 0.5$, $0.5 < X < 1.0$, $1 < X < 2$, $X > 2$. Significant predictors of the response variable were found by using ordinal logistic regression analysis with a logit link function. The statistical software package Minitab was used for this analysis. For all analyses, a significant relationship was supported if $p < 0.05$.

**Results**

*Group-wise Comparisons:* Our group-wise comparison by species compared 163 hooded seals to 421 harp seals using the Mann-Whitney U-Test. We found that, compared to harp seals, hooded seals were significantly less healthy when sighted ($p = 0.016$, Table 1 and Figure 1) and were sighted significantly closer to 30m ocean depth ($p = 0.002$, Table 2 and Figure 2). Otherwise, we found no significant differences in sighting locations by species.

Group-wise comparison by health status compared the following groups: 409 seals that were deemed healthy, 60 seals that were successfully rehabilitated, 60 seals that died in rehabilitation, and 55 seals that were dead when initially assessed. This was done using the Kruskal-Wallis test. We found that sicker animals were more likely than healthier animals to be sighted near a high energy subtidal zone ($p = 0.005$, Table 1, Figure 3). We also found higher human population levels within 30km of locations where sick seals (middle two health categories) were sighted than within 30km of locations where either healthy or dead seals were sighted ($p = 0.002$, Table 2, Figure 4), but no other significant differences in sighting location by health status.

Our group-wise comparison by season compared seals that were sighted in March through August to those sighted in September through
Table 1
Results of group-wise comparison by species, health status, and season using a Pearson Chi-Square test. Significant \((p < 0.05)\) values are indicated with *

<table>
<thead>
<tr>
<th>Grouping by</th>
<th>Independent variable</th>
<th>(p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spices</td>
<td>Health</td>
<td>0.016*</td>
</tr>
<tr>
<td></td>
<td>Subtidal Energy</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>Intertidal Energy</td>
<td>0.070</td>
</tr>
<tr>
<td>Health</td>
<td>Subtidal Energy</td>
<td>0.559</td>
</tr>
<tr>
<td></td>
<td>Intertidal Energy</td>
<td>0.005*</td>
</tr>
<tr>
<td>Season</td>
<td>Health</td>
<td>0.085</td>
</tr>
<tr>
<td></td>
<td>Subtidal Energy</td>
<td>0.014*</td>
</tr>
<tr>
<td></td>
<td>Intertidal Energy</td>
<td>0.745</td>
</tr>
</tbody>
</table>

Figure 1
Bar graph shows the results of group-wise comparison by species of seal health status using a Pearson Chi-Square test. Hooded seals are significantly less healthy than are harp seals when sighted
Table 2
Results of group-wise comparison by species, health status, and season using a Kruskal-Wallis test. Significant \((p < 0.05)\) values are indicated with *.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Group by species M-WU</th>
<th>p-value</th>
<th>Group by health Chi-sq.</th>
<th>p-value</th>
<th>Group by season M-WU</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>32437</td>
<td>0.305</td>
<td>14.5</td>
<td>0.002*</td>
<td>38172</td>
<td>0.105</td>
</tr>
<tr>
<td>East-West</td>
<td>32046</td>
<td>0.215</td>
<td>2.9</td>
<td>0.409</td>
<td>39939</td>
<td>0.458</td>
</tr>
<tr>
<td>North-South</td>
<td>31298</td>
<td>0.099</td>
<td>4.1</td>
<td>0.138</td>
<td>39852</td>
<td>0.432</td>
</tr>
<tr>
<td>Public Land</td>
<td>34288</td>
<td>0.099</td>
<td>5.5</td>
<td>0.138</td>
<td>40374</td>
<td>0.599</td>
</tr>
<tr>
<td>30m</td>
<td>29581</td>
<td>0.002*</td>
<td>1.7</td>
<td>0.635</td>
<td>40570</td>
<td>0.668</td>
</tr>
<tr>
<td>60m</td>
<td>33581</td>
<td>0.675</td>
<td>2.9</td>
<td>0.401</td>
<td>40813</td>
<td>0.758</td>
</tr>
<tr>
<td>Cashes L.</td>
<td>31712</td>
<td>0.155</td>
<td>4.9</td>
<td>0.177</td>
<td>39739</td>
<td>0.400</td>
</tr>
<tr>
<td>Jeffreys L.</td>
<td>32680</td>
<td>0.373</td>
<td>2.8</td>
<td>0.421</td>
<td>40380</td>
<td>0.601</td>
</tr>
<tr>
<td>Wilkinson B.</td>
<td>32204</td>
<td>0.249</td>
<td>4.3</td>
<td>0.233</td>
<td>39620</td>
<td>0.368</td>
</tr>
<tr>
<td>Georges B.</td>
<td>31950</td>
<td>0.197</td>
<td>3.9</td>
<td>0.267</td>
<td>38961</td>
<td>0.219</td>
</tr>
<tr>
<td>Jordan B.</td>
<td>31976</td>
<td>0.202</td>
<td>2.5</td>
<td>0.467</td>
<td>39812</td>
<td>0.421</td>
</tr>
</tbody>
</table>

Figure 2
Bar graph shows the results of group-wise comparison by species of the distance between each sighting location and 30m ocean depth using a Kruskal-Wallis test. Hooded seals were sighted in locations significantly closer to 30m ocean depth.
Figure 3

Bar graph shows group-wise results of comparison by health status of the intertidal shoreline energy nearest each seal sighting location using a Pearson Chi-Square test. Healthier seals are significantly more likely to come ashore through lower energy intertidal zones than are sicker seals.

Figure 4

Bar graph shows the results of group-wise comparison by health status of the human population living within 30km of each sighting location using a Kruskal-Wallis test.
February. We found that 22% of seals sighted in September through February were sighted near a low energy intertidal level area, 51% were sighted in proximity to a medium energy intertidal area. For seals sighted from March through August, these fractions were 32% and 44%, respectively. Other than this significant difference ($p = 0.014$), for which the reason is unknown, we found no significant differences between the sighting locations of seals by season.

**Seal sighting density analysis:** There were 524 grid boxes with 2km on a side that contained coast, of which 185 also contained seal sightings. The highest number of seal sightings in any grid box was 24, and > 99% of seal sightings (581/584) occurred in grid boxes that contained coast. The largest amount of coast in any single grid box was 22.2km. When we constructed the Ordinal Logistic Regression model with the logit link function, the quality of fit was very good with a $p$-value of 1.0 with both the Pearson Chi-Square and the Deviance methods. The Log-Likelihood $p$-value of 0.000 indicated that at least one of the predictors was significant. Significant predictors were $X$-distance (coefficient = 0.6760, $p = 0.020$), $Y$-distance (coefficient = $-0.2344$, $p = 0.048$) and Distance to Public Land (coefficient = $0.0001841$, $p = 0.041$). Human population approached significance with a coefficient of $-0.000011$, and a $p$-value of 0.064.

Negative coefficients in our ordinal logistic regression model indicate that, as the predictor value associated with a grid box increases, the grid box was more likely to fall in a higher seal density category. Thus we interpret these results as follows: as the distance from the centroid of a grid box to public land increases the probability of that grid box being in a high sighting density category decreases; as human population within 30km of a grid box’s centroid increases, the probability of that grid box falling into a high sighting density category trends (non-significantly) toward an increase; as the distance of a grid box’s centroid from the west boundary of the study area increases, the likelihood of that grid box falling into a high sighting density category decreases; and, as the distance of the grid box’s centroid from the north boundary of the study area increases, the likelihood of that grid box falling into a high sighting density category increases.
Discussion

Seal sighting density determinations: Some areas of the southern Maine coast certainly seem to have more ice seal sightings than do others [8, 9]. However, the appropriate mechanism for quantifying the number of sightings in any given area is not obvious. To determine the density of seal sightings along the coast, we constructed 2km grid boxes of areas that contain coast, counted the number of sightings in each box, and then normalized this value to the amount of coastline in each box. This technique yields a sighting density (in seal sightings/km of coast) that we then used as the dependent variable in a regression analysis.

Because both the independent and the dependent variables are highly skewed, we could not use a normal linear regression analysis. Poisson regression, an alternative that requires a discrete dependent variable, might have been appropriate if we had used the raw count of seals in each grid box as the dependent variable and included the length of coast in each box as an independent variable. However, we rejected this option because the mean and the variances of the seal counts in each grid box were very different (1.11 vs. 8.34) and used Ordinal Logistic Regression analysis instead.

This approach is similar to a method used previously to conduct a GIS-based analysis of human-elephant interactions in Kenya, Africa [34]. Both in that, and this study, a grid box technique is employed to determine the characteristics of event locations and logistic regression is then used rather than linear regression because the resulting dataset is highly skewed. However, elephant-human interactions are such rare events that an analysis of their locations can be carried out by simply comparing grid boxes in which events occur to those in which they do not [34]. Our use of Ordinal Logistic Regression allows us to consider the fact that some grid boxes contain multiple ice seal sightings.

We rejected the idea of reporting the number of seal sightings in each grid box without normalization because the land, ocean, and coast composition of the boxes was so variable. Seal sightings recorded by a stranding organization almost always occur along the coastline because seals in the water do not fall under the legal purview of the organization and seals cannot move far inland (very occasionally an ice seal will swim well inland along a river before being sighted) [8, 9]. Consequently,
we normalized the number of seal sightings in each grid box to the length of coast in that box. This idea of normalizing onshore sightings of marine mammals to coast length is similar to the practice used to analyze odontocete (toothed whale) stranding patterns in the Hawaiian islands by eight compass directions [18]. Our approach extends this practice from 8 compass points to many (524) grid boxes.

However, use of this method contains several assumptions. First, it assumes that seals have equal access to all parts of the coast. We eliminated coastline that can be reached only via a channel of < 100m width because there were no seals sighted in these locations and this absence is more likely to reflect that fact that seals did not find these areas than that they actively avoided these locations. The technique also assumes that there is no overall orientation to seal movements near the coast. For instance, if all seals were swimming east to west when they came ashore, it might be more reasonable to normalize the seal sightings in each grid box to the north-south profile of the coast in that grid box. Visual inspection of ice seal sighting locations gave no indication that there was any such orientation.

It is also vital to note that results in any grid analysis can be critically dependent on the level of resolution chosen [19, 36]. (This has been dubbed the “scale effect” of the modifiable areal unit problem [28]). Here we report results from an analysis of 2km grid boxes. We chose this level of resolution because 5km grid boxes produced an inferior fit to our data set and 1km grid boxes yielded a very high fraction of zero-count boxes. This does not rule out the possibility that other levels of resolution could reveal important predictors of seal sighting density. We also performed our seal sighting density analysis with both larger and smaller numbers of categories and obtained similar results.

Reporting bias: We acknowledge that the seal sighting database is an entirely opportunistic and likely biased data set; seals must be observed and reported (usually by a member of the general public), and then observed again by a trained representative of the stranding organization before they can appear in this data set. Thus, any factor that impacts reporting likelihood will influence our results. Our finding that high seal sighting density is less likely when the distance between the sighting location and public land is low and trends toward being more likely when
human population living within 30 km of the sighting location is high suggests that our results are indeed impacted by reporting bias. If so, then there may be many more ice seals onshore in the southern Gulf of Maine that are not reported. This alone is a potentially important result if onshore ice-seal sightings reflect regional populations for that species, as seems to be the case for stranded odontocetes [18].

It is also important to recognize the range of variables that could impact reporting of ice seal sightings but were not measured in this study. Some parts of the Maine coast, such as sand beaches, are easily accessible to people while others (e.g. rock cliffs) are less so. To the extent that sand beaches are more likely to occur in the south and west of our study area, reporting bias might impact our finding of higher ice seal sighting densities in the south and west. (Also, note that the coast of Maine runs predominantly from southwest to northeast, so the X and Y coordinates of points along the coast autocorrelate.) Further, we did not measure human attitudes or propensity towards reporting a stranding event. People’s attitudes toward carnivores in general vary depending on such factors as age, sex, and education [10]; and attitudes towards seals may be less positive (i.e., less conservation-oriented) among those who fish commercially [11]. Those with more positive attitudes may be more likely to report ice seal sightings.

**Health status data:** Our findings:

(1) of higher human population within 30 km of sick seals sighting locations than within that distance of sighting locations of either healthy or dead seals (Table 2, Figure 4), and

(2) that sicker animals were significantly more likely than healthier animals to be sighted near a high energy intertidal zone (Table 1 and Figure 3) may reflect a combination of reporting bias and seal behavior.

These conclusions assume that dead seals died onshore rather than washing up in the location where they were observed, and this may not be the case. They also assume that health determinations, and decisions about rehabilitation, are made in a consistent manner at all times, and this too is likely not the case. For instance, the number of seals already in rehabilitation at any facility and behavior differences by species (e.g., hooded seals are generally more aggressive than harp seals) may impact whether or not a seal is taken into rehabilitation.
Ice seal behavior: Both harp and hooded seals are capable of exploiting a wide range of vertebrate and invertebrate species as food. In general, however, hooded seals are believed to forage further offshore and to dive more deeply than do harp seals [1, 27, 31], although records of interactions between offshore cod trawlers and ice seals suggest that harp seals feed far offshore as well [29]. In the Gulf of St. Lawrence, hooded seals occupy a slightly higher trophic position than do harp seals [16], but prey choice can be highly variable. Location, age of the animals, and season of the year can all impact the diet of ice seals [14, 15].

The diet and foraging strategy of ice seals in the Gulf of Maine is not known. Our observation that, compared to harp seals, hooded seals are sighted at onshore locations that are closer to 30m ocean depth is consistent with the hypothesis that the hooded seals in the Gulf of Maine, as elsewhere [31], forage in deeper water than do harp seals. Our finding that hooded seals were significantly less healthy than harp seals when sighted may reflect behavioral differences between the two species.

Ice seals are generally sighted in the southern Gulf of Maine [8, 9] and further south in the winter [27] suggesting that this appearance may be part of the seasonal movements of these species. Species differences also may exist; hooded seals are particularly known for ranging widely with rare sightings as far south as Florida [26], and Puerto Rico [25], and even in on the coast of Europe [2]. Our group-wise comparison of seal sighting locations for March through August with those of September through February found no significant differences other than in closest intertidal energy level (Tables 1 and 2). This probably indicates that our study area is too geographically limited for analysis of large-scale seal movements. A larger geographic area might also yield explanations for our finding that ice seal sighting densities are higher in the south and west than in the north and east of Maine, a result that agrees with previous reports [8, 9, 22, 33].

Consideration of other methods: Given the limitations in this study method discussed above, it is important to consider other possible sources of information about ice seals in the Gulf of Maine. One obvious idea is to perform transects of the coast and to patrol them at regular intervals. However, the large amount of coastline in this study area (2600km) makes it clearly impractical to do this even once per day for the six-year period of this study. As discussed above, the finding that human variables (high population and less distance to public land) predict high seal sighting
density does suggest significant reporting bias. If this is the case, there may be many more ice seals onshore that are never reported to a stranding organization.

NOAA Fisheries does keep a database of seal sightings that covers a much wider geographical area, and could be an important source of information about long-range ice seal movements. However, the NOAA Fisheries data set contains only animals deemed “stranded” (that is, either sick or injured). Compared to the database used in this study, the NOAA Fisheries database contains information about seals with a narrower health-status range, and may not be as appropriate for comparing behavioral differences of sick vs. healthy ice seals. There are also satellite tracking data [35] that provide valuable information about the offshore behavior of ice seals. However, this information source shows the locations of only a handful of seals, and the animals tagged with satellite tracking tags are generally seals released after rehabilitation. Thus, their behavior may not be typical of the general ice seal population.

**Conclusions:** We report a GIS-based method for analysis of ice seal sighting locations onshore in the southern Gulf of Maine. This simple method allows the analysis of events that occur at a border between two areas, even if the variables that describe those events are highly skewed and have a high variance relative to their mean. We have found between-group differences by species (harp vs. hooded seal) and health status that may provide information about seal behavior. We have also found map and human variables that correlate with high seal sighting density. Our results may provide insight into ice seal number and behavior in the Gulf of Maine, but given the opportunistic nature of these seal sighting data, our correlations should be interpreted with caution.

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