Progress Report

Sighting frequency and distribution of marine mammals opportunistically recorded in Glacier Bay, Alaska and adjacent waters (2005-2014)

Six species opportunistically sighted in Glacier Bay and adjacent waters. From top left to bottom right: harbor seal, raft of Steller sea lions, Dall's porpoise, pod of killer whales, harbor porpoise, and sea otter.

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INTRODUCITON

The Glacier Bay ecosystem, located in northern Southeast Alaska, is a rapidly evolving fjord in Glacier Bay National Park (GBNP). Since the Glacier Bay ecosystem resides in a marine protected area, it remains relatively undisturbed. High productivity is driven by nutrient-rich output from surrounding glaciers and strong currents from the Gulf of Alaska that support an abundant prey base for a biodiversity of marine mammals (Mathews et al., 2011). Due to the large aggregations of prey and dynamic geological features of the Glacier Bay fjord system, unique opportunities exist to study the biology and habitat use of marine mammal species within and near the protected marine waters of GBNP (Chenoweth, 2011; Robards et al., 1999; Gabriele and Neilson, 2013).

The most common species of marine mammals sighted within GBNP and adjacent waters are humpback whales (*Megaptera novaeangliae*), sea otters (*Enhydra lutris*), Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina richardsii*), harbor porpoises (*Phocoena phocoena*), and killer whales (*Orcinus orca*). Less commonly sighted marine mammals include minke whales (*Balaenoptera acutorostrata*), Dall's porpoises (*Phocoenoides dalli*), California sea lions (*Zalophus californianus*), and gray whales (*Eschrichtius robustus*). Monitoring efforts for several of these species have been sustained for years, including the humpback whale monitoring program, which was initiated due to the specie's endangered status (Gabriele and Neilson, 2013). National Park Service (NPS) biologists have conducted systematic summer humpback whale monitoring surveys since 1985 to study the abundance and distribution of the species in and around GBNP (Gabriele and Neilson, 2013). Starting in 1994, NPS biologists began recording opportunistic sightings of all other marine mammal species in conjunction with the humpback whale monitoring surveys.

Apart from opportunistic sightings recorded by NPS biologists, only a handful of other federal and state agencies have monitored marine mammals near or in GBNP. Sea otters have been monitored since 1994 by the U. S. Geological Survey (USGS) (Bodkin et al. 2005), and a new sea otter monitoring survey methodology is currently being developed (J. Womble, pers. comm); harbor seals have been monitored on land and ice haul-outs throughout Glacier Bay since 1992 by the National Park Service (NPS) (Mathews and Pendleton 2006); Steller sea lions have been monitored at known haul-outs (including South Marble Island) since 1975 by the Alaska Department of Fish and Game (ADFG) (Mathews et al., 2011); and harbor porpoises have been periodically surveyed in southeastern Alaska since 1991 by the National Marine Mammal Lab (NMML) (Dahlheim et. al. 1992, Waite and Hobbs 1999).

An important distinction between the GBNP opportunistic sighting data and the monitoring efforts listed above is that the latter use distance sampling or other quantitative marine mammal data collection methods, which are designed to evaluate the abundance of a species (Bodkin et al., 2005; Dahlheim et. al., 1992; Waite and Hobbs, 1999). By contrast, opportunistic sightings are not suitable for estimating population abundance because the sighting data occur over non-systematic survey transects. This is an inherent feature of humpback whale monitoring surveys, which are akin to a census in that they are designed to identify individual animals according to unique markings on the ventral fluke surface (Gabriele and Neilson, 2013). Despite the difference in survey objectives, opportunistic sighting data still offer a valuable opportunity to monitor other marine mammal species.

This report utilized a standardized subset of opportunistic sighting data (2005-2014) for sea otters, Steller sea lions, harbor seals, harbor porpoises, and killer whales. The numbers, locations, and group sizes of minke whales, Dall's porpoises, California sea lions, and gray whales are also documented in the report. To make the sighting data as effective as possible for the purpose of long-term monitoring of each species, the following two objectives were chosen as the study's primary focus: (1) analyze trends in sighting rates (relative abundance) over time and (2) analyze the spatial and temporal

distribution of sighting rates. Additional objectives were to: (a) assess distribution of effort throughout the study area, (b) discuss how humpback whale monitoring efforts affect the collection and use of opportunistic sighting data, (c) describe the proportions and group sizes of opportunistically sighted species, and (d) provide histograms on depth and temperature relative to sightings.

The goal of the report was to aid in the monitoring of marine mammal species in GBNP and adjacent waters by summarizing opportunistic sighting data and providing a preliminary analysis that highlighted spatial and temporal changes to the relative abundance and distribution of each species. Providing this information will hopefully direct future research as well as to inform and complement the work of other marine scientists and resource managers concerned with the Glacier Bay marine ecosystem.

METHODS

Study Area

The study area encompassed nearly all of the marine waters of Glacier Bay proper and the waters directly adjacent in Icy Strait, covering approximately 1,692,130 km^2. This large area was broken into three general regions: (1) the main body of Glacier Bay, (2) Icy Strait, and (3) upper Glacier Bay (see Figure 1). The locations of humpback whales affected how survey effort was divided amongst these three regions.

The main body of Glacier Bay was defined as the rectangle formed by Bartlett Cove, Point Carolus, Geikie Inlet, and Garforth Island (Figure 1). The main body of Glacier Bay was surveyed 3-4 days per week; a different area of the bay was focused on each day (e.g. lower bay, east side, and west side). The survey waters in Icy Strait extended from the GBNP boundary to the mouth of Idaho Inlet, across the shoreline of Chichagof Island to the east side of Point Adolphus, and to the south and west shorelines of Pleasant Island (Figure 1). This region was surveyed 1-2 days per week. Upper Glacier Bay mainly encompassed the West Arm, extending as far north as Russell Island, but also included the mouth of Adams Inlet in the East Arm. In the West Arm, Scidmore Bay and Hugh Miller Inlet were surveyed prior to 1996 before the areas were closed to motorized traffic (NPS 1995). Due to its remoteness and low humpback whale density, the Upper Glacier Bay region was surveyed only a few times per summer season (Figure 1).

Data Collection

Opportunistic marine mammal sightings were recorded in the study area during humpback whale surveys (see Neilson *et al.* 2014 for a full description of humpback whale survey methodology). Most surveys were conducted during the "summer season," defined as the period of time between June 1 and August 31. However, some surveys did occur as early as April and continued sporadically into November in some cases. Surveys outside of the defined summer season were not included in the report's analyses because they were highly variable, with surveys often only conducted a couple times per week and focused towards areas with previously known humpback whale activity. During the summer season (from here on referred to as "years"), approximately five surveys were conducted per week, each in a different location. This way the majority of the study area was surveyed once per week.

The methodology used for recording opportunistic sighting data has gone through modification since the monitoring program began. Prior to 2005, humpback whales were not recorded until the designated survey region was reached, but marine mammals *were* recorded from the moment the vessel left the dock. To compensate for oversampling regions that were transited on the way to survey regions (such as the lower bay and Bartlett Cove), marine mammals were only recorded on the *outgoing* transit from Bartlett Cove, and not on the return trip (marine mammal observations ended when a humpback whale survey ended).

Starting in 2005 and remaining consistent to present day, marine mammal sightings were *only* recorded in the day's survey region (Gabriele and Lewis, 2000). Since this report analyzed

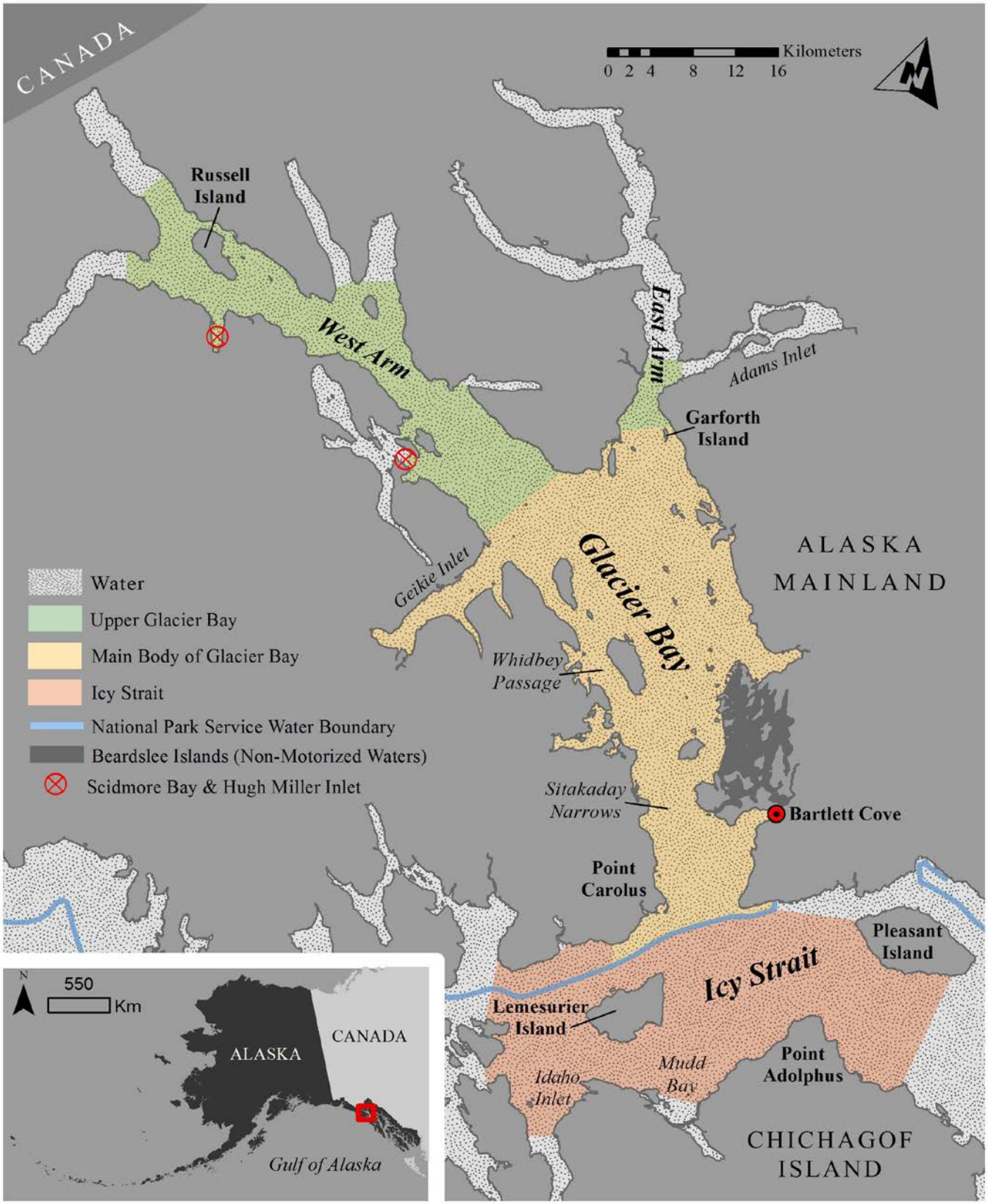

FIGURE 1. *Map of the survey area (Glacier Bay National Park (GBNP) and adjacent waters). Major place names are shown, along with the location from where the survey vessel left for surveys (Bartlett Cove). The blue line designates the boundary of GBNP and Icy Strait waters. The Upper Glacier Bay region is shown in green; the Main Body of Glacier Bay region is shown in yellow; the Icy Straight region is shown in orange.*

data collected after the change to methodology in 2005, only the details regarding methods and equipment used after this change are described in detail in this report. At the start of a survey, a small vessel (4.9 m – 6.7 m) would depart Bartlett Cove for the day's designated survey region. Opportunistic sightings were recorded when the designated region for that day's survey was reached and NPS biologists went "on-effort," meaning sightings for humpback whales and other marine mammals began. Opportunistic sightings would continue until NPS biologists went "off-effort." All "on" and "off" effort times were recorded on the appropriate field data sheet.

Keeping opportunistic sightings within the same effort times for humpback whales prevented the disproportionate sampling of areas that were transited on the way to and from the day's survey region. This method also ensured that sampling effort was randomly distributed across tidal cycles. However, data collection was inherently biased by GBNP's weather systems and humpback whale behaviors. For example, sightings were biased more towards earlier times of day and lower sea states due to afternoon westerly winds; these winds often degraded viewing conditions during later hours or ended a survey completely. The tendency for humpback whales to forage within approximately 1 mile of shore also concentrated survey effort to near-shore areas (Gabriele and Neilson, 2013).

When on-effort, an opportunistic sighting of a marine mammal was only recorded if the animal or group of animals was within 100 meters of the survey vessel. This 100 m criterion ensured that the proper species and size of the group was identified. On occasion, a single individual or group of animals was observed at greater than 100 m and was approached and recorded if the sighting was notable (e.g., a species was sighted in an area where it was not commonly sighted or there was a large congregation of animals). In addition to uncommon occurrences, killer whales and minke whales were approached when sighted to photograph them for individual identification.

For each sighting, the species and the group size was recorded on a field data sheet. A group was defined as either 1 animal or ≥ 2 individuals within several body-lengths of each other exhibiting a synchronous surfacing pattern with a common direction of travel. Three estimates – maximum, best, and minimum – were recorded for each group of animals encountered. The "maximum" represented the largest number of individuals the observer believed could be in the group. "Best" represented the observer's best guess as to how many animals were present. "Minimum" represented the least number of individuals seen by the observer. The number recorded for "best" group size was used for analyses. In some cases, the observer recorded a range of animals (e.g., 6-10); in these instances the midpoint was used as the "best" group size (e.g., 8). In addition to recording the species and group size, a global positioning system (GPS) logged a location (latitude/longitude), depth, and sea surface temperature (SST) for each opportunistic sighting. Behaviors the observer found noteworthy were also documented.

Data from the field sheets and sighting locations were later entered into a Microsoft Access database. The sighting locations were downloaded from the survey vessel's GPS unit, which reported coordinates in degrees minutes and decimal minutes. All coordinates were converted to decimal degrees (with 7 decimal places). Survey track-logs were also saved and periodically downloaded from the vessel's Garmin chartplotter. Track-logs were recorded automatically during surveys, consisting of a series of coordinate points that logged the vessel's position at pre-determined time intervals. Each track-log point had an associated leg-time, defined by the interval of time between the current and the previous track-log point. Leg times were used in the calculation of the standardized measure of sighting frequency required for data analysis.

Data Analysis

The purpose of the opportunistic sighting data was to monitor marine mammal species, thus sighting data had to identify high or low use areas within the study area and detect changes to those areas over time. Before sighting data could

be utilized this way, a standardization process was used to control for the unequal distribution of effort time within the study area. This was achieved by calculating sightings per unit effort (SPUE) from observation and effort time data. Sightings per unit effort (SPUE) were calculated as *the number of observed individuals (by species) divided by the total time spent on effort, divided by area (m^2)* (Wikgren et al., 2014). SPUE values were applied to determine trends in marine mammal sighting rates over time and to analyze the spatial and temporal distributions of marine mammals within the study area.

In order to calculate SPUE values, sighting data from the Access database were first queried to get both the number of sightings and number of individuals (group sizes) by species for each year. To determine time spent on effort, GPS track-logs were compiled and truncated in Access according to the "on" and "off" effort times reported during humpback whale surveys. Regrettably, complete GPS track-logs were not saved until 2005, effectively eliminating 1994-2004 survey data from the report's analyses. Years prior to 2005 only had records of time spent on effort, but no associated track points that provided the necessary leg times for calculating standardized SPUE values. Survey data from approximately 42 additional survey days between 2005-2014 (primarily in 2010 and 2013) were eliminated due to discrepancies between the reported on-effort times and the time stamped track-logs recorded from the Garmin chartplotter (see Figure 2). Once track points were truncated, the same was done to the marine mammal observation data so that no observations outside of effort times would be included in analysis.

The study area was then divided into a grid with 2 km *x* 2 km (4 km^2) "sighting units" using ArcView Geographic Information System (ArcGIS) software. Because of the study area's complex geography, the grid contained many units that partially overlapped land along the shorelines. To contain sighting units to only the water areas surveyed, the grid was clipped such that all parts of units lying on land were eliminated; unfortunately, this left the clipped units bordering shorelines at a fraction of their original 4 km^2 size. The solution was to merge clipped units with full neighboring units to avoid excluding the now small, oddly shaped sections of the study area from analysis. The merging of clipped units was somewhat arbitrary and subjective; however, to keep sighting unit merging consistent throughout the study area, criteria were used to merge units such that the new units created had (1) boundaries roughly perpendicular to the shore and (2) a total area roughly equal to the original 4 km^2 unit size.

Truncated track points and observations for each year were overlaid on top of the sighting unit grid. This effectively allowed for the summation of *leg time* and the *number of individuals* for *each sighting unit*. Before summed values were used to calculate SPUE, sighting units that were surveyed less than 3 times from 2005-2014 were considered "null" and excluded. Sighting units that were surveyed at least three times but contained no sightings *were* included (SPUE = 0). It was this final truncated dataset that was used to compile the majority of the report's histograms, graphs, and maps (see Appendix Tables 1 and 2).

The final truncated dataset was used to calculate individual SPUE values ($\mathbf{SPUE^i}$) for each sighting unit for each year by species (yielding a maximum of 10 $SPUE^i$ values per sighting unit per species). $SPUE^i$ calculations were only made for the five common species (sea otters, Stellar sea lions, harbor seals, harbor porpoises, and killer whales). Species were defined as being "common" if their relative proportion of sightings represented > 1%. Species were considered "uncommon" if their relative proportion of sightings represented < 1% (see Figure 5). The $SPUE^i$ values were used for calculating (1) *total average SPUE* ($\mathbf{SPUE^T}$), (2) *location-specific average SPUE* ($\mathbf{SPUE^L}$), and (3) *Kendall's tau-b correlation coefficient* ($\tau_\mathbf{B}$), which was used to asses increases and decreases in $SPUE^L$ over time.

(1) Sighting Rates Over Time ($SPUE^T$)

To analyze trends in sighting rates over time across the entire study area, *total average SPUE values* ($\mathbf{SPUE^T}$) were calculated. The $SPUE^T$

values were determined for each species by averaging $SPUE^i$ from *all* sighting units for each year. In total, there were 10 $SPUE^T$ values for each species (Appendix Table 1). $SPUE^T$ was plotted against year and checked for normality before a linear regression analysis was used to evaluate trends in relative abundance between 2005-2014 (see Figures 6A and 6B).

(2) Spatial Distribution of Sighting Rates ($SPUE^L$)

Whereas $SPUE^T$ evaluated sighting rates across the entire study area, *location-specific average SPUE values* (**$SPUE^L$**) were used to evaluate variation in sighting rates *within* the study area. This was accomplished by averaging $SPUE^i$ *within each sighting unit for all years*. This gave – for each species – a single $SPUE^L$ for each sighting unit (N = 426). The $SPUE^L$ values were displayed in ArcGIS as a color gradient to show the spatial distribution of sighting rates between 2005-2014 (see Appendix 5A – 5E). The Anselin Local Moran's I spatial statistic was used to identify outliers, which were marked on the spatial distribution maps.

The ArcGIS Spatial Hot-Spot analysis tool was used to evaluate the significance of spatial variation in sighting rates within the study area. The geospatial analysis tool calculated the Getis-Ord Gi Star (Getis-Ord Gi*) statistic, which determined if a sighting unit was part of a cluster of units containing similar $SPUE^L$ values and whether those values were different enough from the mean $SPUE^L$ to be considered significant. To determine significance, the Getis-Ord Gi* statistic related a sighting unit's value to that of its neighbors, which required a pre-set "Distance Band" to define which neighboring units should be considered for analysis.

The statistic required that the Distance Band chosen ensured that sighting units ended up with a minimum of 8 neighbors, otherwise the output hot-spots would not be reliable for non-normally distributed data (and the majority of $SPUE^L$ values did not follow a normal distribution). To meet this 8-neighbor requirement, a minimum distance of 4000 meters (4 km) was needed. A minimum distance of 2000 m would have met the 8 neighbor requirement for sighting units out in the open waters of the study area, but would have produced fewer than 8 neighbors for many units bordering shorelines or nestled in bays and inlets.

The actual Distance Band determined for each species was done using the Global Moran's Statistical Autocorrelation (Moran's I) test in ArcGIS. The test was run multiple times for each species to compare the Z-scores related to varying distance bands. The distance was increased by 100 m increments from the 4000 m starting distance until a peak in Z-score versus distance was reached, inferring that an appropriate scale at which to run the hot-spot analysis was found. The Distance Bands determined for each species are as follows: sea otters (4300 m), Steller sea lions (4200 m), harbor seals (4200 m), harbor porpoises (4100 m), and killer whales (4400 m).

The Spatial Hot-Spot statistic had several other pre-sets. One defined how distance was measured (we chose Euclidean Distance – "as the crow flies") and another defined how sighting units related to one another (we chose "Zone of Indifference" – includes all sighing units in the analysis, but weights units so that neighbors within the Distance Band had a greater impact than those outside of it). Once all pre-sets were chosen and appropriate Distance Bands identified, the Getis-Ord Gi* statistic was run for each species. The output of the analysis was a set of Z-scores and p-values indicating the statistical significance of each sighting unit's value in relation to neighboring units. Sighting units determined to be statistically significant hot-spots had high Z-scores and low p-values; sighting units determined to be statistically significant cold-spots had large negative Z-scores and low p-values. Significant hot and cold spots for each species were displayed on maps in conjunction with spatial distribution ($SPUE^L$) maps (Scott and Janikas, 2010; Wikgren et al., 2014) (Appendix 5A – 5E).

(3) Temporal Distribution of Sighting Rates (τ_B)

The nonparametric Kendall's tau-b correlation

coefficient (τ_B) was used to analyze temporal variation in sighting rates within the study area. $SPUE^i$ were compiled by species in SPSS and the Kendall's tau-b statistic was calculated for each sighting unit. Correlation coefficients with a significance of $p < 0.05$ were displayed in ArcGIS. Correlation coefficients ranged from -1 to +1, indicating the *measure of association* between $SPUE^i$ and year. There were three measures of association: (1) decrease together, (2) increase together, or (3) no correlation (Hervé Abdi, 2007; Bolboaca and Jantschi, 2006). Sighting units with either increasing or decreasing measures of association were displayed on colored maps (see Figure 7A); the total number of significantly increasing and decreasing sighting units were summarized by species in Figure 7B.

RESULTS

Effort Time and Humpback Whales

The total amount of survey effort analyzed from 2005-2014 was 2,690 hours. Survey effort was relatively consistent across years with a mean of 269 ± 36.8 hours per year. Total effort times for each year are given in Appendix Table 1. The years with the greatest degree of variation were 2007, 2010, and 2013 (Figure 2). 2007 had the greatest amount of survey effort with 320 hours. 2010 and 2013 had the lowest amount of survey effort with 217 and 193 hours, respectively.

Survey effort was abnormally low in 2010 and 2013 due to discrepancies between reported effort times and the recorded track-logs from the Garmin chartplotter, *not* actual reduced survey effort. It was reported in the annual whale progress reports that 2010 had 293 hours of effort and 2013 had 309 hours (Neilson et al., 2014); this was a 26% loss of 2010 data and a 38% loss of 2013 data. There were whole survey days (mostly in 2010 and 2013) that appeared to have incorrect time stamps, which caused track-points to not line up with reported effort times for those survey days. This made it impossible to tell which track-points fell in or out of the reported effort times, effectively eliminating those survey days from analysis due to the necessity of linking track-points to a particular sighting unit (a crucial step in calculating $SPUE^i$ values). There also appeared to be occasions where the chartplotter's memory was filled before it was downloaded, resulting in the unit recording over saved track-log data. Outside of 2010 and 2013, an additional 48 hours were lost due to similar issues. The reasons for these time-stamp discrepancies are unknown (Figure 2).

The spatial distribution of survey effort from 2005-2014 is shown in Figure 3, with greater amounts of survey effort colored red and lesser amounts of survey effort colored blue. The average amount of time spent in any one sighting unit (for all years combined) was 5±7.8 hours (range 0.01-63.0). All sighting units that were visited *at least once* during the ten-year period were included in Figure 3 to show the full extent of the study area visited during humpback whale monitoring surveys. Sighting units visited less than three times were later excluded from all spatial analyses because a minimum of three data points were needed to analyze temporal changes in sighting rates within a sighting unit.

The high degree of variability in effort time among sighting units was attributed largely to the unavoidable bias towards humpback whale activity. The co-occurrence of humpback whale sightings and larger amounts of effort time is demonstrated in Figure 4, which shows the total number of individual humpback whale sightings (N = 5,756) within each sighting unit from 2005-2010. The mean number of individual humpback whale sightings was 18±37 for each sighting unit (range 1-321). By comparing the map of effort time to humpback whale sightings, one can see that areas with greater amounts of effort time coincide with areas of higher humpback whale sightings. This favorability is to be expected due to the objectives outlined for humpback whale monitoring surveys.

Figures 3 and 4 serve the purpose of illustrating why a standardization process is necessary for the opportunistic sighting data. Readers should also keep in mind that even with effort standardized, the report's analyses treat areas with as little as 15 minutes of effort time as equal to areas with over 50 hours of effort time.

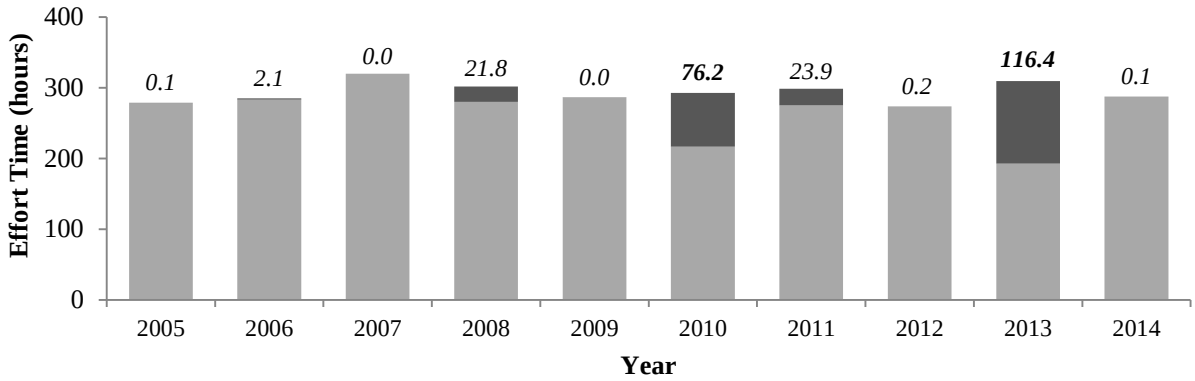

FIGURE 2. *Total amount of time spent on effort for opportunistic marine mammal sightings from 2005-2014. Total amounts of effort time used in the report's analyses are represented as light-grey bars. Dark-grey bars represent effort time that was omitted due to the time-stamp discrepancies between recorded track-logs and reported effort times; omitted effort time had the largest effect on years 2010 and 2013. Actual amounts of omitted effort time are displayed above each survey year.*

Depth and Sea Surface Temperature

Water depth and sea surface temperature (SST) histograms were compiled for sea otters, Steller sea lions, harbor seals, harbor porpoises, killer whales, minke whales, and Dall's porpoises. Gray whales and pinnipeds on land did not have depths and SST's recorded. For all species, the majority of sightings occurred in a depth range of 10-100 m (see Appendix 1A and 1B) and in a temperature range of 5.5-12.5 °C. (see Appendix 2A and 2B).

Sea otters and Steller sea lions had broader depth ranges than other species, with a peak for sea otters at 50-70 m and a double peak for Steller sea lions at 20-30 m and 50-70 m. Harbor seals and harbor porpoises had narrower depth ranges, but also had peaks at 50-70 m. Killer whales exhibited a high peak between 60-70 m, but had a larger distribution of sightings in waters > 100 m compared with other species. Minke whales had the most narrow depth range, with sightings primarily occurring between 20-70 m and a peak at 30-40 m. Dall's porpoises had a peak depth range at 70-80 m, but overall sightings occurred as frequently in 20-30 m as they did in 140-150 m of water.

Sea otters, Steller sea lions, harbor seals, harbor porpoises, and minke whales all had peak temperature ranges at 6.5-8.5 °C. Killer whales had a warmer peak temperature range of 7.5-9.5 °C. Dall's porpoise had the narrowest temperature range at 6.5-7.5 °C.

Marine Mammal Sightings

The number of sightings and associated number of individuals for each species by year are summarized in Appendix Tables 1 and 2. The relative biodiversity of species sighted are shown in Figure 5. Sea otters (n = 11,804) were sighted most frequently, accounting for over half of all observations (65%). Following sea otters were harbor porpoises (n = 2,659) and Steller sea lions (n = 2,595), making up 15% and 14% of sightings, respectively. Killer whales (n = 490) and harbor seals (n = 417) had fewer observations than the other common species, with killer whales accounting for 3% and harbor seals 2% of sightings. The four uncommon species made up a combined 1% of the total proportion of opportunistic sightings (Figure 5). Among the uncommon species, minke whales (n = 55) were sighted most frequently (46%), followed by California sea lions (n = 36) at 30%, Dall's porpoises (n = 27) at 22%, and gray whales (n = 2) at 2%.

It should be noted that the "number of individuals" was the sum of all group sizes reported that year, and does not reflect the actual number of individuals found in the study area. It was assumed that many animals were re-sighted on different survey days, but were recorded as being different individuals since there was no way of identifying one animal from another. For example, California sea lions were all sighted at the Steller sea lion haul-out at South Marble Island. In 2009, 17 California sea lions were

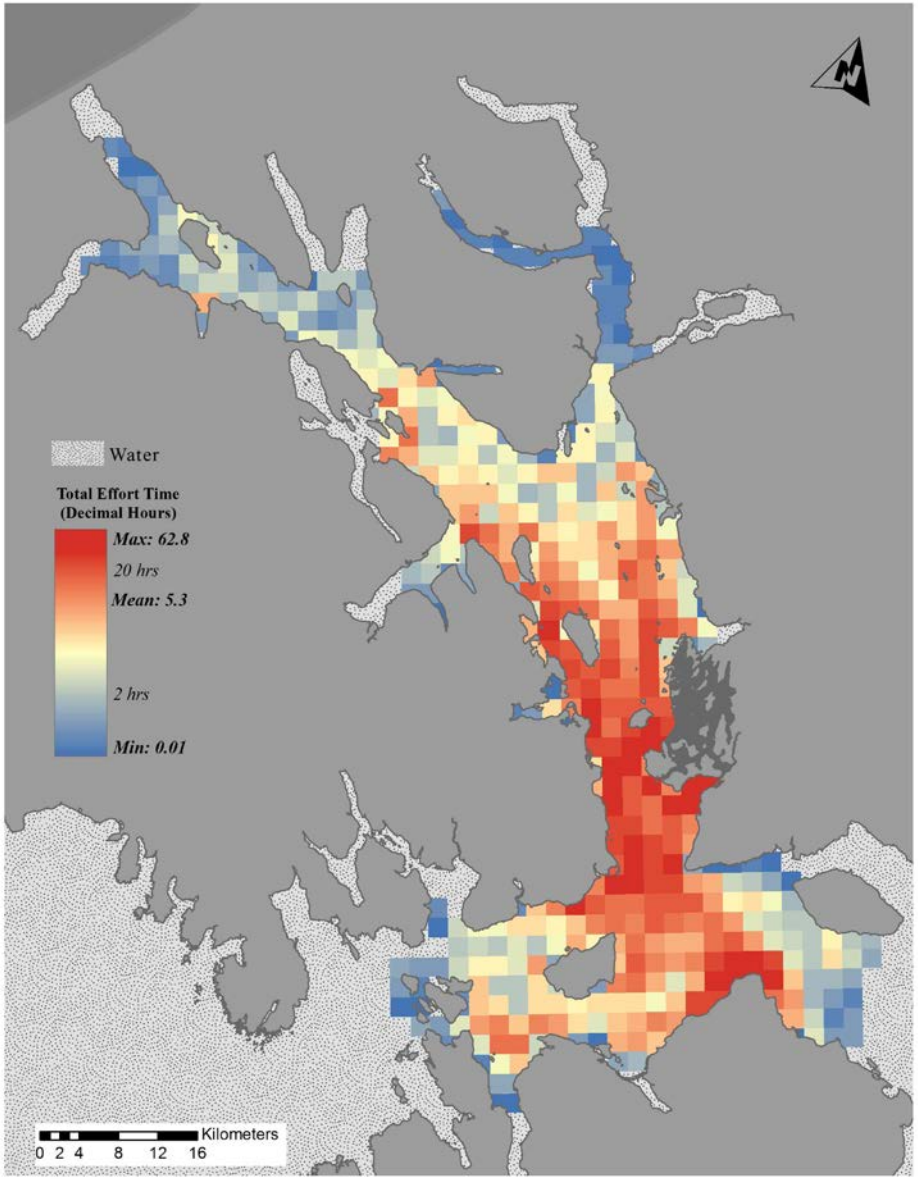

FIGURE 3. *The distribution of effort time throughout the study area from 2005-2014. Red indicates areas with greater amounts of effort time and blue indicates areas with smaller amounts of effort time.*

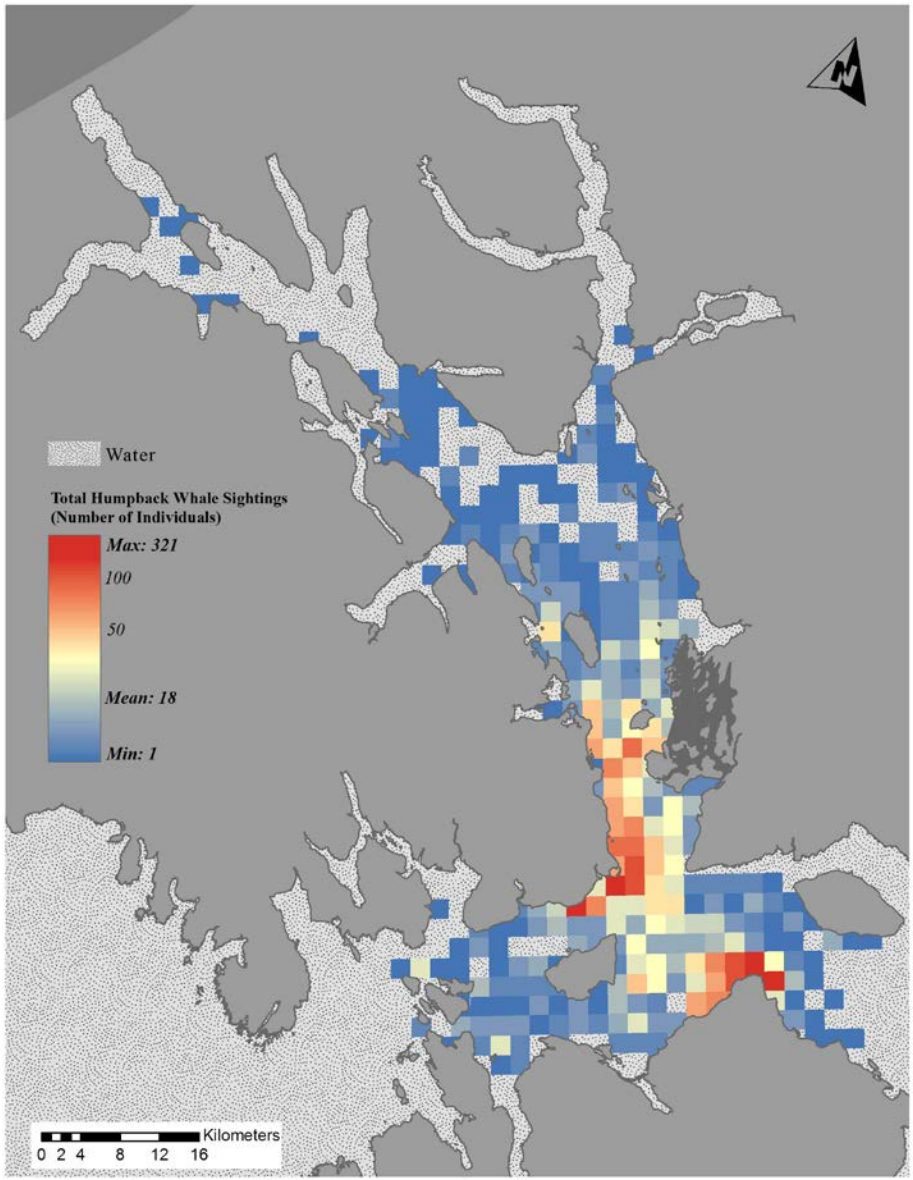

FIGURE 4. *The distribution of humpback whale sightings throughout the study area from 2005-2010. Red indicates areas with greater numbers of humpback whale sightings; blue indicates areas where at least one humpback whale was sighted.*

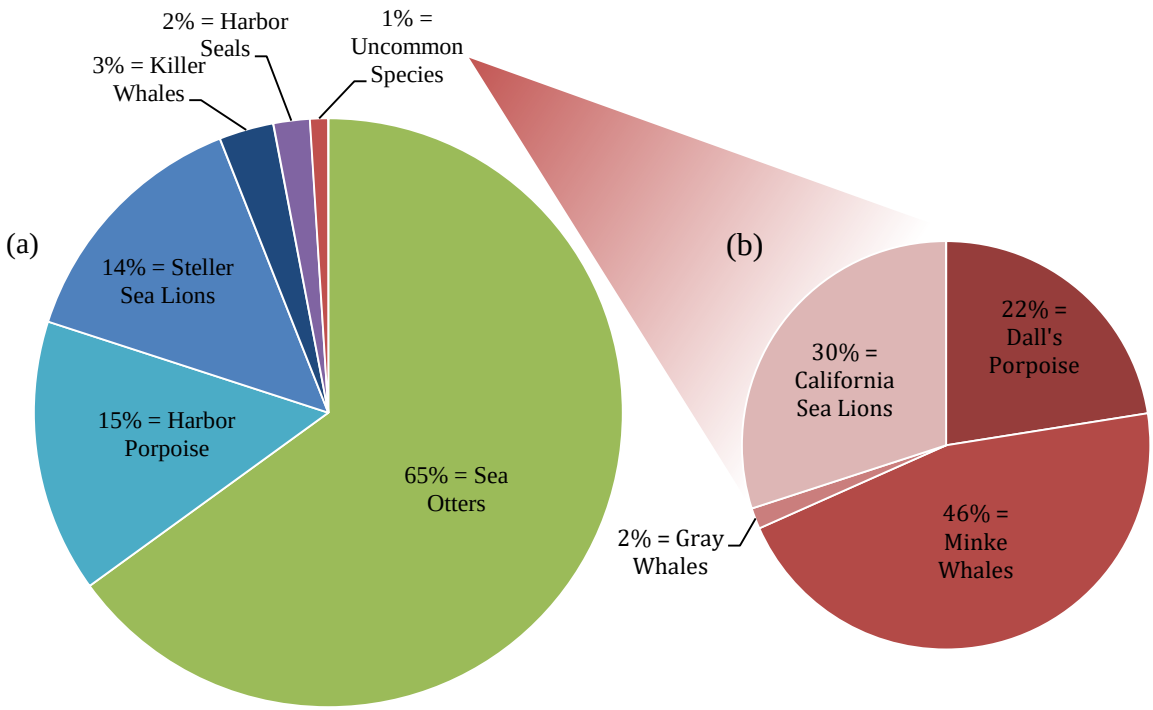

FIGURE 5. *Proportion of sightings (n = 3,169) by species from 2005-2014. (a) Relative biodiversity of the 5 common species: sea otters, Steller sea lions, harbor seals, harbor porpoises, and killer whales. The 4 uncommon species combined equate to 1% of the total opportunistic sightings. (b) Expanded chart showing the relative biodiversity of uncommon species: minke whales, California sea lions, Dall's porpoises, and gray whales.*

reported; most likely these were re-sights of one or a few individuals since sightings occurred on 17 separate survey days (Maniscalco et al., 2004).

Group size histograms are given in Appendix 3A (common species) and Appendix 3B (uncommon species). Sea otters were most often recorded as single individuals (80%); there were large rafts of 400 individuals reported, however these large congregations only made up 2% of the total relative frequency of sightings for the species. Single individuals were also the most common group size for harbor porpoises (66%) and Steller sea lions (68%); however, sightings of small groups of 2 to 3 individuals were more common for harbor porpoises and Steller sea lions than for sea otters. Harbor seals were almost exclusively seen alone (97%). Group sizes of killer whales varied the most, with the most common groups containing 2-6 individuals; there were also records of larger killer whale groups ranging from 20-30 individuals, which made up approximately 7% of all sightings.

Three of the uncommon species (minke whales, grey whales, and California sea lions) were almost exclusively sighted as single individuals. California sea lions were seen in groups, but only 7% of the time. Dall's porpoises were observed the majority of the time in groups ranging from 2 to 5 individuals, with approximately one third of Dall's porpoise sightings being groups of 2 (33%), followed by groups of 3 and 5 (each at 22%).

(1) Sighting Rates Over Time ($SPUE^T$)

Standardized $SPUE^T$ values for each year by species are reported in Appendix Table 1. For common species, $SPUE^T$ (N = 10) were plotted against year and fitted with a linear model to investigate correlation. Because year 2010 was missing 26% of observation data and 2013 38%, a second regression was run without 2010 and

2013 data to investigate how those years affected the significance of the linear models (see Figure 6A).

The model significance test for sea otters when including all years and when excluding 2010 and 2013 showed that the model was significant at $p < 0.001$. The slope of the linear model for all years (2005-2014) indicated an annual increase of 23.6% in sighting frequency (relative abundance); the slope of the linear model excluding 2010 and 2013 indicated an annual increase of 26.3% in relative abundance.

The model significance test when including all years for Steller sea lions showed non-significant trends at $p < 0.05$. However, the slope of the $SPUE^T$ linear model for all years did indicate a positive annual increase of 1.3% in sighting frequency at $p < 0.1$. Additionally, the model significance test when excluding 2010 and 2013 data did show a significant trend at $p < 0.05$, with the slope of the linear model indicating an annual increase of 1.9%.

Model significance tests for harbor seals, harbor porpoises, and killer whales showed non-significant trends at $p < 0.05$ when including all years and when excluding 2010 and 2013. Additionally, diagnostic plots of the killer whale data did not support a linear trend between sighting frequency and year, and thus no linear model was applied. A plot of the killer whale $SPUE^T$ values was shown in Figure 6B.

Due to their small number of sightings (see Appendix Table 2), $SPUE^T$ values were not calculated for the four uncommon species. Their locations and numbers of individuals are shown in Appendix 4. All sightings of California sea lions occurred on or near the Steller sea lion haul-out at South Marble Island, ranging from groups of 1-9 individuals. There are only two sightings of gray whales, each occurring in different regions of the study area (one in the main body of Glacier Bay and the other on the east side of Point Adolphus in Icy Strait). Minke whales were sighted over a large portion of the study area, but sightings appeared to be concentrated in Icy Strait waters near the GBNP boundary. Two-thirds of all Dall's porpoise sightings were recorded in Icy Strait (groups of 4-5 individuals). The remaining sightings of Dall's porpoises (groups of 1-3 individuals) occurred throughout the main body of Glacier Bay.

(2) Spatial Distribution of Sighting Frequency ($SPUE^L$)

The spatial distributions of sightings within the study area were analyzed using $SPUE^L$ values for the five common marine mammal species (N = 426 per species). Maps displaying $SPUE^L$ values are shown in Appendix 5A through 5E. The mean and range of $SPUE^L$ for each species are as follows: sea otters = 1.3±3.54 (range 0 - 32), Steller sea lions = 0.1±0.23 (range = 0 - 1.7), harbor seals = 0.05±0.135 (range 0 -1.4), harbor porpoises = 0.2±0.42 (range 0 - 5.2), and killer whales = 0.1±0.81 (range 0 - 15.8).

The corresponding hot-spot maps (see Appendix 5A – 5E) display the results of the Getis-Ord Gi* statistical analysis of each species' $SPUE^L$ map (see Appendix Table 3 for a summary of the mean, max, minimum, and standard deviations of the Getis-Ord Gi* statistic). The colored areas on the hot-spot maps represent clusters of units containing statistically significant $SPUE^L$ values. If clusters of $SPUE^L$ values produced Z-scores that were >1.96 standard deviations from the mean Z-score, then areas were identified as hot-spots. Likewise, if clusters of $SPUE^L$ values produced Z-scores that were < -1.96 standard deviations from the mean Z-score, then areas were identified as cold-spots.

Superimposed hot-spots for sea otters, Steller sea lions, harbor seals, and harbor porpoises are shown in Appendix 6. The general lack of overlap among identified hot-spots for each species suggests habitat partitioning. The greatest areas of hot-spot overlap are between Steller sea lions and harbor porpoises by Point Carolus, and between sea otters and Steller sea lions by the Beardslee Islands.

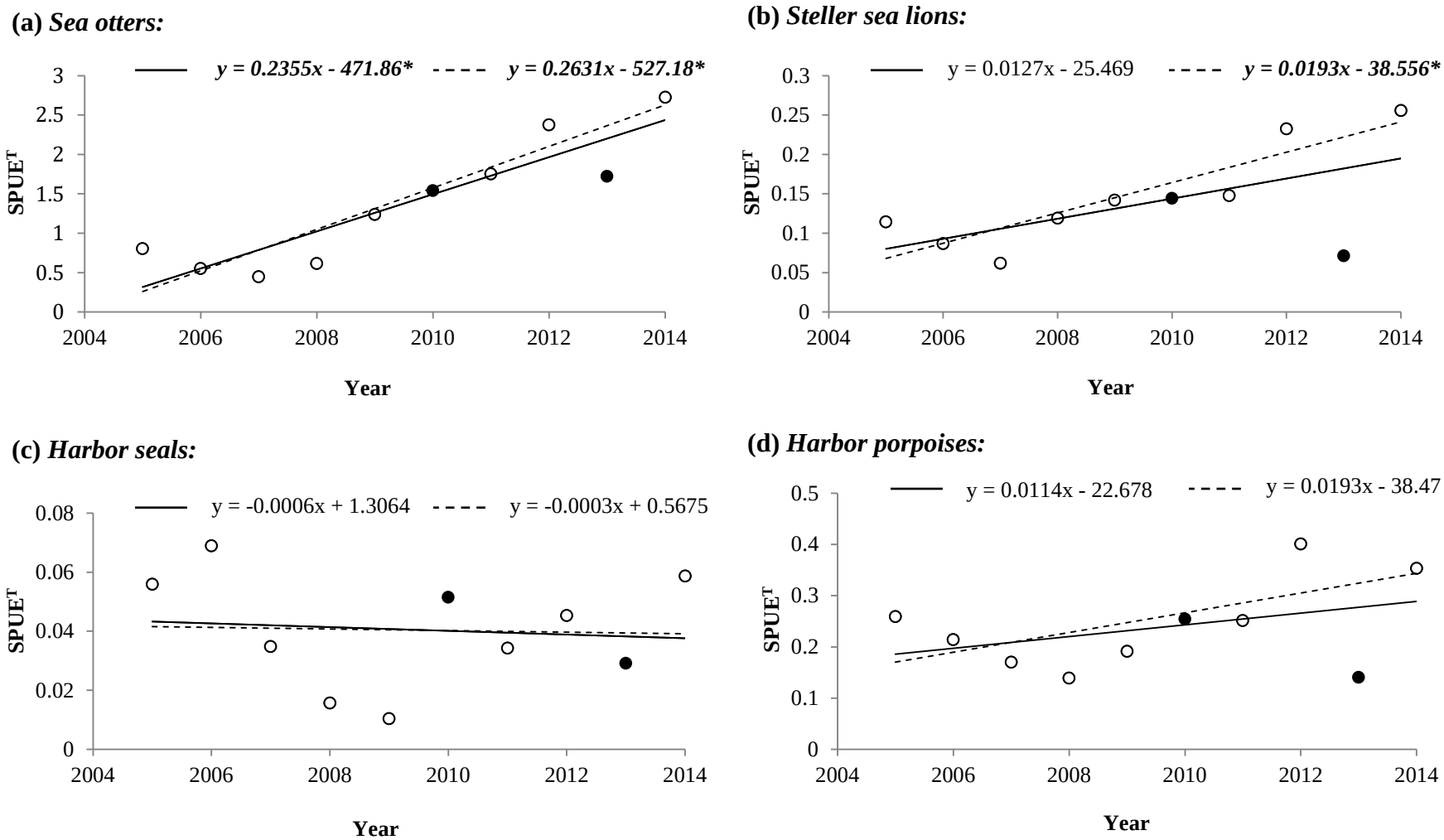

FIGURE 6A: *Linear regressions of $SPUE^T$ versus year and model equations for (a) sea otters, (b) Steller sea lions, (c) harbor seals, and (d) harbor porpoises. Solid trend lines) represent models that included all years; dotted trend lines represent models that omitted 2010 and 2013 from analysis (solid circles). Statistically significant models ($p < 0.05$) are marked with an asterisk (*). (a) Sea otters: $p = 0.0003$ with all years and $p = 0.0007$ when omitting 2010 and 2013. (b) Steller sea lions: $p = 0.064$ with all years and $p = 0.003$ when omitting 2010 and 2013. (c) Harbor seals: $p = 0.782$ with all years and $p = 0.926$ when omitting 2010 and 2013. (d) Harbor porpoises: $p = 0.253$ with all years and $p = 0.071$ when omitting 2010 and 2013.*

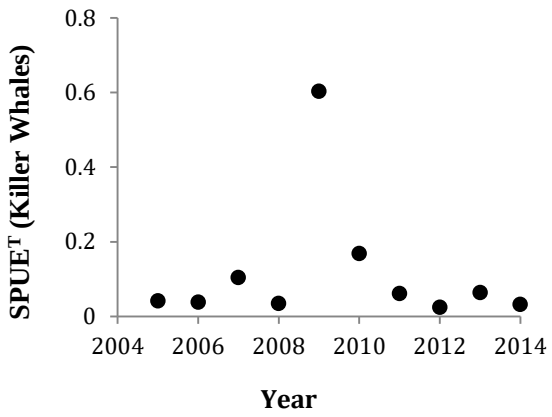

FIGURE 6B. *Plot of SPUE^T versus year for killer whales. Sighting frequency was not linearly related to year. The model was also not significant after removing 2009 SPUE^T, which was done because it appeared to be an outlier. The model proved non-significant.*

(3) Temporal Distribution of Sighting Frequency (τ_B)

The temporal distributions of marine mammal sightings within the study area were analyzed using the nonparametric Kendall's tau-b correlation coefficient (τ_B) (N = 426 per species). Out of the total sample size N = 426, the test only found a handful of τ_B values (correlation between SPUE^i and year) to be significant at $p < 0.05$: sea otters (n = 32), Steller sea lions (n = 5), harbor seals (n = 4), and harbor porpoises (n = 7). Killer whales did not have a large enough sample size to yield any significant results.

Figure 7A shows the locations of significant increases in activity (red regions) and decreases in activity (blue regions) between 2005-2014. Most of the study area had neutral activity (white regions). The numbers of sighting units with significant increases in activity are as follows: sea otters (n = 29), Steller sea lions (n = 3), harbor seals (n = 3), and harbor porpoises (n = 5) (Figure 7B). The numbers of sighting units with significant decreases in activity are as follows: sea otters (n = 3), Steller sea lions (n = 2), harbor seals (n =1), and harbor porpoises (n = 2) (Figure 7B).

DISCUSSION

In this study we showed that opportunistic sighting data gathered during routine humpback whale monitoring surveys could be used to simultaneously monitor a variety of marine mammal species within and near GBNP. Sighting data can be used to inform visitors, boat operators, and NPS resource managers for recreational viewing of marine mammals, directing future research, implementing protection for a particular species, or for responding to a disaster, such as an oil spill. Additionally, data collected doesn't exclusively focus on documenting marine mammals *within* the GBNP boundary (as is the case for many abundance surveys focused on the area); rather, opportunistic sighting data represent more of the extended habitat used by marine mammals that travel back and forth over the GBNP boundary to waters in Icy Strait, offering a wider view of marine mammal distribution and movement.

The analyses presented in this study were able to assess the relative abundance and distribution of marine mammals by using SPUE as a proxy for an abundance estimate. Doing so allowed for changes in sighting frequency to be detected, a fundamental component in monitoring a species. Sighting trends and distributions offer a foundation for future work in analyzing correlations with environmental and biotic factors such as depth, SST, salinity, habitat type, interspecies interactions, prey distributions, tidal currents, seasonality, phytoplankton blooms, and human activity. Since depth and SST were already collected during surveys, a good starting point for future reports would be to look at how depth and SST correlate with sighting frequency. Another analysis would be to explore variation in sighting frequencies between survey months (June, July, and August).

Depth and Sea Surface Temperature

Water depth and SST histograms indicate that there is a preference of many of the marine mammal species to remain within certain depth and temperature boundaries. Future reports may better quantify these findings through spatial analysis, which could help determine the affects of both the dynamic environment of GBNP, as

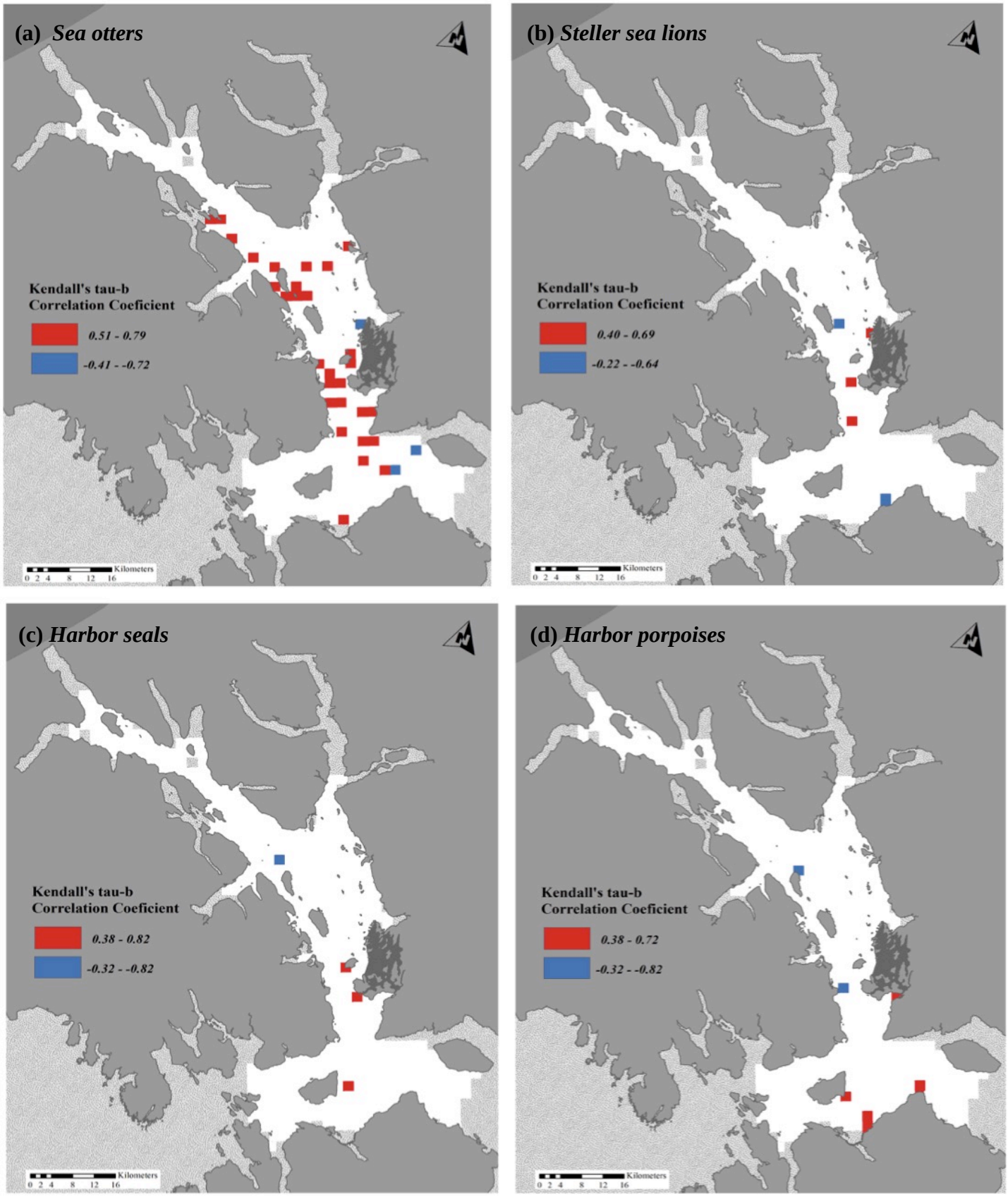

FIGURE 7A. *Kendall's tau-b correlation coefficients at $p < 0.05$ from 2005-2014. White areas on the map had no measurable increase or decrease over time, while red sighting units show increases in sighting frequency and blue sighting units show decreases in sighting frequency for: (a) sea otters, (b) Steller sea lions, (c) harbor seals, and (d) harbor porpoises. There were no significant correlations for killer whales.*

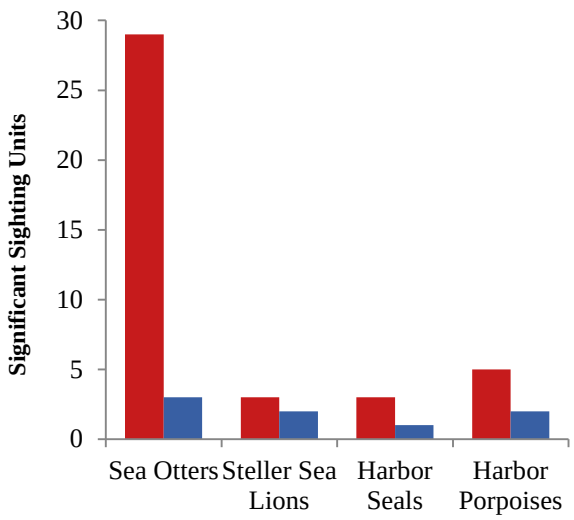

FIGURE 7B. *The number of sighting units with significant increases in activity (red columns) and decreases in activity (blue columns) for sea otters, Steller sea lions, harbor seals, and harbor porpoises.*

well as the individual life histories of the species' observed (predator-prey interactions, foraging strategy, and prey preferences).

Marine Mammal Sightings

Due to the diverse life histories of the marine mammal species observed, the suitability of the analyses used to determine relative abundance, distribution, and activity varied for each species. For example, sea otters' relatively restrictive home ranges, coupled with numerous and frequent sightings, produced results supported by other monitoring surveys (Johnson, 1982; Esslinger et al., 2013; Bodkin et al., 2005); this demonstrated the usefulness and viability of opportunistic sighting data for monitoring sea otter distributions and relative abundance. On the other hand, killer whales' relatively large home ranges and complex social structures, coupled with cohabitating ecotypes (Deeke et al.,2006), produced results that offered very little conclusive insight into the specie's activity within the study area.

Although the species observed were diverse, the results regarding marine mammal sighting frequencies and distributions are still useful. For example, when hot-spots for each species were overlaid, evidence of habitat partitioning within the study area became apparent for sea otters, Steller sea lions, harbor seals, and harbor porpoises (Appendix 6). Habitat partitioning in marine environments is a documented phenomenon given the coexistence of species that all depend on shared resources (Waldner and Ross, 1980; Bearzi, 2005). These results provided insight into how the habitat within the study area was utilized by coexisting marine mammal species, which may be used to direct research efforts in the future.

To account for the diverse nature of the species observed in GBNP and adjacent waters, future analyses may be improved by using an explanatory variable other than "year." A nonlinear explanatory variable such as prey distribution and movement, substrate type, or tidal cycles may produce more significant results when analyzing specie's sighting frequency across the entire study area. Spatial distributions and hot-spot analysis also utilized the linear variable "year," but these results only showed where animals had been seen and in what magnitudes; the analyses did not shed light on the cause of these distributions. Once again, the application of more relevant abiotic and biotic explanatory variables may produce results that better address causation.

Sea Otters:

All findings related to sea otters pointed to an increase in sighting frequency throughout the study area. A positive correlation was found between $SPUE^T$ and year for both linear models (Figure 6A). The increase in relative abundance is corroborated by other systematic studies on sea otter abundance in Glacier Bay (Esslinger et al., 2013; Bodkin et al., 2001, 2002, 2004), however the reported increase in sighting frequency from opportunistic sighting data was only a little more than half (~24-26%) of the rate reported by Esslinger et al. (2013). Despite this difference in rate, future analysis can use $SPUE^T$ to explore correlations with depth, current, and prey distribution, all of which are most likely correlated with $SPUE^T$ more than year (Mathews et al., 2011; Bodkin et al., 2004). It is possible

that the significant positive correlation between relative sighting frequency and year was due to the magnitude of expansion observed in the sea otter population in and near GBNP. It may also be that whatever explanatory variable is closely associated with their activity happens to also be linearly correlated to year.

The overall increase in sea otter sighting frequency is reflected in the spatial distribution ($SPUE^L$) and hot-spot analysis maps (Appendix 5A). Sea otters show sighting frequencies close to the mean in nearly the entire study area, indicating that they have a widespread presence. Three outliers correspond to sighting observations of large congregations – rafts – of sea otters (number of individuals >100). These outliers were accounted for in the hot-spot analysis, which showed that sighting frequencies are concentrated primarily in the middle of the main body of Glacier Bay by the Beardslee Islands and Whidbey Passage. Similar distribution patterns are shown in annual reports from Esslinger et al. (2013) and Bodkin et al. (2001, 2005). These annual reports also show that the hot-spot analysis does not capture finer-scale habitat utilization that may be occurring either annually, monthly, or daily (e.g. diurnal tidal cycles). Some of this detail may be captured in future studies if sighting units were not made from an arbitrary grid, but rather from bathymetry or known prey distributions.

Temporal distributions (τ_B) for sea otters showed no clear emigration or immigration of sea otters from one spot to the other (Figure 7A), as would be the case if there were an approximate equal number of red to blue sighting units (Figure 7B). Instead, there is a general increase in sea otter sighting frequency over the past ten years spread throughout the study area. It is important to keep in mind that τ_B only shows increases and decreases in activity – it does not show the magnitude of change. Therefore there may be some sighting units where there has been a relatively constant frequency of sea otter sightings and only a small increase or decrease over the past ten years; there may also be sighting units where there has been large changes in sighting frequency. There is no distinction between these scenarios in the τ_B maps, and may be a point to improve upon in the future by creating a color gradient that better reflects the magnitude of change among these correlations. The τ_B results indicate that whatever the magnitude of change, there has been a steady increasing trend over the past decade that implies population growth rather than movement from one location to another within the study area. There were some regions identified as having decreased activity over the past decade; a possible reason for decreased activity may be depletion of prey or increased competition for the remaining resources.

Steller Sea Lions:

Although there was no evidence of increasing or decreasing trend for Steller sea lions based on $SPUE^T$ for all years (at $p < 0.05$) (Figure 6A), there was a significant increase in sighting frequency when years 2010 and 2013 were removed from the regression model (Figure 6A). Other systematic abundance surveys have reported an 8.2% rate of increase for Steller sea lions between the 1970s and 2009 (Mathews et al., 2011). As it was for sea otters, the model's reported increase in relative abundance of Stellar sea lions is a fraction of the increase reported by the systematic survey; however, a significant increase was still detected.

The spatial distribution and hot-spot analysis maps (Appendix 5B) showed a very distinct pattern of movement for Steller sea lions. Hot-spot analysis showed that sightings are concentrated around the known haul-out at South Marble Island, continuing through a corridor in the Sitakaday Narrows to Point Carolus, another documented haul-out, and on to the foraging site at Point Adolphus. All of these regions are known to have riptides and upwelling, and coincide with humpback whale habitat (Mathews et al., 2011; Chenoweth et al., 2011). Additionally, the analysis shows cold-spots up in the West Arm where Steller sea lions are not commonly sighted.

Temporal distributions (τ_B) for Steller sea lions showed neutral activity in the majority of the study area (Figure 7A), with only five sighting units showing a significant increase or decrease

in activity (Figure 7B). The sighting units that were identified as having significant change in activity over the past decade implied that there may be a shift in habitat use, indicated by the roughly equal amounts of red to blue sighting units. This suggests sea lion activity has shifted over the past ten years from around Whidbey Passage and west of Point Adolphus to the main body of GB proper by Point Carolus, Sitakaday Narrows, and the Beardslee Islands

Harbor Seals:

There was no evidence of increasing or decreasing trend for harbor seals based on $SPUE^T$ for either linear model; in fact, the model fit better when all years were included than when 2010 and 2013 were omitted (Figure 6A). The harbor seal sighting data may have been significantly impacted by the species having concentrated numbers in regions of the study area where survey effort was either limited or prohibited (Womble et al., 2014). Harbor seals have cohabitating terrestrial and glacial life-history strategies. Harbor seals rest, nurse pups, travel, and forage to and from two different habitat types: terrestrial haul-outs influenced by tides and glacial ice-flows up in the far reaches of the West and East Arms of GBNP (Blundell et al., 2011; Womble et al., 2014; Mathews and Adkison, 2010). The only terrestrial haul-out site that received frequent visits during humpback whale surveys was near the Beardslee Island entrance, a non-motorized region. Known glacial sites are either in non-motorized waters or are only visited a few times a year due to low humpback whale activity; however, these sites are known to have some of the largest congregations of harbor seals (Blundell et al., 2011). Additionally, harbor seals may avoid areas frequently used by Steller sea lions, killer whales, and humpback whales due to competition for similar prey sources and predation risk from killer whales and Steller sea lions (Womble et al., 2014; Mathews and Adkison, 2010; Herreman et al., 2009).

Given the factors above and the design of humpback whale monitoring surveys, analyses used to assess opportunistic sighting data for harbor seals were not as effective as with sea otters or Steller sea lions. This does not invalidate the data gathered. The spatial distribution of harbor seal sightings and corresponding hot-spot analysis (Appendix 5C) support literature and known activity at both the terrestrial haul-out near the Beardslee Island entrance and near glacial ice-flows in the West Arm (Mathews and Adkison, 2010). It is important to note that although the only major hot-spot identified is in the West Arm, areas in the main body of GBNP and Icy Strait were *not* identified as cold-spots, indicating there is a regular presence of harbor seals utilizing habitat throughout the study area.

Temporal distributions (τ_B) for harbor seals showed neutral activity in the majority of the study area (Figure 7A), with only four sighting units showing significant increases or decreases in activity (Figure 7B). However, 3 of the 4 sighting units identified as having significant change over the past decade pointed to an increase in activity, centered near the main body of GBNP and Icy Strait rather than in the West Arm.

Harbor Porpoises:

There was no evidence of increasing or decreasing trend for harbor porpoises based on $SPUE^T$ (Figure 6A). Although other systematic surveys show harbor porpoises frequenting the main body of Glacier Bay (Dahlheim et al., 1992), the spatial distribution map showed the greatest amount of sighting frequency in Icy Strait (Appendix 5D). The hot-spot map complimented the spatial distribution map, which showed a large hot-spot extending from the entrance of GBNP and south along the east side of Lemesurier Island to Mudd Bay (Appendix 5D). Hot-spot analysis also showed cold-spots throughout the West Arm. Bathymetry or prey preference and distribution may be more suitable variables for analyzing the activity of harbor porpoises rather than year.

Just as for Steller sea lions and harbor seals, temporal distributions (τ_B) for harbor porpoises showed neutral activity in the majority of the study area (Figure 7A), with only seven units showing significant increases or decreases in

activity (Figure 7B). However, 5 of the 7 significant sighting units demonstrated increased activity over the past decade, particularly in Icy Strait near Point Adolphus, Mudd Bay, and Lemesurier Island.

Killer Whales:

SPUE did not prove effective in detecting changes in the relative abundance of killer whales in Glacier Bay and adjacent waters, and opportunistic data will need to be approached differently in future reports. It would be easy to blame the specie's insufficient $SPUE^T$ data and inconclusive spatial results on a small sample size; however, killer whales were sighted more frequently than harbor seals, which did successfully provide insights into the specie's relative abundance and distribution.

The complex and varied life histories of killer whales may be the largest contributing factor to the report's inconclusive results. First, killer whales have large home ranges, with some Glacier Bay pods being reported as far south as California. When they are present within the study area, killer whales move quickly, making it both more difficult and less likely to come across individuals than other species (Deecke et al., 2006). Second, killer whales have contrasting life-history strategies within their own species, with both transient and resident ecotypes inhabiting the study area (Deecke et al., 2011). This report made no distinction between sightings of transient and resident killer whale ecotypes. Since these ecotypes have different foraging and social constructs, separating transient and resident sightings may greatly alter sighting rate and distribution analysis (Deecke et al., 2006).

Although $SPUE^T$ and temporal trends for killer whales were non-significant, and the $SPUE^L$ map did not show any distinguishable patterns in sighting frequency (Appendix 5E), the hot-spot map did reveal a region right in the middle of the main body of Glacier Bay as having significantly higher sightings of killer whales than almost anywhere else in the study area (Appendix 5E). This region may represent a transit point for both cohabitating ecotypes of killer whales coming and leaving Glacier Bay. This doesn't mean killer whales only utilize this one region, but rather the majority of killer whales have chosen to pass through that area. It is also possible that a convergence of prey supports killer whale activity in that particular region. The hot-spot is centered near the South Marble Steller sea lion haul-out, the terrestrial harbor seal haul-out at the Beardslee Entrance, and prime foraging habitat for sea otters, all potential prey for transient killer whales (Deecke et al., 2006; Deecke et al., 2011).

Current Methodology

Since marine mammal observations are gathered during humpback whale monitoring surveys, humpback whale activity will dictate where effort is concentrated. Direct application of opportunistic sighting data are limited unless the data are first standardized to account for bias towards locations with humpback whale activity. The standardization process instigated in this report required that data be formatted and transferred between multiple programs. The process could be improved by organizing and pre-formatting data to be ready for standardization, such as pre-building database queries to quickly gather desired sets of data.

An unavoidable consequence of opportunistic sighting data being concentrated to areas with humpback whale activity was that many sighting units within the study area received only a small amount of effort time. This likely means the data were unrepresentative of the true sighting frequency across many locations. Although standardization did account for the bias in effort time, spatial and temporal analyses did not differentiate a sighting unit with 24 hours of effort time from a sighting unit with 24 minutes of effort time. In order to have data better approximate reality at each defined location, more effort across more sighting units would be required. Unfortunately, getting more effort time at each location would *not* be a feasible solution given the objectives of humpback whale monitoring surveys, as well as the vast size and geographic complexity of the study area. Instead, possible solutions to overcoming this limitation would be to eliminate less reliable

sighting units or to change how sighting units were defined. For instance, it may be possible to create a grid that defines sighting units by the amount of effort time in a given area, such that all sighting units created have close to equal amounts of time rather than space.

Another strategy for improving the analyses of opportunistic sighting data would be to use independent variables other than year to assess sighting rates and distribution. A more meaningful analysis may include assessing $SPUE^T$ against abiotic and biotic factors such as prey distribution, substrate type, tidal cycles, time of day, month, currents, salinity, and SST (Chenoweth et al., 2011; Herreman et al., 2009; Robards and Drew, 1999; Gabriele and Neilson, 2013). Spatial and temporal distributions could be greatly improved by basing the sighting unit grid on bathymetry or habitat type rather than an arbitrary grid. Using abiotic and biotic features to define sighting units may help account for the difference in life-history and foraging strategies of the marine mammals sighted. For instance, sea otters have small home ranges and are strongly correlated with depth (Bodkin et al., 2004); in contrast, headland wake systems are favored by harbor porpoises, harbor seals, and humpback whales (Chenoweth et al., 2011).

Future reports would also benefit from careful review of the track-log data. Missing track-log data was the main reason large portions of sighting data were excluded from analysis. It remains unclear as to what caused the technical discrepancies identified in the track-log time stamps or why large portions of track-logs went missing entirely. Although an average SPUE value could be calculated for the entire study area without track-log data, calculating SPUE values that allow for spatial and temporal analyses without track points is not possible.

CONCLUSION

This report provides a preliminary analysis of the distribution and relative abundance of the five common marine mammal species (sea otters, Steller sea lions, harbor seals, harbor porpoises, and killer whales) opportunistically sighted in GBNP and adjacent waters to aid in long-term monitoring efforts. Opportunistic sighting data were also summarized for the 4 uncommon marine mammal species (minke whales, Dall's porpoises, California sea lions, and gray whales).

The results of this report provide a baseline for future analyses and demonstrate that opportunistic sighting data collected during humpback whale monitoring surveys can be standardized and adapted for monitoring relative abundances and distributions of multiple marine mammal species. Linear regression models and Kendall's tau-b correlation coefficient were used to assess species' temporal distributions and $SPUE^L$ maps were used to assess species' spatial distributions. An analytical interpretation of the $SPUE^L$ maps were given as hot-spot analyses, which suggested habitat partitioning within the study area for sea otters, Steller sea lions, harbor seals, and harbor porpoises. Further development of the report's analyses would benefit those directly studying and working to conserve the diverse and complex marine ecosystem of Glacier Bay, as well as others opportunistically documenting marine mammal species around the globe.

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Appendix Table 1

Summary of total effort time, SPUE^T, number of individuals, and number of sightings per year for sea otters, Steller sea lions, harbor seals, harbor porpoises, and killer whales in GBNP and adjacent waters. Effort time is the same for all species, totaling 2,690 hours from 2005-2014.

YEAR	Total Effort Time (hours)	Sea Otters			Steller Sea Lions			Harbor Seals			Harbor Porpoises			Killer Whales		
		SPUE^T	*# Indv.*	*# Sight.*	*SPUE^T*	*# Indv.*	*# Sight.*	*SPUE^T*	*# Indv.*	*# Sight.*	*SPUE^T*	*# Indv.*	*# Sight.*	*SPUE^T*	*# Indv.*	*# Sight.*
2005	278.23	0.803	1043	*84*	0.114	147	*51*	0.056	40	*32*	0.259	235	*86*	0.041	72	*13*
2006	282.92	0.549	981	*90*	0.087	169	*50*	0.069	43	*42*	0.214	238	*77*	0.038	62	*9*
2007	319.85	0.447	727	*95*	0.062	213	*54*	0.035	42	*30*	0.170	219	*86*	0.104	65	*9*
2008	279.76	0.615	760	*114*	0.119	395	*56*	0.016	24	*20*	0.139	172	*65*	0.034	25	*7*
2009	285.91	1.238	861	*114*	0.142	374	*60*	0.010	23	*16*	0.191	222	*84*	0.603	54	*15*
2010	216.45	1.539	849	*130*	0.144	187	*55*	0.051	45	*34*	0.254	212	*77*	0.168	29	*4*
2011	274.81	1.752	1280	*134*	0.148	303	*56*	0.034	44	*33*	0.251	377	*74*	0.061	31	*9*
2012	272.74	2.374	1352	*139*	0.232	377	*91*	0.045	55	*40*	0.401	418	*114*	0.024	57	*9*
2013	192.84	1.721	1078	*138*	0.071	102	*19*	0.029	27	*23*	0.141	120	*58*	0.063	61	*12*
2014	286.75	2.726	2873	*201*	0.256	328	*94*	0.059	74	*48*	0.353	446	*121*	0.032	34	*5*
TOTALS:	**2,690.27**	**13.764**	**11,804**	***1239***	**1.375**	**2,595**	***586***	**0.404**	**417**	***318***	**2.374**	**2,659**	***842***	**1.168**	**490**	***92***

Appendix Table 2

Summary of total effort time, SPUE^T, number of individuals, and number of sightings per year for minke whales, Dall's porpoises, California sea lions, and gray whales in GBNP and adjacent waters. Effort time is the same for all species, totaling 2,690 hours from 2005-2014.

YEAR	*Total Effort Time (hours)*	Minke Whales		Dall's Porpoises		California Sea Lions		Gray Whales	
		# Indv.	# Sight.	# Indv.	# Sight.	# Indv.	# Sight.	# Indv.	# Sight.
2005	278.23	5	*5*	0	*0*	1	*1*	1	*1*
2006	282.92	5	*5*	0	*0*	3	*1*	1	*1*
2007	319.85	10	*10*	9	*2*	2	*2*	0	*0*
2008	279.76	10	*10*	3	*1*	0	*0*	0	*0*
2009	285.91	8	*8*	0	*0*	17	*17*	0	*0*
2010	216.45	0	*0*	4	*2*	1	*1*	0	*0*
2011	274.81	5	*5*	3	*2*	9	*1*	0	*0*
2012	272.74	6	*6*	0	*0*	0	*0*	0	*0*
2013	192.84	4	*4*	8	*2*	2	*2*	0	*0*
2014	286.75	2	*2*	0	*0*	1	*1*	0	*0*
TOTALS:	**2,690.27**	**55**	***55***	**27**	***9***	**36**	***26***	**2**	***2***

Appendix Table 3

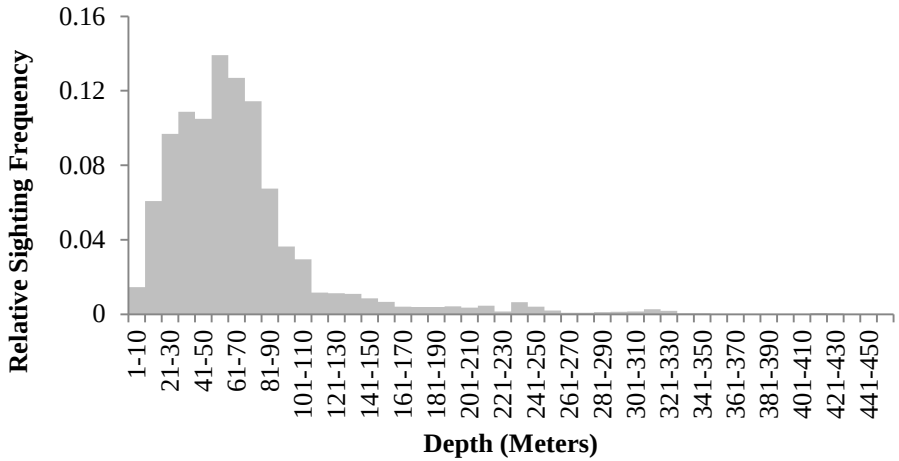
Z-score ranges, means, and standard deviations for the Getis-Ord Gi statistical analysis.*

	Min	*Max*	*Mean*	*SD*
Sea Otters	-1.425	6.196	-0.006	1.4618
Steller Sea Lions	-1.930	7.057	-0.079	1.6660
Harbor Seals	-1.355	4.609	-0.070	1.0230
Harbor Porpoises	-2.001	6.824	-0.021	1.7797
Killer Whales	-0.465	5.524	0.061	1.0799

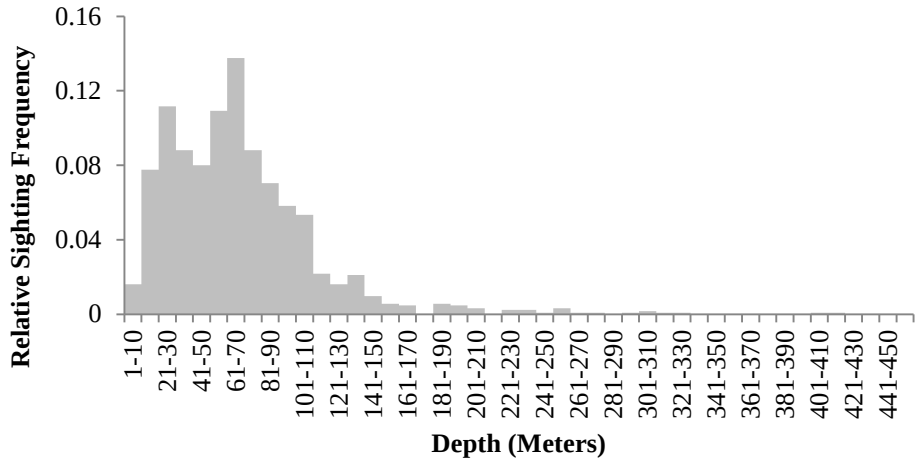
Appendix 1A

Depth histograms for (a) sea otters, (b) Steller sea lions, (c) harbor seals, and (d) harbor porpoises. Depths are from a subset of truncated opportunistic sighting data (sightings that included both depth and SST). Most sightings occurred between depths of 10-100 m.

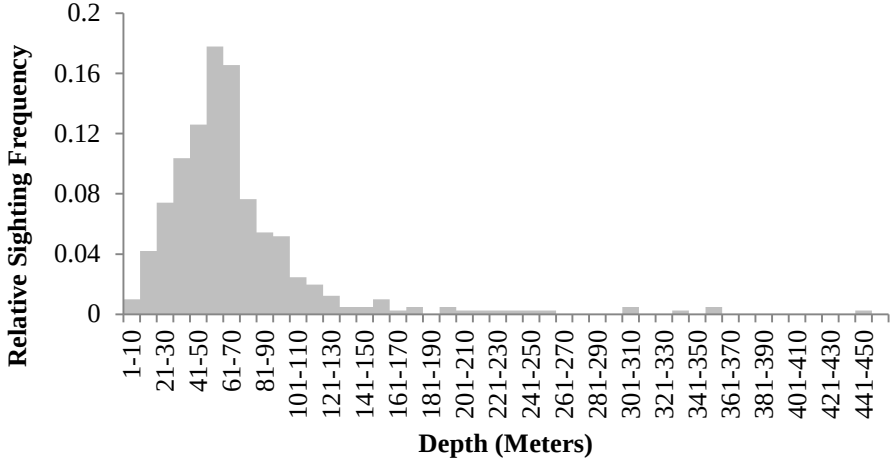
(a) Sea otters:



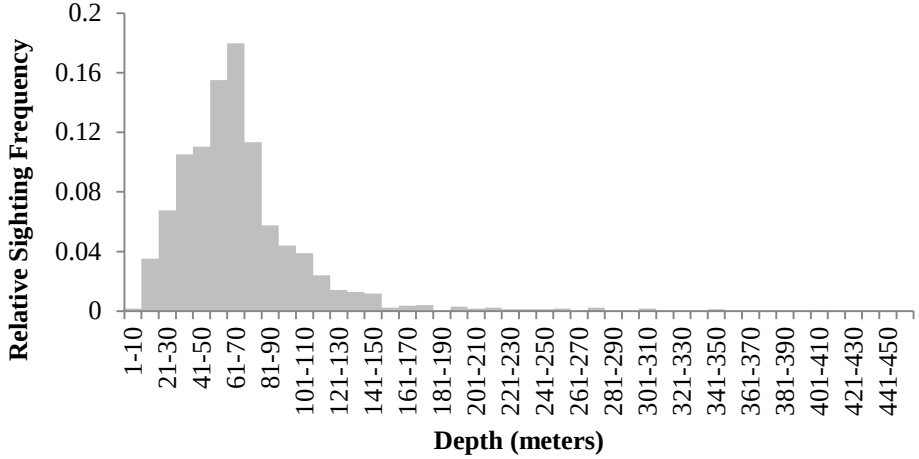
(b) Steller sea lions:



(c) Harbor seals:

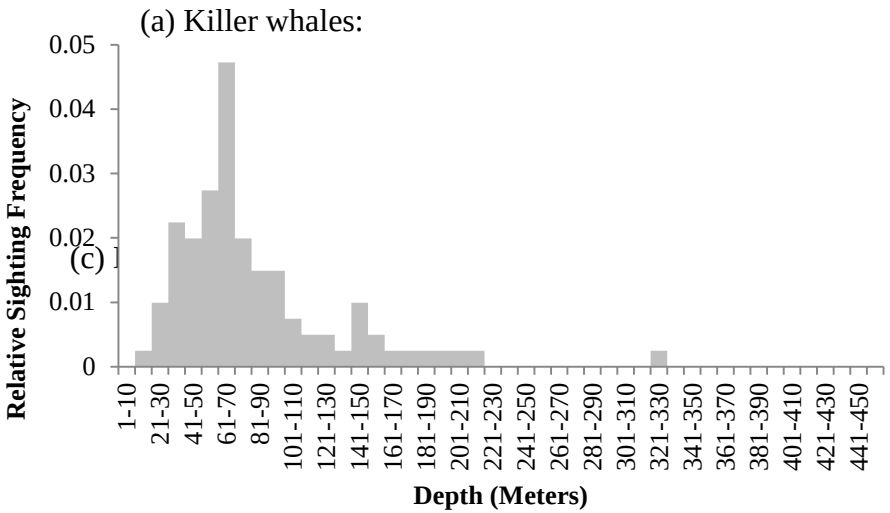


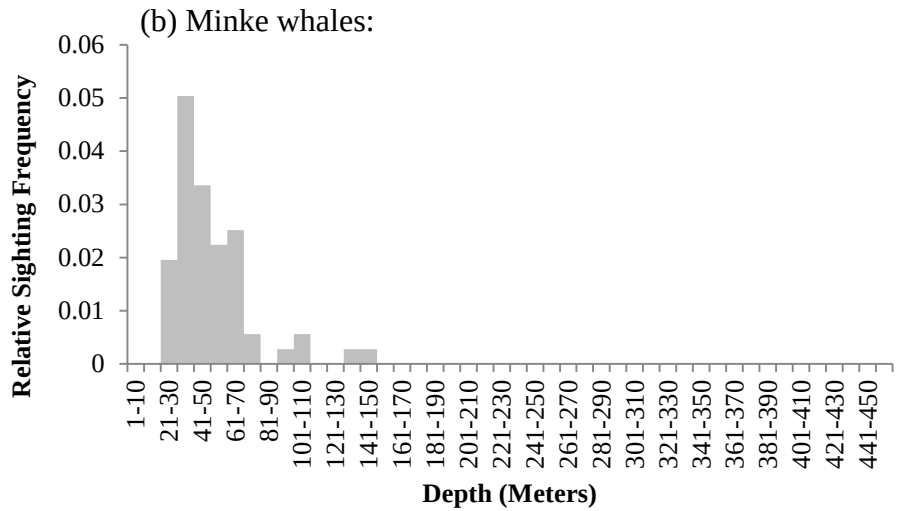
(d) Harbor porpoises:

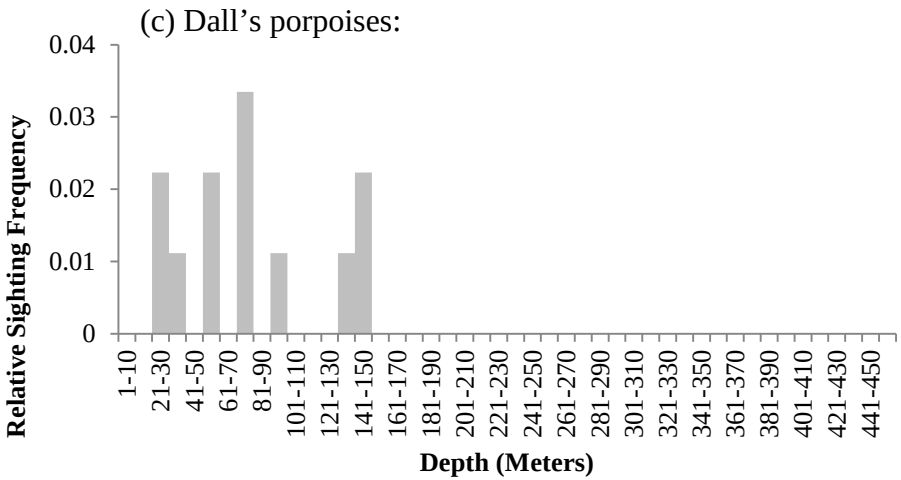


Appendix 1B

Depth histograms for sightings of (a) killer whales, (b) minke whales, and (c) Dall's porpoises. Depths are from a subset of the truncated opportunistic sighting data (sightings that included both depth and SST). Most sighting occurred between depths of 10-100 m.



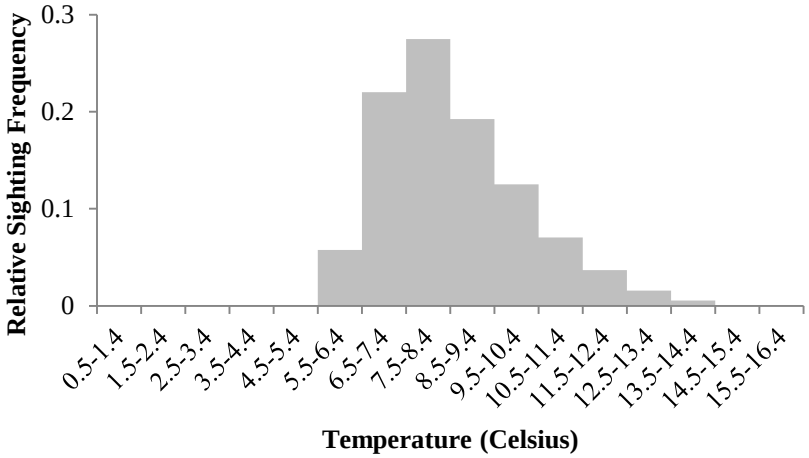




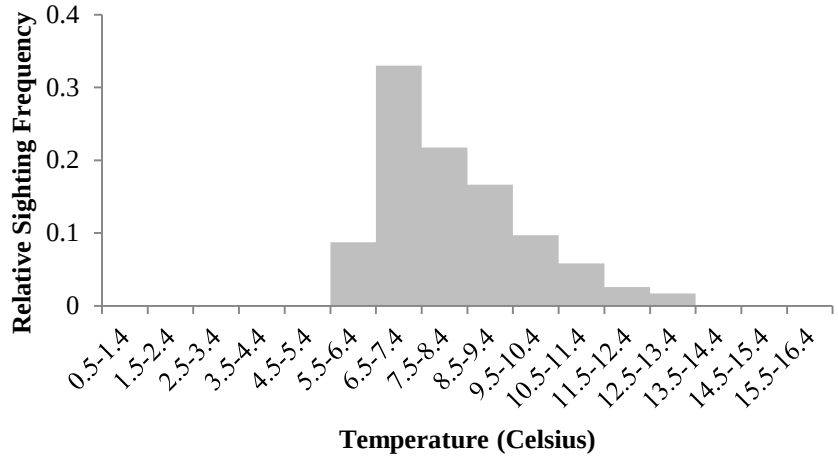
Appendix 2A

SST histograms for sightings of (a) sea otters, (b) Steller sea lions, (c) harbor seals, and (d) harbor porpoises. Temperatures are from a subset of the truncated opportunistic sighting data (samples include sightings with both depth and sea surface temperature).

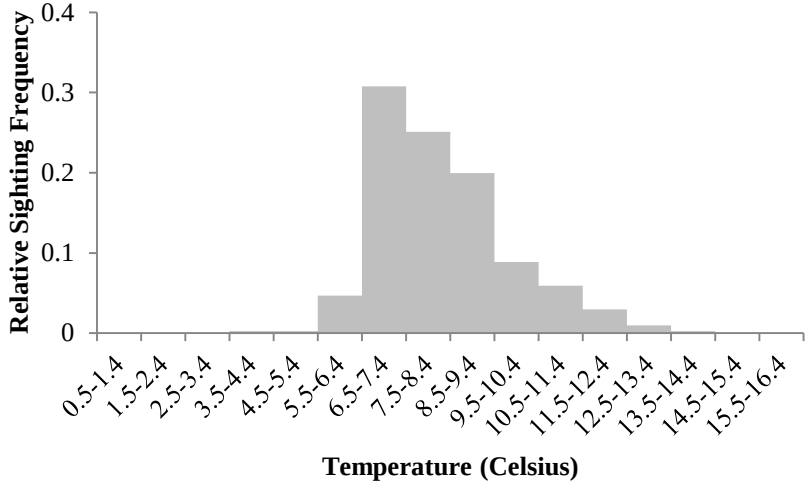
(a) Sea otters:



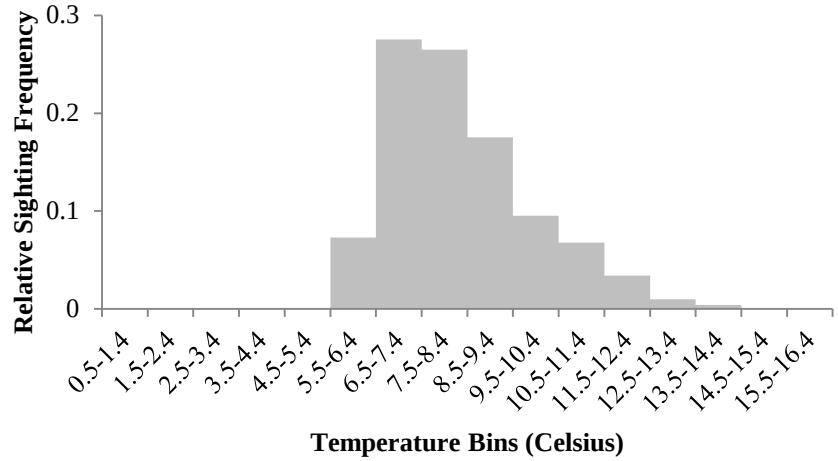
(b) Steller sea lions:



(c) Harbor seals:

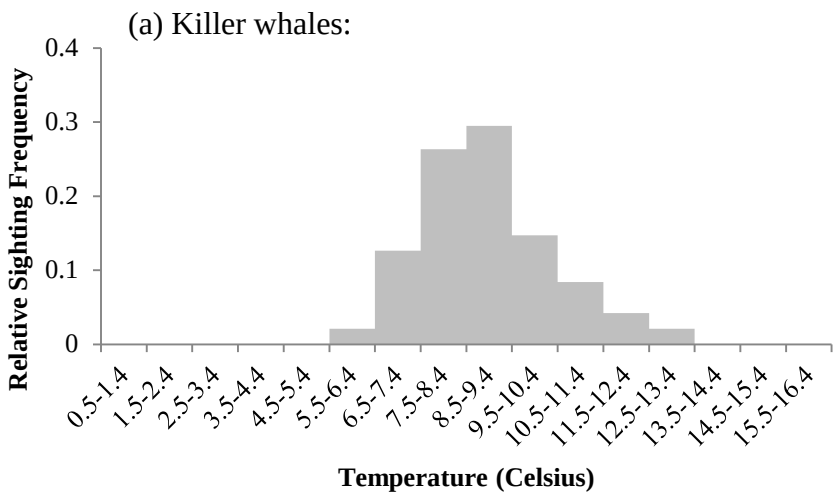


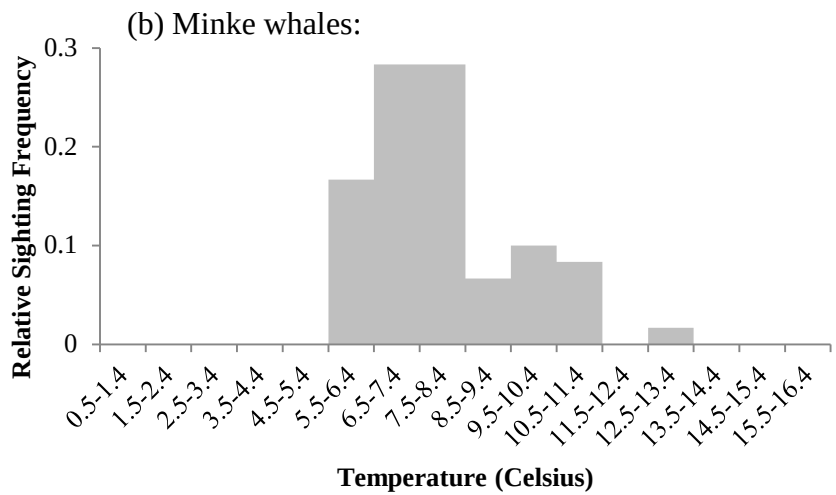
(d) Harbor porpoises:

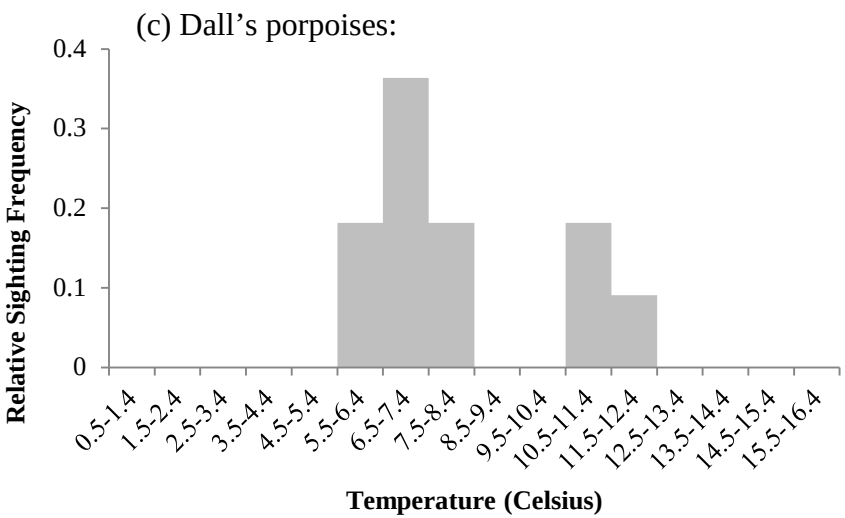


Appendix 2B

SST histograms for sightings of (a) killer whales, (b) minke whales, and (c) Dall's porpoises. Depths are from a subset of the truncated opportunistic sighting data (samples include sightings with both depth and sea surface temperature). Gray whales and pinnipeds on land did not have temperatures recorded.

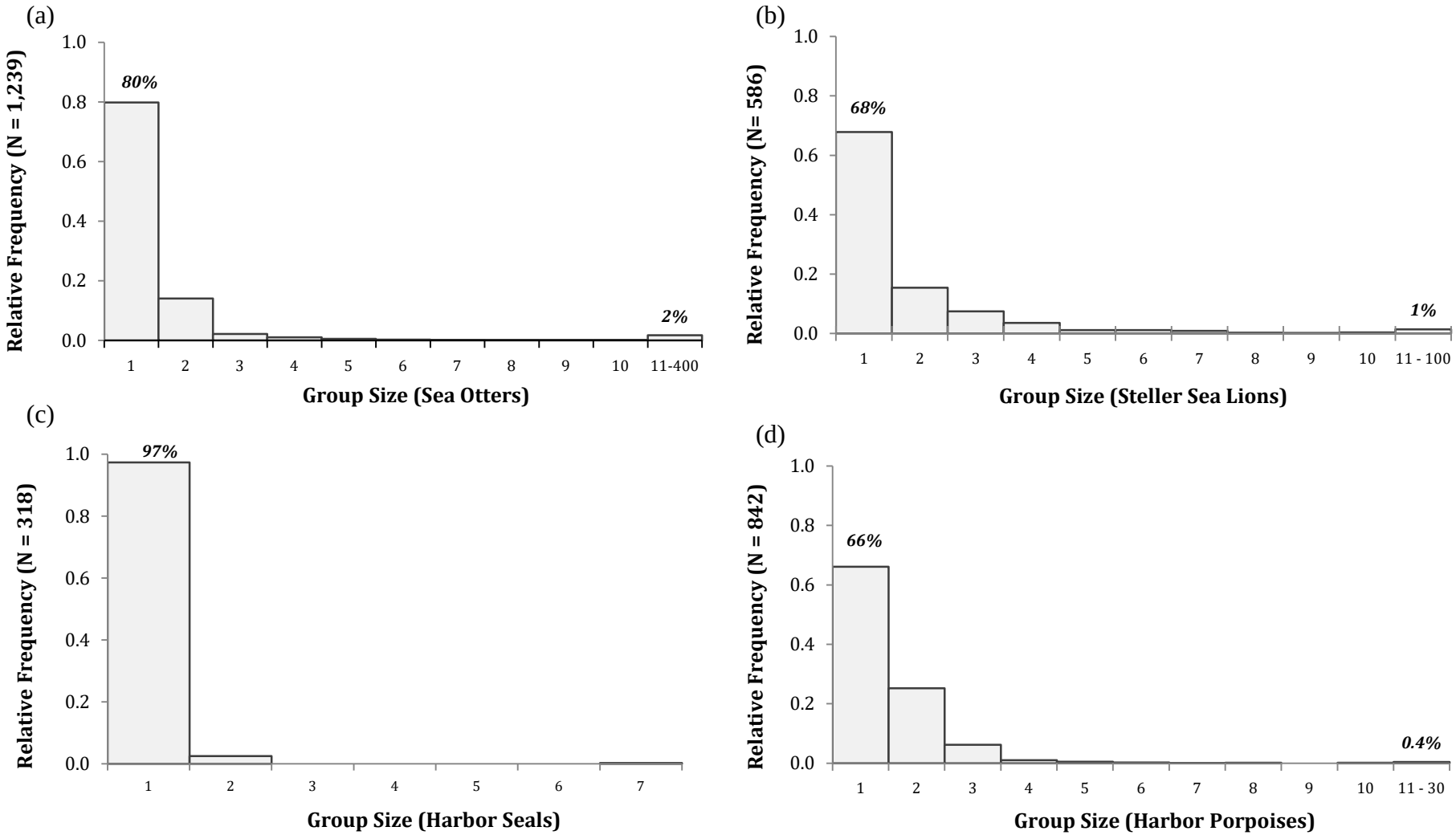






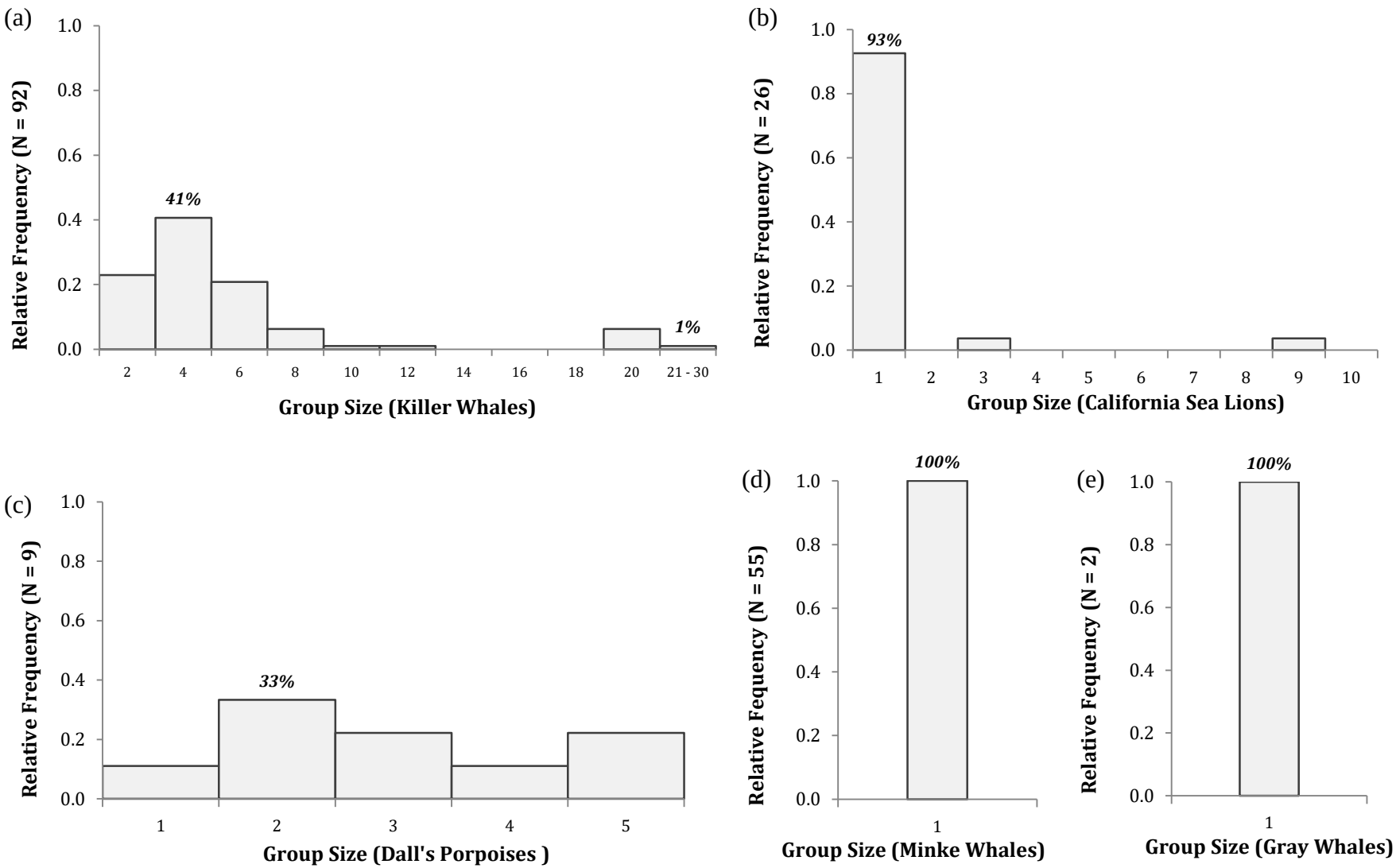
Appendix 3A

Histograms showing the distribution of group size for each species: (a) sea otters, (b) Steller sea lions, (c) harbor seals, and (d) harbor porpoises. Frequency is reported as a cumulative percent, with sample size (N) representing the number of sightings for each species. The cumulative percent of the most frequent group size of a species is shown. The cumulative percent of bins that represent a range of group sizes is also shown.



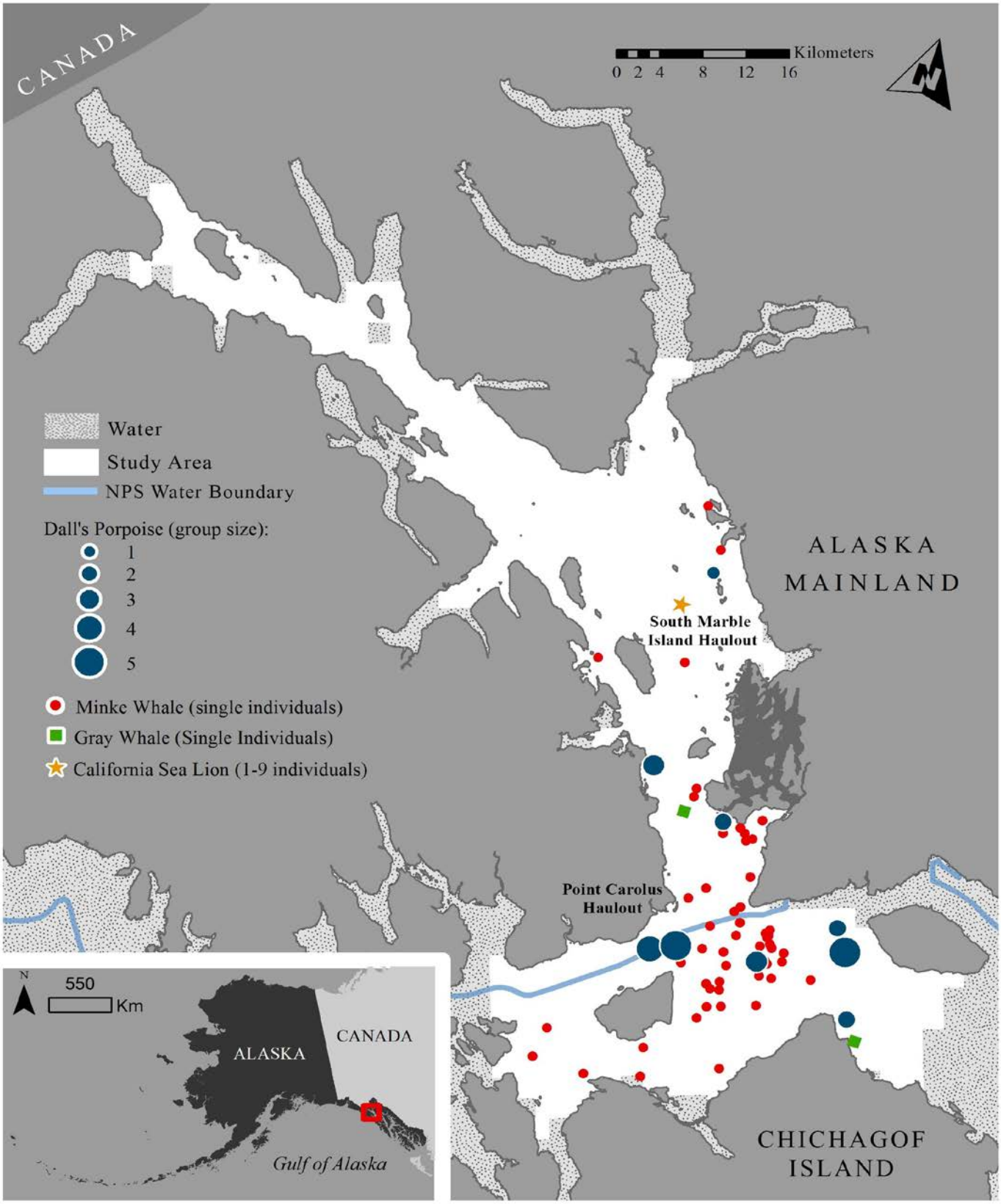
Appendix 3B

Histograms showing the group sizes of each species: (a) killer whales, (b) California sea lions, (c) Dall's porpoises, (d) minke whales, and (e) gray whales. Frequency is reported as a cumulative percent, with sample size (N) representing the number of sightings for each species. The cumulative percent of the most frequent group size of a species is shown. The cumulative percent of bins that represent a range of group sizes is also shown.



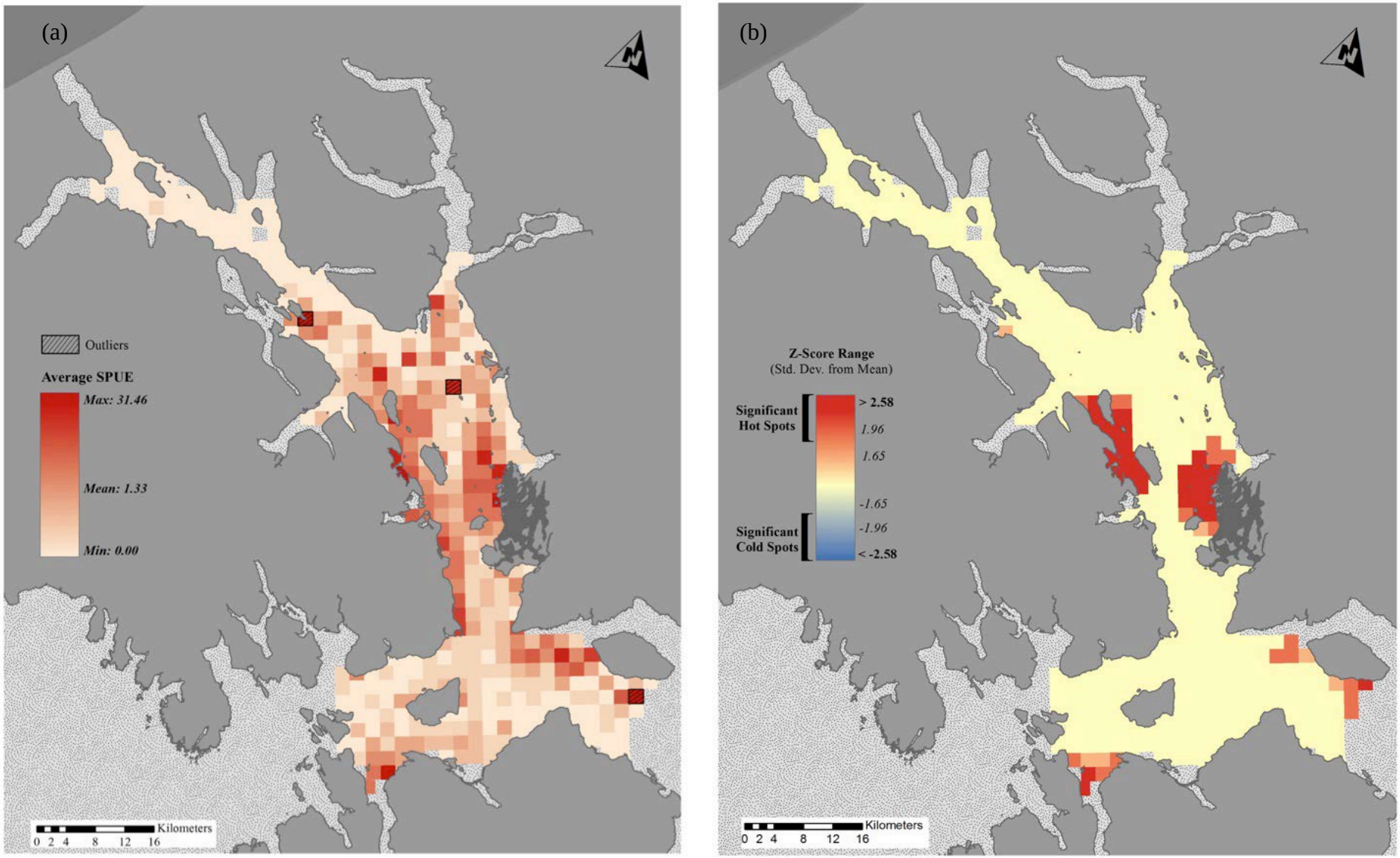
Appendix 4

Locations and numbers of individuals for uncommon species: minke whales, Dall's porpoises, California sea lions, and gray whales. Dot size corresponds with the group size for Dall's porpoises. All other species were seen alone or in one location (i.e. California sea lions at the South Marble Island Steller sea lion haulout).



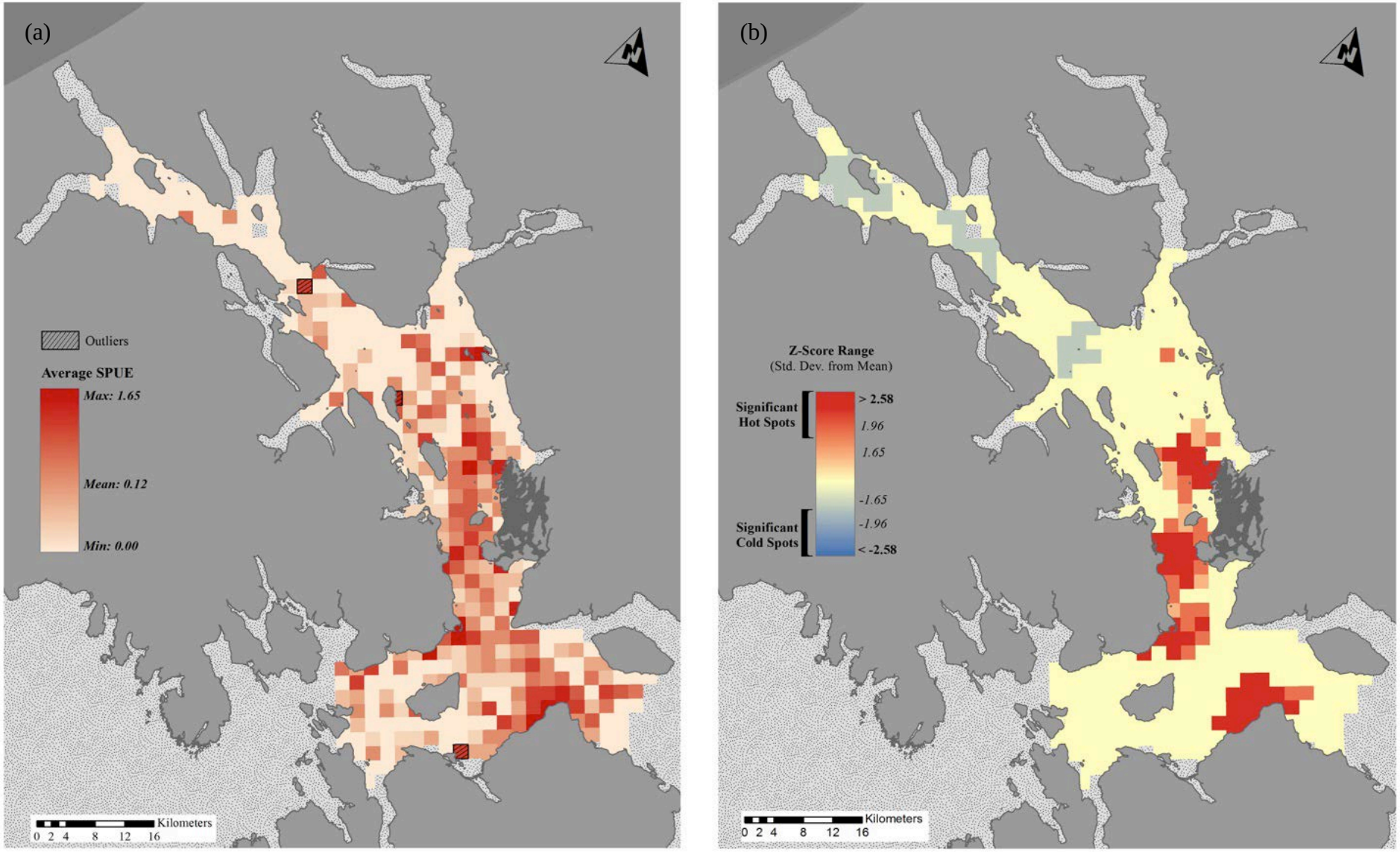
Appendix 5A

(a) *Spatial distribution of* ***sea otters*** *in the study area. Displayed SPUE^L values show the average SPUE value for each sighting unit for all years (2005-2014). Darker red units indicate a higher sighting frequency. Units identified as outliers are marked.* ***(b)*** *Hot-spot analysis of SPUE^L values. Areas where sighting frequency was statistically higher than the mean (>1.96 SD) are shown as red "hot-spots". There were no "cold-spots" identified for sea otters. In-between colors indicate areas where sighting frequency was either close to the mean SPUE^L or a relatively high/low sighting frequency was attributed to chance (an outlier).*



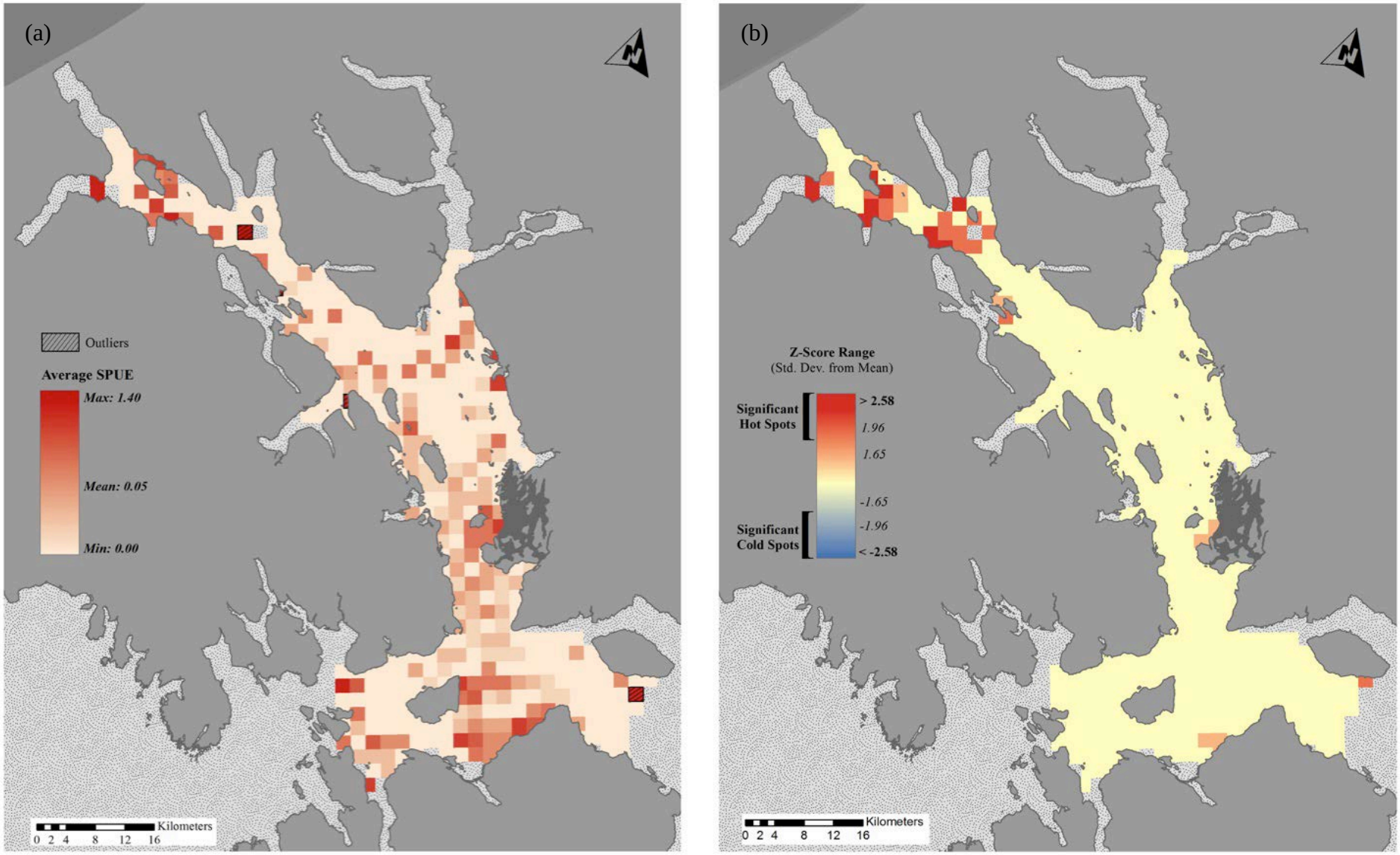
Appendix 5B

(a) *Spatial distribution of* ***Steller sea lions*** *in the study area. Displayed SPUE^L values show the average SPUE value for each sighting unit for all years (2005-2014). Darker red units indicate a higher sighting frequency. Units identified as outliers are marked.* ***(b)*** *Hot-spot analysis of SPUE^L values. Areas where sighting frequency was statistically higher than the mean (>1.96 SD) are shown as red "hot-spots". Areas where sighting frequency was statistically lower than the mean (< 1.96 SD) are shown as blue "cold spots." In-between colors indicate areas where sighting frequency was either close to the mean SPUE^L or a relatively high/low sighting frequency was attributed to chance (an outlier).*



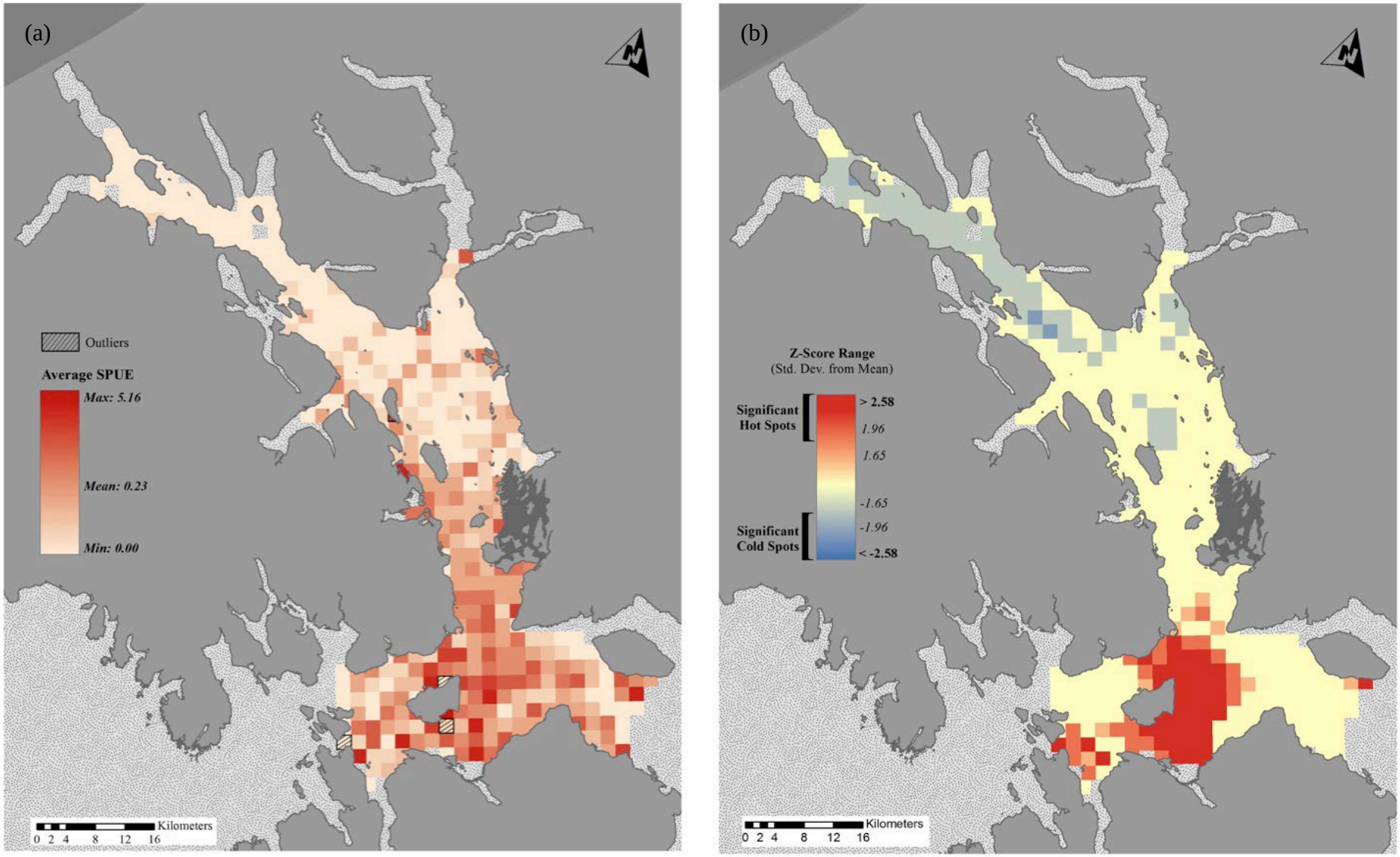
Appendix 5C

(a) *Spatial distribution of* ***harbor seals*** *in the study area. Displayed SPUE^L values show the average SPUE value for each sighting unit for all years (2005-2014). Darker red units indicate a higher sighting frequency. Units identified as outliers are marked.* ***(b)*** *Hot-spot analysis of SPUE^L values. Areas where sighting frequency was statistically higher than the mean (>1.96 SD) are shown as red "hot-spots". There were no "cold-spots" identified for sea otters. In-between colors indicate areas where sighting frequency was either close to the mean SPUE^L or a relatively high/low sighting frequency was attributed to chance (an outlier).*



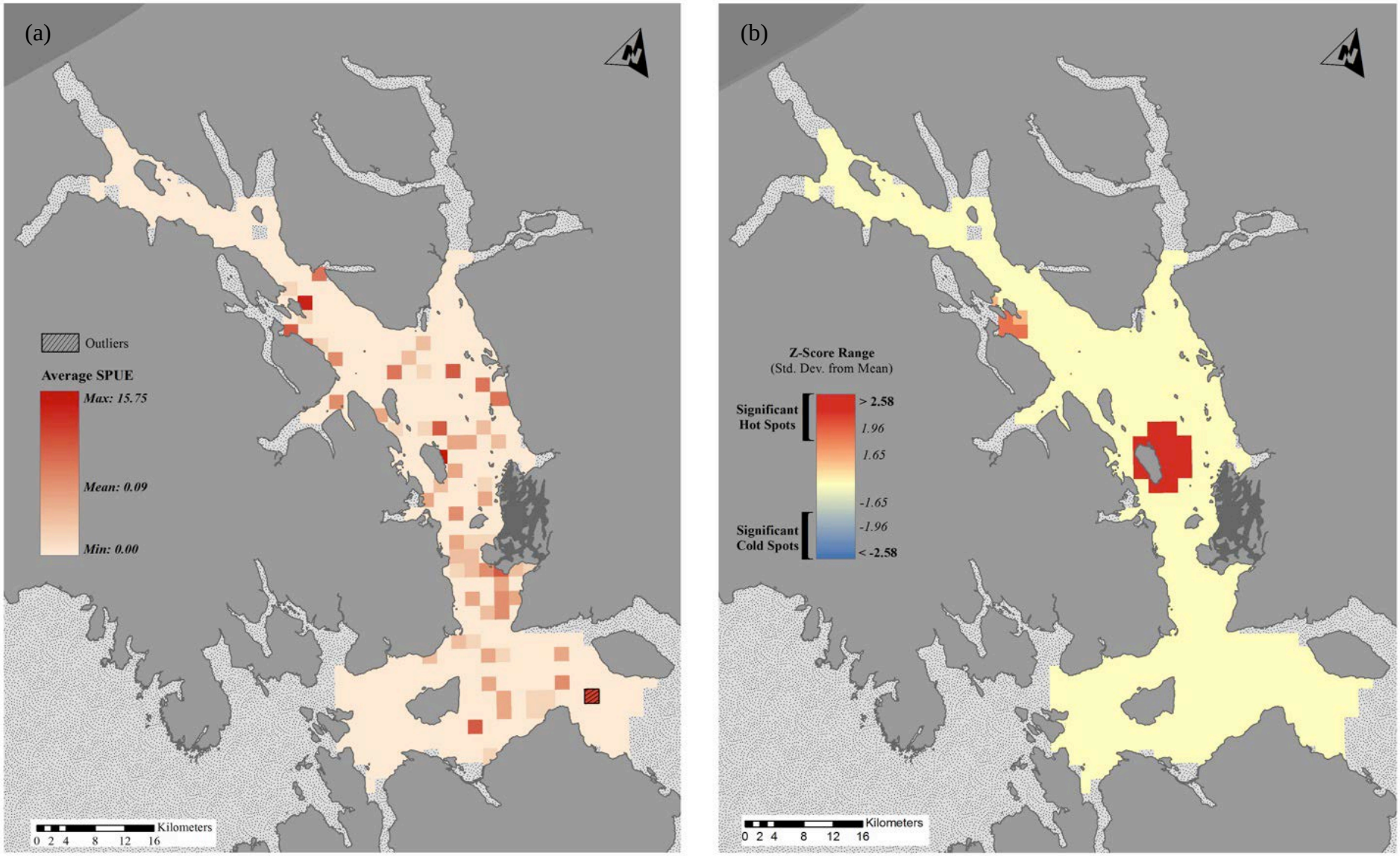
Appendix 5D

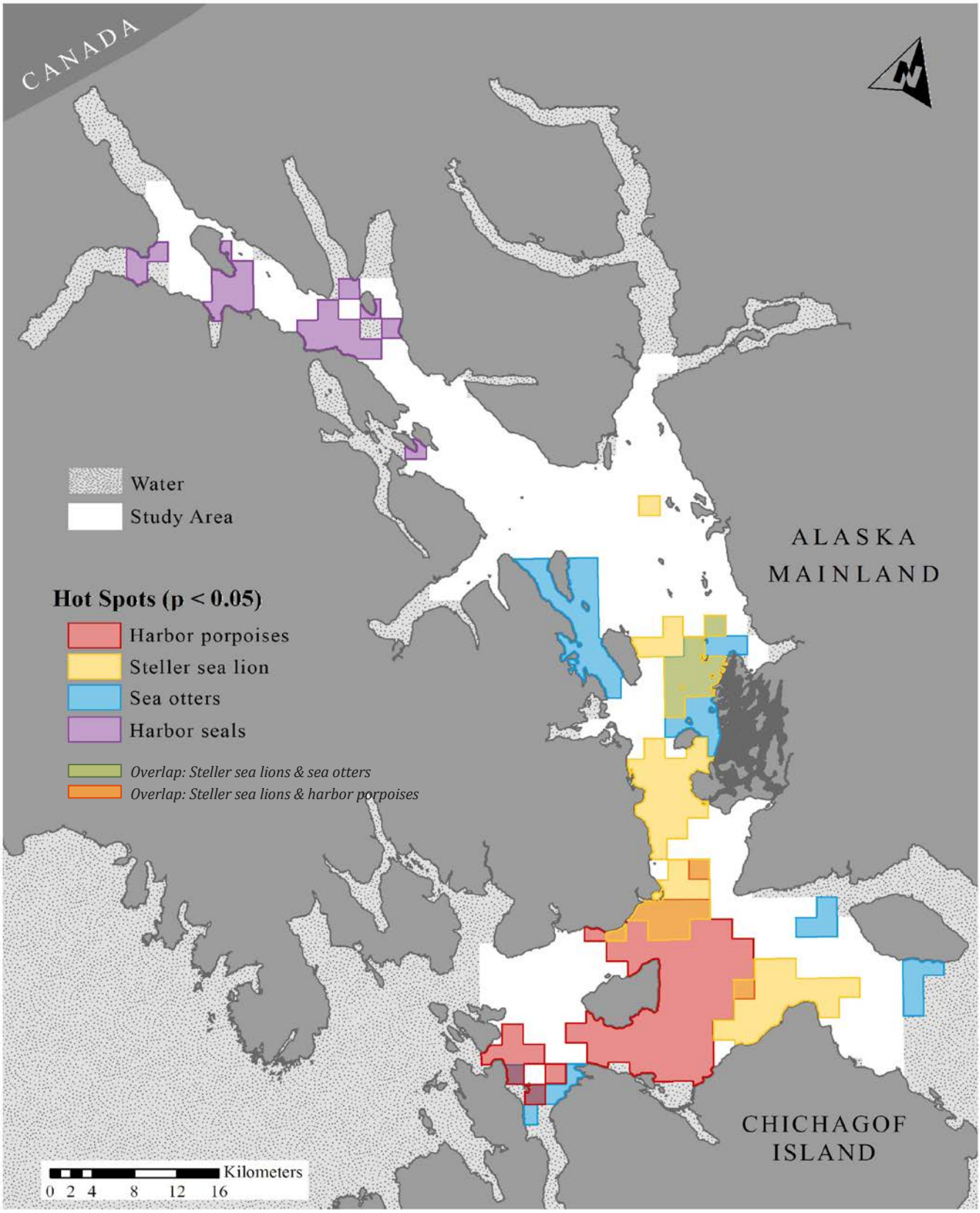
(a) *Spatial distribution of* ***harbor porpoises*** *in the study area. Displayed SPUE^L values show the average SPUE value for each sighting unit for all years (2005-2014). Darker red units indicate a higher sighting frequency. Units identified as outliers are marked.* ***(b)*** *Hot-spot analysis of SPUE^L values. Areas where sighting frequency was statistically higher than the mean (>1.96 SD) are shown as red "hot-spots". Areas where sighting frequency was statistically lower than the mean (< 1.96 SD) are shown as blue "cold spots." In-between colors indicate areas where sighting frequency was either close to the mean SPUE^L or a relatively high/low sighting frequency was attributed to chance (an outlier).*



Appendix 5E

(a) *Spatial distribution of* ***killer whales*** *in the study area. Displayed SPUE^L values show the average SPUE value for each sighting unit for all years (2005-2014). Darker red units indicate a higher sighting frequency. Units identified as outliers are marked.* ***(b)*** *Hot-spot analysis of SPUE^L values. Areas where sighting frequency was statistically higher than the mean (>1.96 SD) are shown as red "hot-spots". There were no "cold-spots" identified for sea otters. In-between colors indicate areas where sighting frequency was either close to the mean SPUE^L or a relatively high/low sighting frequency was attributed to chance (an outlier).*



Appendix 6

Superimposed hot-spots of sea otters, Steller sea lions, harbor seals, and harbor porpoises. The lack of overlap among identified hot-spots for each species suggests habitat partitioning. The greatest areas of hot-spot overlap are between sea otters and Steller sea lions by the Beardslee Islands (green on the map) and Steller sea lions and harbor porpoises by Point Carolus (orange on the map).