COMPARISON OF AERIAL AND AT-SEA SURVEY METHODS FOR ESTIMATING ABUNDANCE AND DISTRIBUTION OF MARBLED MURRELETS AND OTHER MARINE BIRDS AND MAMMALS

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PROJECT SUMMARY

The use of aerial surveys is the primary method for assessing risk to marine birds and mammals from oil spills and for providing data for natural resource damage assessment. Relatively little information is available, however, on the accuracy of density estimates from aerial surveys and potential differences between such estimates from aerial and boat-based surveys. To address those issues, we conducted simultaneous aerial and boat-based surveys of marine birds and mammals, with a special emphasis on the Marbled Murrelet (*Brachyramphus marmoratus*), a small threatened seabird. We surveyed 45 8-km transects off Santa Cruz, California, over six days during the winter of 2005/2006. We found that density estimates of Western/Clark's Grebes (*Aechmophorus occidentalis/clarkii*) and all loons combined were significantly greater based on aerial surveys and that species richness per transect was significantly greater based on boat-based surveys. Density estimates for Marbled Murrelets from the two platforms were nearly identical, and there was no statistical difference between density estimates by platform for all birds combined or for other individual species. These results indicate that aerial surveys can provide accurate density estimates for Marbled Murrelets, and that for most species, density estimates from aerial surveys and boat-based surveys are comparable. However, for some species, boat avoidance may lead to biased density estimates from boat-based surveys. This study also provided important information on the winter distribution and abundance of Marbled Murrelets in the Monterey Bay area.

INTRODUCTION

At-sea (boat-based) surveys for marine birds and mammals have been used since the early 20th century to assess abundance and distribution patterns (Tasker et al. 1984). These surveys have an advantage over aerial surveys in that observers have more time to identify animals and data on biological and physical characteristics of the ocean can be collected concurrently. Aerial surveying, however, is an effective tool for surveying marine birds and mammals over large areas in a short amount of time. Aerial surveys have been used consistently for several decades to monitor marine bird and mammal distribution and abundance on the California continental shelf (e.g., Gebel and Miller 1984, Briggs et al. 1985a & 1985b, Dohl et al. 1986, Bonnell and Ford 1987, Briggs et al. 1987, Forney et al. 1995, Bonnell and Ford 2001, Lowry and Forney 2005). Aerial surveys are typically used in the event of oil spills to quickly assess resources at risk (RAR) and subsequently provide information for natural resources damage assessment (NRDA; Tyler et al. 2002).

Several previous studies have compared density estimates of birds and mammals from aerial and at-sea surveys. Briggs et al. (1985b) compared density estimates of seabirds from simultaneous aerial and ship-based surveys and found that densities from aerial surveys were three to four times greater than those from ship-based surveys. Additional comparisons conducted on a regional scale, using data from surveys that were not conducted simultaneously, revealed no significant difference between density estimates from the two platforms. More recently, Ford et al. (2004) compared density estimates of Common Murres (*Uria aalge*) and phalaropes (*Phalaropus* spp.) from aerial and boat-based surveys off central California, conducted during the same season but on different days. Density of Common Murres was similar between survey platforms; density of phalaropes was greater from aerial surveys. For both taxa, zero counts within 10’ x 10’ (degrees latitude/longitude) cells were more common on boat-based surveys, and aerial surveys detected more large flocks of phalaropes. Both of these studies indicate that while density estimates derived from the two different methods may vary, the differences between the density estimates on a regional scale may be small relative to variability from other sources, such as season or location. Piatt et al. (1991) similarly compared data from simultaneous aerial and boat-based surveys for Marbled Murrelets (*Brachyramphus marmoratus*) in Southeast Alaska and found no statistical difference between density estimates based on the two techniques.

In contrast to these studies, Nysewander et al. (2005) conducted several studies using simultaneous aerial and boat-based surveys in Puget Sound and found that for most species aerial surveys resulted in density estimates less than 50% of those from boat-based surveys (although aerial density estimates for sea ducks were proportionally higher than for other species). Marbled Murrelet densities based on aerial surveys conducted during summer months were less than 40% of density estimates from boat-based surveys. These results were similar to other studies comparing aerial and boat-based surveys for waterfowl, in which aerial surveys resulted in lower density estimates (Stott and Olson 1972, Conant et al. 1988).
Few data are available comparing marine mammal density estimates using aerial and boat-based surveys, but Bodkin and Udevitz (1999) compared aerial surveys of sea otters (*Enhydra lutris*) with shore-based counts and found that aerial strip transects detected 0.52 – 0.72 of the otters detected from shore.

The Marbled Murrelet is a small seabird that is federally-listed as Threatened south of Alaska and state-listed as Endangered in California. Marbled Murrelets breed in mature forests from the Alaska Peninsula south to the Santa Cruz Mountains in central California. At-sea, birds can occur regularly as far south as San Luis Obispo County, although the winter distribution of the species has not been well studied (Peery et al. in review). Population declines of Marbled Murrelets over the last several decades are thought to be due primarily to loss of suitable breeding habitat, but populations have also been negatively impacted by gill-netting and oil spills (Nelson 1997, McShane et al. 2004). An estimated 8,400 Marbled Murrelets were killed in the *Exxon Valdez* oil spill in Alaska, and the 1984 *Puerto Rican* and 1986 *Apex Houston* spills resulted in significant mortality of Marbled Murrelets in California (Carter and Kuletz 1995). More recently, Marbled Murrelets were impacted by the *New Carissa* spill in Oregon and the *Kure* and *Styvuysent* spills in California. Because of consistently declining populations, Marbled Murrelets are of extremely high concern to agencies and others involved in oil spill response, NRDA, and restoration.

Population estimates of Marbled Murrelets have traditionally been based primarily on data from at-sea surveys conducted nearshore during the breeding season (May through September). Considerable effort has been spent to determine the most precise methods for estimating abundance with boat-based surveys (Ralph and Miller 1995, Strong et al. 1995, Becker et al. 1997, Mack et al. 2002, Rachowicz et al. 2006). These studies have shown that Marbled Murrelets are typically found in highest densities between 400 m and 1500 m from shore but can sometimes occur more than 2 km from shore. The Marbled Murrelet technical committee of the Pacific Seabird Group is currently in the process of refining at-sea survey methods. The current protocol for at-sea surveys within the area covered in the Northwest Forest Plan (Washington to Northern California) calls for line transects to be conducted in 4 km lengths at random distances from shore, between 400 m and 2 km from shore. Rachowicz et al. (2006) found that both this scenario and zig-zag surveys from 500 m to 1500 m offshore resulted in high power to detect population declines. Line transects use distance sampling, in which distance to each sighting from the track line is estimated, and models are developed using DISTANCE software (Buckland et al. 1993) to generate more precise density estimates.

Marbled Murrelets, which are among the smallest diving birds off California, may be difficult to detect from a fast-moving plane, particularly if viewing conditions are less than ideal. Few studies have attempted to assess the accuracy of aerial surveys for Marbled Murrelets. Varoujean and Williams (1995) conducted a cursory test of aerial survey methods using murrelet decoys on flat water. They found that observers on the non-glare side of the plane missed 9-30% of the decoys, but there were problems in the layout of the trials, and density was substantially greater than that expected in nature. As noted above, Piatt et al. (1991) found no difference between density estimates from boat-based and aerial surveys conducted during the breeding season in Southeast Alaska.

Because aerial surveys are used extensively during oil spills, it is important to assess the accuracy of density estimates generated from aerial surveys, particularly for species of concern, such as the Marbled Murrelet. In this study, our primary objective was to assess the effectiveness of aerial surveys for Marbled Murrelets and other marine birds and mammals.

METHODS

Survey Methods

Aerial and at-sea surveys were conducted on six days during winter 2005/2006 in Monterey Bay, California. Surveys were conducted on 6 December 2005 and 17 January, 24 January, 8 February, 21 February, and 8 March 2006. Wind conditions ranged from Beaufort 0 (calm) to Beaufort 3 (small whitecaps forming).

On each survey day, simultaneous aerial and boat-based surveys were conducted. Several different 8-km long transects were surveyed parallel to shore in northern Monterey Bay, California, spaced at 200 m intervals (Fig. 1). Transects surveyed varied by day and survey platform; the aerial survey team surveyed all transects surveyed by the boat-based team plus several additional transects each day (Fig. 1 & 2). The aerial team also conducted several ad-hoc surveys extending farther offshore to assess the offshore extent of Marbled Murrelet occurrence.

For aerial surveys, a Partennavia Observer aircraft was used, flown at a speed of 145 km/hr (90 kts) and an altitude of 60 m (200 ft). Trained observers on either side of the plane conducted strip transect surveys, recording all sightings of Marbled Murrelets and other marine birds and mammals within 75 m, for a combined strip width of 150 m. Because the strip directly under the plane was not surveyed, the total width of the area surveyed was >200 m, considerably wider than the area surveyed from the boat (see below). Observers each had > 2 years experience estimating a 75 m transect at this altitude. Each observer calibrated his or her strip width estimate using a clinometer. Time-referenced sighting data for all bird and mammal species were recorded on hand-held recorders.

Boat-based surveys were conducted from a 9 m (30 ft) boat, the *R/V Sheila B.* Two observers sat on an observation platform with eye-level approximately 3.5 m off the water. Trained observers conducted line transects for Marbled Murrelets and harbor porpoises (*Phocoena phocoena*). Perpendicular distance off the trackline was estimated visually. Before each survey, surveyors calibrated distance estimation using a laser rangefinder on objects (e.g., buoys) at a variety of distances. All other birds and mammals were recorded within a 100-m strip transect (50 m on either side of the boat). Time-referenced sighting data were recorded on hand-held recorders.

Data Processing and Analyses

Aircraft and boat position and time were recorded using GPS units linked to onboard computers running dLOG software (Ford 1999). dLOG records times and positions at user-defined intervals (e.g., 5 s) and provides an instantaneous display of aircraft/boat position relative to the coastline and other geographic or biological features. Transects were programmed into dLOG prior to surveys to assist with navigation. The position of animal sightings was estimated by interpolation, assuming straight transects at a constant speed over each 5-second interval. Survey data were processed and placed in a standard format compatible with CDAS (Bonnell and Ford 2001), ArcView, and other GIS mapping software.

For each transect, densities of each species of bird and mammal were estimated from aerial and boat-based surveys. For strip surveys (aerial surveys and boat-based surveys for most species), density was estimated as the number of animals multiplied by the area surveyed (e.g., 8 km x 100 m strip width = 0.8 km^2). No compensation was made for potential bias associated with counting birds in flight (Spear et al. 1992). For boat-based surveys, densities of Marbled Murrelets and harbor porpoises were estimated using DISTANCE 5.0 software (Buckland et al. 1993). Using this program, we tested a variety of curves to model the decrease in detectability with increasing distance and chose the model with the best fit based on the lowest Akakike's Information Criterion (AIC) value. DISTANCE 5.0 uses this curve to determine the effective strip width (ESW). All missed detections inside the ESW equal the number of observed detections outside the ESW, meaning that density estimates using all observed data, and a sample area based on the ESW, represent 100% actual density (based on 100% detectibility on the track line). For optimal accuracy with boat-based data, we developed two density models for Marbled Murrelets based on viewing conditions (fair/good, or very good/excellent), and the model providing the lowest AIC value for each category was chosen for surveys with that viewing condition.

For density estimates using distance sampling, data were truncated at 100 m and binned into five categories (0-20 m, 20-40 m, etc.). Density estimates for Marbled Murrelets under fair/good conditions were based on a uniform curve with one cosine adjustment (n = 84 sightings; Fig. 3). Effective strip width (ESW) was 67.8 m (95% CI = 55.9-89.2 m). Under very good/excellent conditions, density estimates for Marbled Murrelets were based on a hazard-rate curve with one cosine adjustment (n = 128; Fig. 3). ESW was 86.2 m (95% CI = 76.8-96.7 m). Density estimates for harbor porpoises were based on a uniform distribution with one cosine adjustment (n = 52; Fig. 3). Because of the relatively low number of sightings, density estimates for harbor porpoises were not estimated separately based on viewing conditions. ESW was 65.9 m (95% CI = 52.1-83.4 m).

For comparisons of the two survey methods, 45 individual samples of paired surveys were available (although for comparisons, surveys on which zero animals were detected on both surveys were not used). To test for effects of platform and viewing conditions, factorial analysis of variance (ANOVA) tests were used, with date and platform (as well as the interaction of date and platform) as the independent variables. These tests were conducted on density estimates for Marbled Murrelets, density estimates for all birds, and species richness (the number of species recorded per transect). Density estimates from aerial surveys were generated independently using all data from both observers (regardless of glare conditions) and data only from observers with less than 30% glare (typically only one side of the plane). Data were tested for normality using the Kolmogorov-Smirnov test. For analyses that included aerial surveys for Marbled Murrelets including the glare side of the plane, data were log transformed to achieve normality. Variances were not always equal, but ANOVA is robust with respect to heteroscedastity.

For seven other of the most abundant taxa observed, data were not always sufficient to conduct analysis by date and platform (e.g., that taxa was not observed on a given date). In addition, variances were not equal for most data sets. For these taxa, non-parametric randomization tests were used to compare density estimates from paired boat-based surveys and aerial surveys. Randomizations were run 10,000 times in which the two data sets were combined and shuffled and re-assigned to two random data sets; each time the sum of the differences between paired surveys was calculated. Sums of differences between actual data sets were considered significantly different if they were greater than or less than 2.5% of the random differences (2-tailed alpha = 0.05). Again, density estimates from all aerial data as well as data excluding the sunny side of the plane were used.

In addition, regressions were run of density estimates from aerial data against boat-based data. Quadratic regressions were calculated using the Marquardt-Levenberg algorithm (Marquardt 1963) as implemented in SigmaPlot 10.0.0.54. Results of the quadratic regression analysis should be interpreted with care since datasets for most species did not meet the regression criteria of normality and constant variance (Table 1).

RESULTS

Comparisons Among Survey Platforms

For all multifactor analyses, there were no significant interactions of date and platform (Table 1). This indicates that variable viewing conditions on different dates did not affect the relative differences between density estimates from the two platforms. As noted above, most species did not meet the criteria of normality and constant variance for parametric tests. For the two taxa that met these criteria, BRCO and all loons (LOON), the regressions were not significant (Table 1). Significance of the other regressions should be viewed with caution.

All Birds

There were no significant differences in density estimates by platform type or by day for all birds combined (Table 1; Figure 4). However, based on the regression analysis, aerial surveys resulted in substantially greater density estimates, particularly when higher numbers of birds were involved (Figure 9). Many transects had densities of less 50 birds/km^2 recorded from either platform. If aerial and boat-based surveys resulted in similar density estimates, we would expect a 1:1 correspondence of data (as indicated by red dashed lines on Figures 9-12). At low densities (>50), the 95% confidence interval encompassed the expected 1:1 ratio. However, at higher densities, density estimates from aerial surveys were more than three times greater than those from boat surveys.

Species Richness

Species richness (the number of individual species or taxa identified on each survey) was significantly greater on boat-based surveys than on aerial surveys with data from the glare side of the plane excluded (Table 1, Figure 5). There was no significant difference between platforms when all aerial data were used. The difference between platforms was expected, given the greater amount of time available to observers on the boat to identify individual birds, and the ability to use binoculars if needed. There was also a difference in richness among dates.

Marbled Murrelet

For Marbled Murrelet, there were no significant differences in density estimates by platform type or by day (Table 1; Figure 4). The regression analysis indicated that density estimates from aerial and boat-based surveys were very similar (Figure 9). Marbled Murrelet, in fact, was the only species for which the expected 1:1 ratio of air to boat surveys fell entirely within the 95% confidence intervals for the observed regression.

Gulls

Gulls included (in order of abundance) California Gull (*Larus californicus*), Western Gull (*Larus occidentalis*), Bonaparte's Gull (*Larus philadelphia*), Heermann's Gull (*Larus heermanni*), Mew Gull (*Larus canus*), Glaucous-winged Gull (*Laurus glaucescens*), Herring Gull (*Larus argentatus*), Black-legged Kittiwake (*Rissa tridactyla*), Thayer's Gull (*Larus thayeri*), Ring-billed Gull (*Larus delawarensis*), and unidentified gulls. For all gulls combined, density estimates from aerial surveys did not differ significantly from boat-based surveys (Table 2, Figure 5). However, density estimates from all aerial surveys were very close to being significantly greater than boat-based surveys (Table 2). As with all birds combined, the regression for gull densities from aerial and boat-based surveys indicated that at densities greater than about 20 birds/km^2, aerial surveys recorded substantially greater densities (Figure 10). Overall, aerial surveys resulted in densities approximately three times greater than those from boat-based surveys.

Western/Clark's Grebe

Because of difficulties involved in identifying these species from a moving platform, data for Western Grebes (*Aechmophorus occidentalis*) and Clark's Grebes (*A. clarkii*) were combined. Density estimates from aerial surveys were significantly greater than those from boat-based surveys (Table 2; Figure 6). Similarly, regression analysis showed that the expected 1:1 ratio of aerial and boat-based densities overlapped with 95% confidence intervals for the observed ratio only at very low densities (Figure 10). The shape of the curve for observed data suggest a decline in densities from aerial surveys when high numbers of grebes occurred, but this decline is based on a single data point and therefore not likely to represent a real trend.

Brandt's Cormorant

Density estimates for Brandt's Cormorant (*Phalacrocorax penicillatus*) did not differ significantly between platforms (Table 2; Figure 6). However, density estimates from aerial surveys in which data from the glare side of the plane were excluded were very close to being significantly less than density estimates from boat-based surveys (Table 2). Regression analysis also indicated that boat-based surveys resulted in greater densities than aerial surveys (Figure 11). The expected 1:1 ratio is encompassed with the 95% confidence interval for observed data only at densities less than 4 birds/km^2. There is considerable dispersion of the observed data for this species, resulting in larger confidence intervals. Based on this dispersion, the shape of the trendline for the observed data should be viewed with skepticism.

Surf Scoter

Density estimates for Surf Scoter (*Melanitta perspicillata*) did not differ significantly between platforms (Table 2; Figure 7). Regression analysis indicated that boat-based surveys resulted in greater densities than aerial surveys, but the data are too variable to draw concrete conclusions about this relationship (Figure 11).

Loons

Loons included Pacific Loon (*Gavia pacifica*), Common Loon (*G. immer*), and Red-throated Loon (*G. stellata*). Density estimates from boat-based surveys were significantly less than those from aerial surveys in which data from the glare side of the plane were excluded (Table 2; Figure 7). Regression analysis indicated that aerial survey density estimates were quite similar to those from boat-based surveys (Figure 11). The expected 1:1 ratio fell within 95% confidence intervals at densities greater than 2 birds/km^2. However, the data are again highly variable, and this relationship should be viewed with caution.

Sea Otter

Density estimates for sea otter (*Enhydra lutris*) did not differ significantly by survey platform (Table 2; Figure 8). Regression analysis indicated that boat-based surveys detected more sea otters than aerial surveys at higher densities (Figure 12), but the lack of correspondence between ship and air density estimates limits the strength of this relationship.

Harbor Porpoise

There was no significant difference between densities from either type of boat-based survey and either type of aerial survey (Table 2; Figure 7). Density estimates from aerial surveys in which all data, regardless of glare, were used, were more than three times greater than estimates from standard aerial surveys, but this difference was not significant (t-test; $P = 0.35$; Figure 8). Regression analysis indicated that boat-based surveys detected more harbor porpoises than aerial surveys, but this trend is based heavily on one survey with high densities from both platforms. The distance detection function (Figure 3) indicated potential boat avoidance by this species, based on the lower than expected detection at less than 20 m.

Marbled Murrelet Abundance

The main focus of this study was to compare density estimates for Marbled Murrelets and other birds and mammals from aerial and boat-based surveys. However, valuable new data were collected on Marbled Murrelet distribution and abundance in the study area. Abundance of Marbled Murrelets in the area off Santa Cruz was greater than we expected. Extrapolating densities from aerial surveys (using all data, regardless of glare) to generate abundance estimates for the survey area off Santa Cruz (from 200 m to 4 km offshore), we estimated a maximum daily abundance of 275 Marbled Murrelets (Table 3). This does not include additional birds in the eastern portion of the study area. In addition to occurring in unusually high densities, Marbled Murrelets in this area occurred farther offshore than we expected, up to 4 km from shore (Figure 13).

DISCUSSSION

Survey Methodology

Density estimates for most species, including Marbled Murrelet, were not significantly different based on aerial or boat-based survey data. The tight correspondence between Marbled Murrelet density estimates from the two platforms is likely due to 1) the use of line transect methodology on boat-based surveys for this species, and 2) the relatively even distribution of this species in the study area. Line transect methods provided accurate density estimates from boat-based surveys. Strip transects were used for other bird species, potentially resulting in biased density estimates if birds were missed in the outer portion of the transect strip (density estimates would be lower than they should be; Becker et al. 1997). Compared to other bird species, Marbled Murrelets were relatively evenly distributed throughout the study area in small groups, typically pairs. For species that occurred in larger flocks, such as grebes and gulls, the movement of flocks into or out of the study area between paired surveys probably affected the correspondence of density estimates for these species from the two platforms. In addition, very large flocks of some species required estimation of numbers of birds on-transect rather than direct counts.

Our results for Marbled Murrelet are consistent with those of Piatt et al. (1991), who also found no significant difference between density estimates for Marbled Murrelets from aerial and boat-based surveys. Their methods varied slightly from ours: they conducted their study during the breeding season, when birds were in alternate brown plumage, which could have affected visibility of birds from both boat and plane, and they conducted their aerial surveys at an altitude of only 35 m, with a combined strip width of 200 m, potentially resulting in missed birds from the margins of the aerial survey. Both that study and ours were conducted in fairly calm water (primarily less than Beaufort 3). Both aerial surveys and boat-based surveys may fail to detect some Marbled Murrelets in more severe weather. These studies indicate that aerial and boat-based surveys for Marbled Murrelets are comparable both during the breeding season and during winter. Visibility of juvenile Marbled Murrelets is likely to be similar to adults in winter, based on similar plumage, but it is not known how behavior of juveniles might affect detectibility. For example, juveniles could respond to boats more than to planes, biasing boat-based surveys but not aerial surveys. Because annual productivity estimates based on boat-based surveys are important in determining population trends for this species, this topic may deserve further investigation. Our results contrast with those of Nysewander et al. (2005), who found that aerial surveys detected less than 40% of the Marbled Murrelets observed on boat-based surveys. Their methods were similar to ours, although boat-based surveys used a 200 m strip width, and they used a Beaver aircraft that was considerably louder than the Partenavia that we used. It is not clear why densities in that study were consistently lower based on aerial surveys than on boat-based surveys, although the louder aircraft may have resulted in aircraft avoidance.

Our study indicated that there was little difference between density estimates generated from boat-based strip transects and boat-based line transects or between estimates from aerial strip surveys using the full 150 m strip regardless of glare and aerial strip transects using data only from the 75 m strip on the non-glare side of the plane. Becker et al. (1997) found that density estimates based on line transects from boats were significantly greater than concurrent 100 m strip transects from boats. The lack of a significant difference in density estimates between line transects and strip transects in our study indicates that few Marbled Murrelets within 50 m of the boat (for a combined 100 m strip transect) were missed, whereas Becker et al. (1997) apparently missed some detections within this strip. This difference can be explained by the higher viewing platform we used, potentially calmer viewing conditions (their study was in the more exposed Año Nuevo Bay), or the brighter basic plumage of the birds during winter (their study was conducted during summer, when Marbled Murrelets are brown).

Density estimates from aerial surveys were significantly greater than those from boat-based surveys for Western/Clark's Grebe, and loons. In addition, regression analyses indicated that for all birds combined and for all gulls combined, density estimates from aerial surveys were greater than those from boat-based surveys when abundance of these birds was greater (for other species, regression data were too variable to draw firm conclusions). These results are consistent with those of Briggs et al. (1985b), who reported higher density estimates from aerial surveys than from boat-based surveys, and Ford et al. (2004), who found that aerial surveys detected more large flocks of phalaropes than did boat-based surveys. The discrepancy between density estimates from the two platforms could be due to: 1) differences in observation skills of individual observers, 2) incorrect estimation of strip corridor width, 3) incorrect estimation of flock size of large flocks, 4) different behavioral responses of birds and mammals to the two platforms, or 5) better visibility of animals from the air than from the water. We hypothesize that the first three explanations are not valid. Other researchers have noted individual observer bias in seabird surveys (Van der Meer and Camphuysen 1996, Mack et al. 2002, Spear et al. 2004), but observer configuration varied by survey in our study. All observers were well trained in survey techniques, and the trend toward greater density estimates from aerial surveys was not consistent among species. In addition, it is not likely that movement of animals into or out of a transect between surveys is responsible for this difference since this movement would not result in a consistent trend of greater abundance from one platform over the other.

We hypothesize that the observed differences were based on avoidance of the boat or different detectibility from the two platforms (e.g., based on plumage characteristics from above rather than from an oblique angle). Because of the high speed of the aerial surveys, birds and mammals generally have very little time to react to the approaching plane. In contrast, animals may avoid a relatively slow moving boat. We observed loons taking off from the water several hundred meters in advance of the approaching boat, and grebes often dove in response to the boat. Briggs et al. (1985b) also noted loons avoiding the research boat. Although we had slightly higher density estimates for sea otters from boat-based surveys, Udevitz et al. (1995) found that otters avoided boat-based surveys, affecting density estimates from boats. Similarly, our detection function for harbor porpoise (Figure 3) indicated possible boat avoidance by this species. For diving animals, there is also the possibility that animals would not be detected during normal foraging dives (Laake et al. 1997, Slooten et al. 2004, Lowry and Forney 2005). This potential bias could explain our observed but non-significant trend toward greater densities for marine mammals from the boat than from the plan, since aerial observers had much less time in which to make observations at a given location.

While we expected to be able to "correct" aerial survey estimates for Marbled Murrelets based on "true" density derived from boat-based distance sampling, this study suggests that surveys from these two platforms result in very similar density estimates, and no correction is needed. For Western/Clark's Grebe and loons, however, aerial surveys appear to be more accurate than boat-based surveys, probably due to boat avoidance by these species. Results for all birds combined and for all gulls indicate that further testing is warranted to determine the effect of flock size on density estimates from both platforms. Although more data would be required to develop correction factors for boat-based surveys or aerial surveys, this study indicates that for some species, these corrections would be based on non-linear relationships.

It should be noted that the density estimates from boat-based surveys may vary based on survey platform and transect width, and the relationships we observed between density estimates from the two platforms may not apply in other situations. The boat used in this study is of a size not typically used for surveys of marine birds. Smaller skiffs are often used for Marbled Murrelet surveys, and pelagic surveys are often conducted from much larger research vessels, with considerably wider transect widths. With larger transect widths, boat avoidance may be less of an issue.

Overall, the results of this study indicate that density estimates from aerial and boat-based surveys are comparable. Although density estimates of Western/Clark's Grebes and loons were significantly greater from aerial surveys, these differences may be relatively unimportant with respect to natural variability in abundance of these species and variability of density estimates from either platform based on the clumped distribution of these species. Similarly, other researchers have assumed that the difference in density estimates from surveys conducted on different platforms may be small relative to variability based on location or day (Briggs et al. 1985b, Ford et al. 2004). Based on these results, aerial surveys are an efficient and potentially more accurate method for estimating abundance and distribution of marine animals.

Marbled Murrelet Abundance and Distribution

The area off Santa Cruz has previously been identified as an area used seasonally by Marbled Murrelets (L. Henkel unpubl. data, Peery et al. in review, Becker and Beissinger 2003), leading to our choice of that site for this study. However, we did not expect the consistently high abundances we observed here. We observed somewhat lower abundances along the sandy beaches of northern Monterey Bay than did previous researchers (Henkel 2004; Peery et al. in review); thus the greater abundance off Santa Cruz may have represented a small-scale redistribution of wintering murrelets in the Monterey Bay area. The winter of 2005/2006 was odd oceanographically, and apparent prey declines in the northeast Pacific led to unusually high mortality of other seabird species, based on beached bird studies. We do not know if the high abundance of Marbled Murrelets off Santa Cruz in this study was unusual, since this area has not been extensively surveyed in the past. If it was unusual, unfavorable oceanographic conditions off Northern California or areas farther north may have resulted in southward dispersal of murrelets from these areas to the study area. The estimated maximum abundance of 275 in the discrete northern study area is a substantial proportion of the estimated 600 murrelets in the local Santa Cruz Mountains breeding population (Peery et al. in press). We will continue to monitor the abundance and distribution of Marbled Murrelets in the area off Santa Cruz during the winter of 2006/2007, during regular seabird population aerial surveys. Additional information on both the offshore and along-shore distribution patterns of Marbled Murrelets will provide additional data to refine models testing at-sea survey effectiveness (Rachowicz et al. 2006). Our preliminary data suggest that surveys conducted at 500 m offshore would have significantly underestimated densities of Marbled Murrelets off Santa Cruz (Figure 13).

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Table 1. Results of quadratic regression analyses. P or F indicate that a given species group passed or failed the normality or constant variance tests.

Taxa	Normality	Constant Variance	Significance
MAMU	P	F	<0.0001
WEGR	F	F	<0.0001
LOON	P	P	0.9594
GULL	F	F	<0.0001
SUSC	F	P	<0.0001
BRCO	P	P	0.8974
HAPO	F	F	<0.0001
SEOT	F	F	0.0496

Table 2. Results (P values) of ANOVAs comparing density estimates and species richness from aerial and boat-based surveys. "Air No Glare" refers to estimates using data from observers with less than 30% glare. For Marbled Murrelet, boat-based surveys were used to generate density estimates from line surveys and from 100 m strip transects. Significant P values (alpha = 0.05) are shown in bold.

	Platform	Date	Date x Platform
ALL BIRDS (n = 45)			
Boat vs. Air No Glare	0.14	0.17	0.89
Boat vs. All Air	0.11	0.10	0.81
RICHNESS (n = 45)			
Boat vs. Air No Glare	**<0.001**	**0.004**	0.77
Boat vs. All Air	0.12	**0.002**	0.66
MARBLED MURRELET (n = 40)			
Line vs. Air No Glare	0.09	0.78	0.82
Line vs. All Air	0.86	0.63	0.83
Strip vs. Air No Glare	0.35	0.31	0.42
Strip vs. All Air	0.46	0.21	0.82

Table 3. Results (P values and sample size) of paired randomization tests comparing density estimates by platform. Significant differences ($P < 0.05$) are shown in bold.

Species	Platform	n	P
Gulls	Boat vs. Air No Glare	45	0.26
	Boat vs. All Air	45	0.05
Western Grebe	Boat vs. Air No Glare	34	**0.02**
	Boat vs. All Air	36	**0.01**
Brandt's Cormorant	Boat vs. Air No Glare	41	0.05
	Boat vs. All Air	43	0.15
Surf Scoter	Boat vs. Air No Glare	16	0.81
	Boat vs. All Air	16	0.90
Loons	Boat vs. Air No Glare	33	**0.04**
	Boat vs. All Air	34	0.48
Sea Otter	Boat vs. Air No Glare	24	0.13
	Boat vs. All Air	27	0.08
Harbor Porpoise	Boat Line vs. Air No Glare	11	0.73
	Boat Line vs. All Air	13	0.76
	Boat Strip vs. Air No Glare	11	0.70
	Boat Strip vs. All Air	13	0.79

Table 4. Counts and estimated density and abundance of Marbled Murrelets in northern Monterey Bay. Data are from northern survey lines plus additional ad-hoc transects adjacent to those lines. Estimated abundance is extrapolated to the full survey area (200 m to 4 km offshore, by 8 km wide).

Date	Number on Transect	Total Transect Length (km)	Density	Abundance
6 Dec 05	48	48	6.67	203
17 Jan 06	60	48	8.33	253
24 Jan 06	230	169.4	9.05	275
8 Feb 06	37	86.5	2.85	87
21 Feb 06	138	188.5	4.88	148
8 Mar 06	194	190.8	6.78	206

Figure 1. Study area, in northern Monterey Bay, California, and survey effort for aerial surveys.

Figure 2. Survey effort for boat-based surveys.

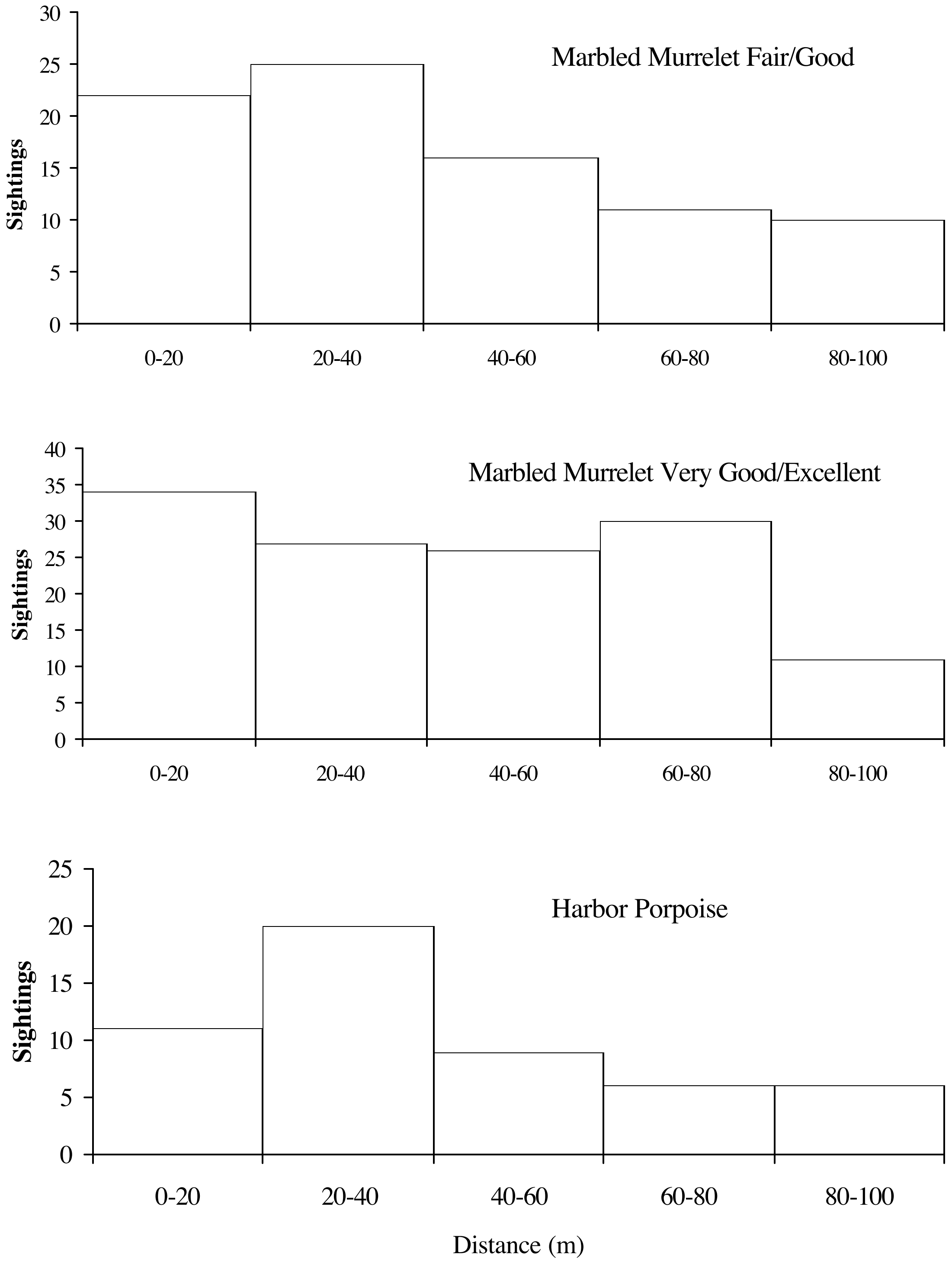


Figure 3. Detection functions (number of detections by distance off the survey trackline) for Marbled Murrelets under fair/good and very good/excellent viewing conditions, and for harbor porpoise. All data were truncated at 100 m.

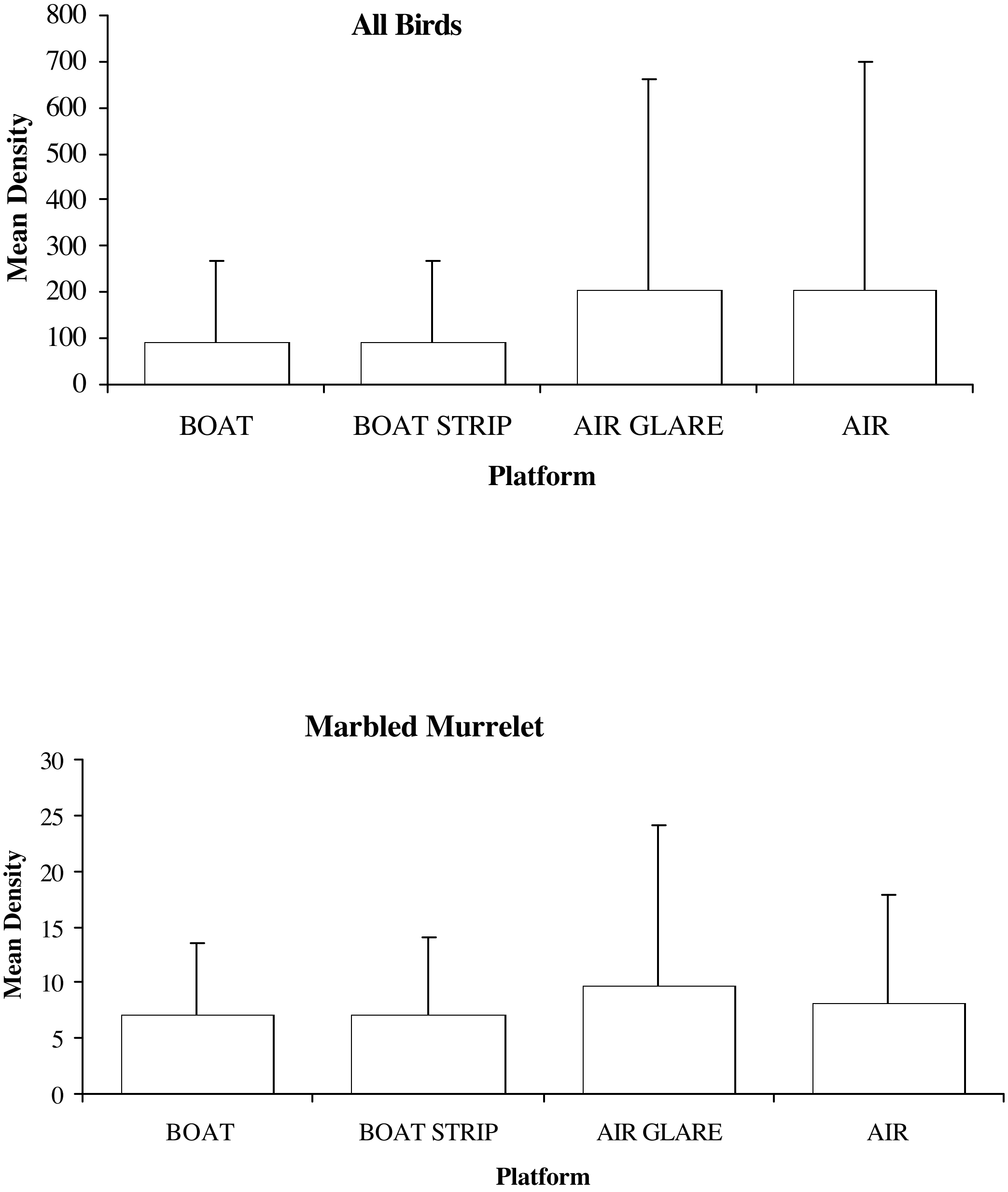


Figure 4. Mean density (birds per km^2) of all birds (top) and Marbled Murrelets (bottom) by survey platform. Error bars are one standard deviation.

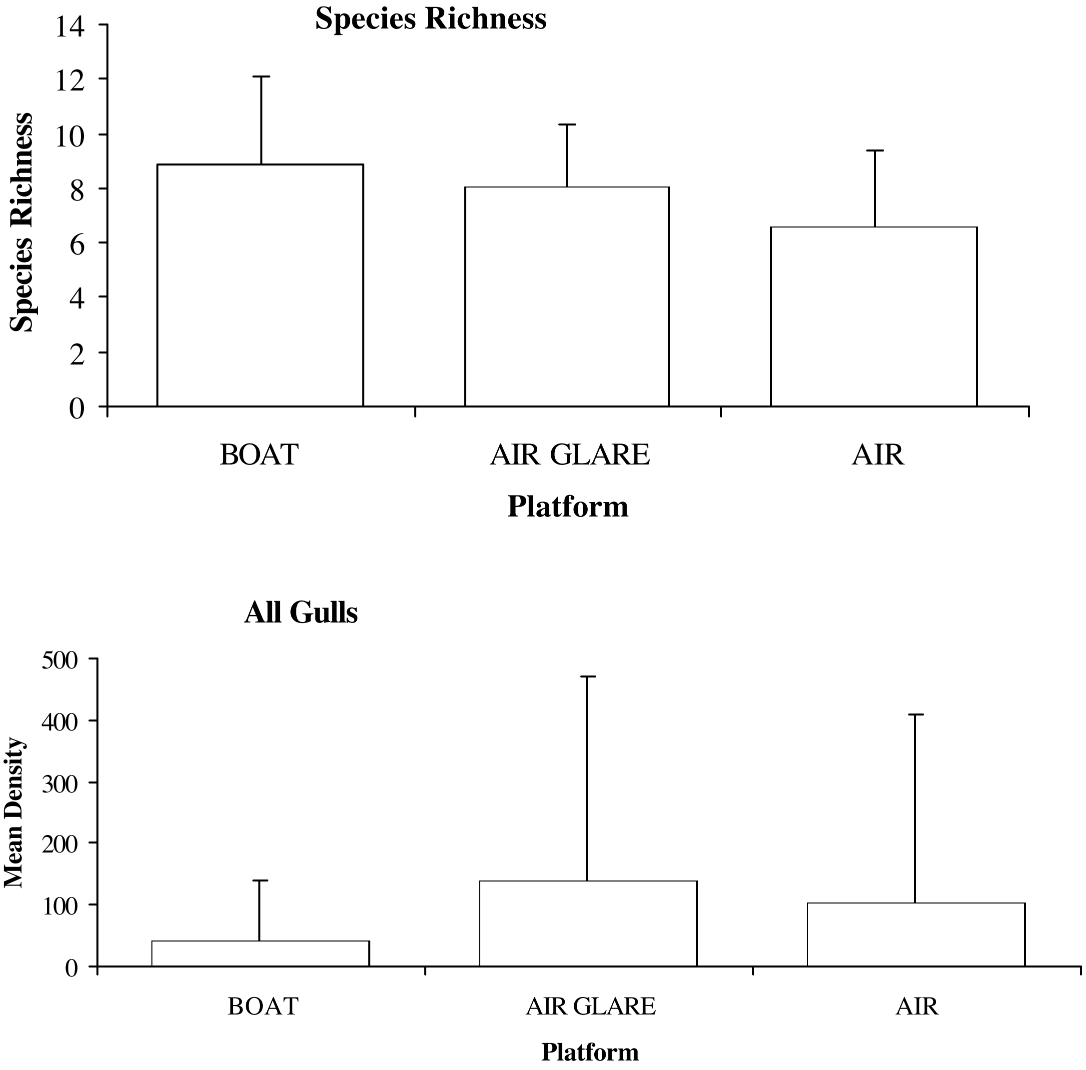


Figure 5. Mean species richness (number of species observed; top) and mean density (birds per km^2) of all gulls (bottom) by survey platform. Error bars are one standard deviation.

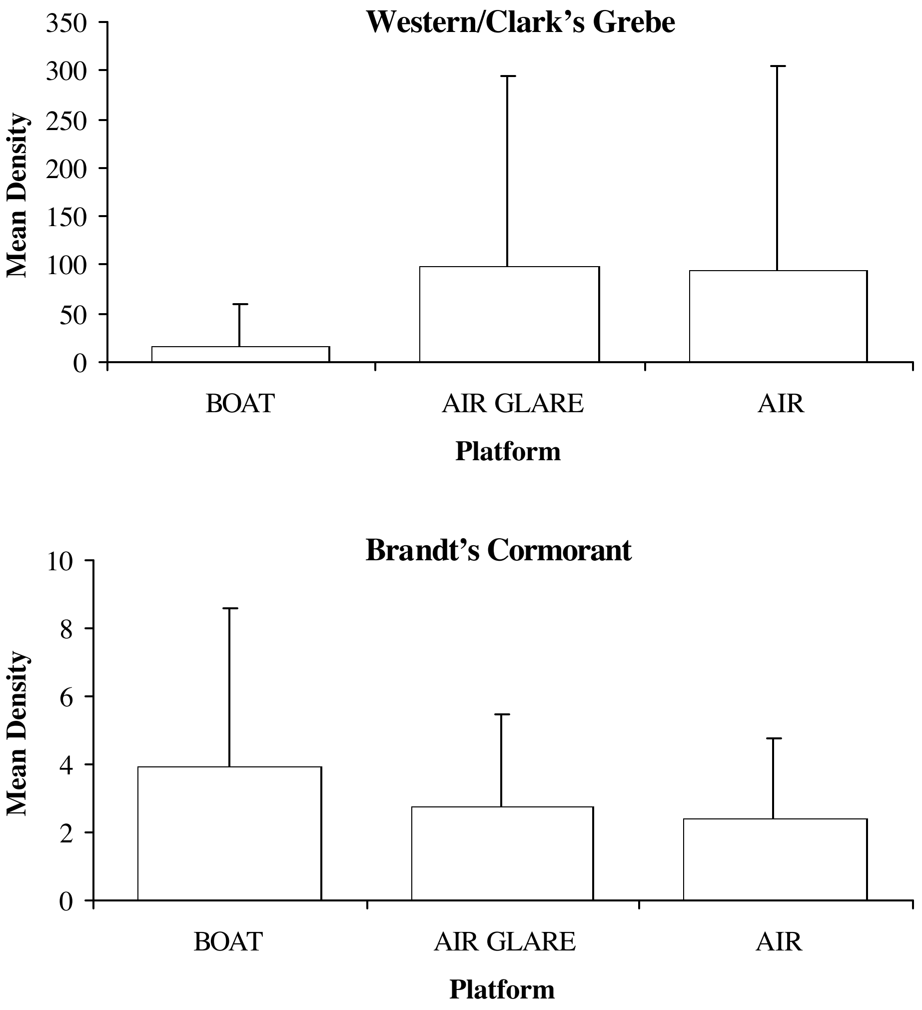


Figure 6. Mean density (birds per km^2) of Western/Clark's Grebes (top) and Brandt's Cormorants (bottom) by survey platform. Error bars are one standard deviation.

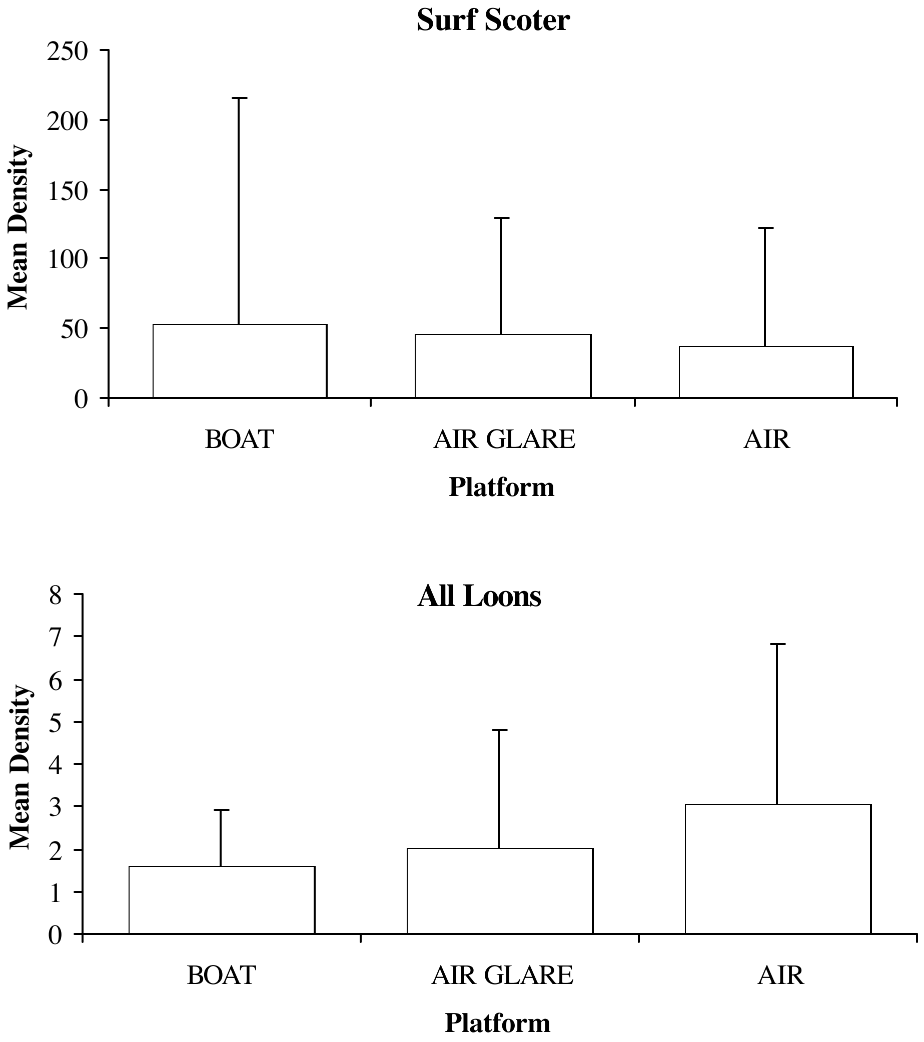
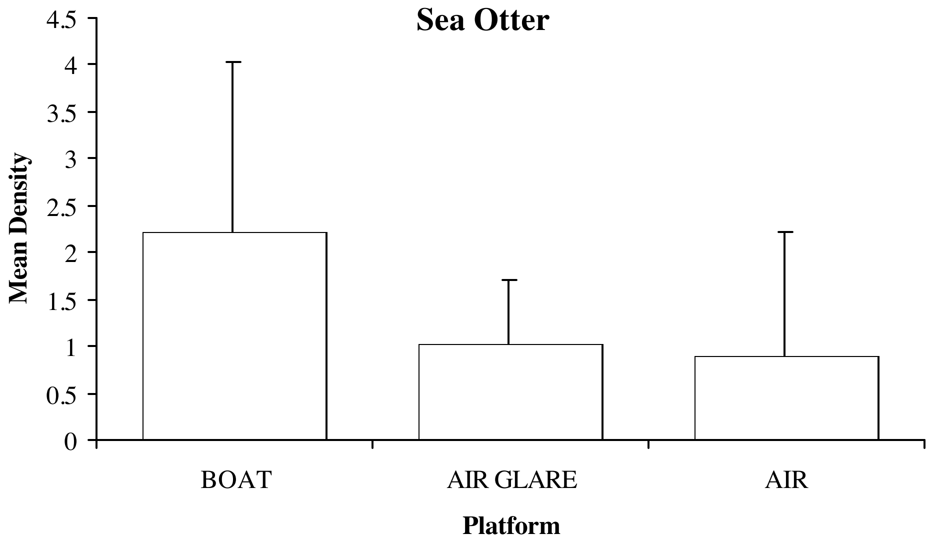


Figure 7. Mean density (birds per km^2) of Surf Scoters (top) and all loons (bottom) by survey platform. Error bars are one standard deviation.



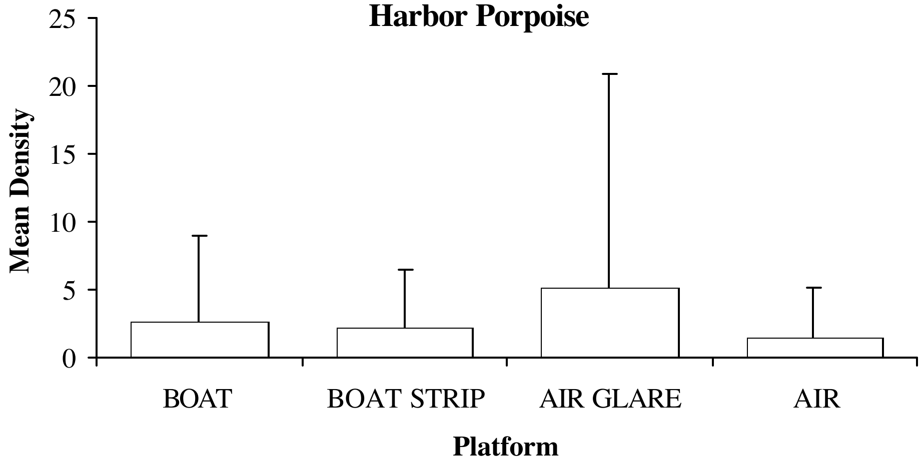


Figure 8. Mean density (animals per km^2) of sea otters (top) and harbor porpoise (bottom) by survey platform. Error bars are one standard deviation.

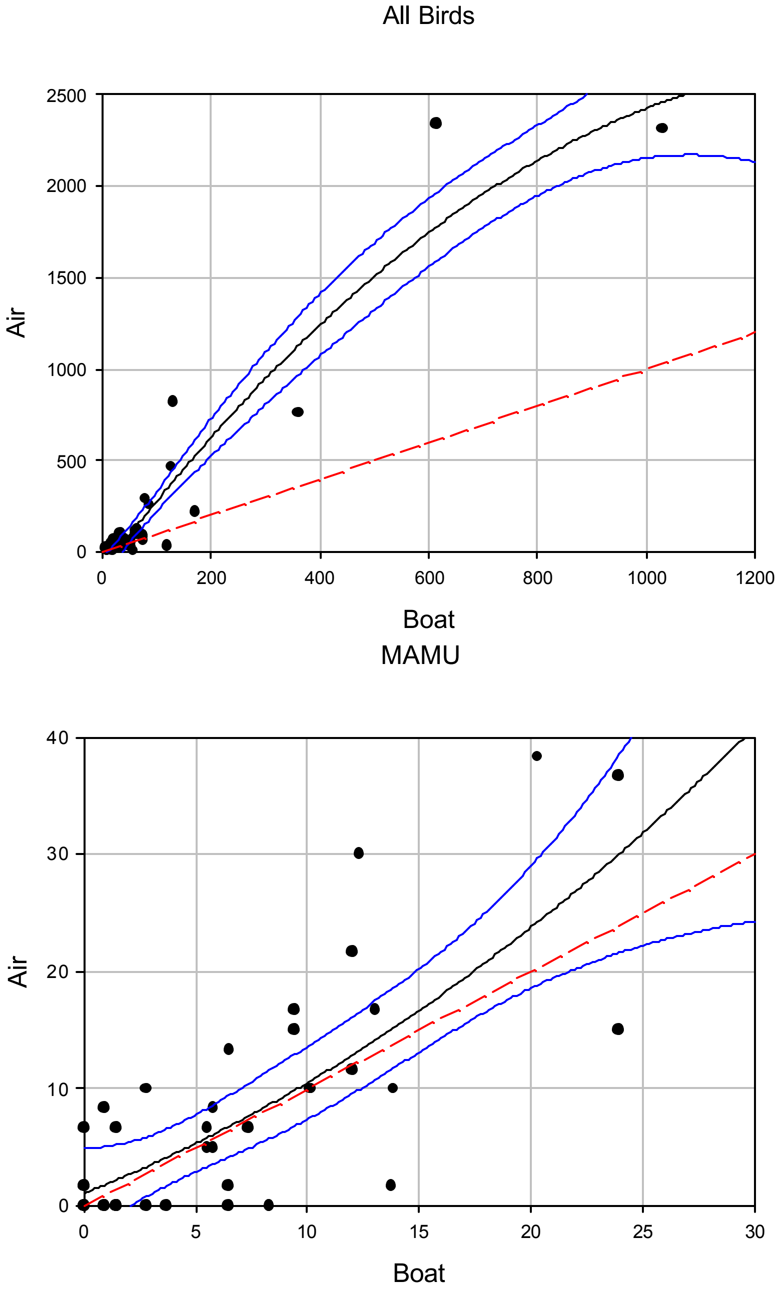
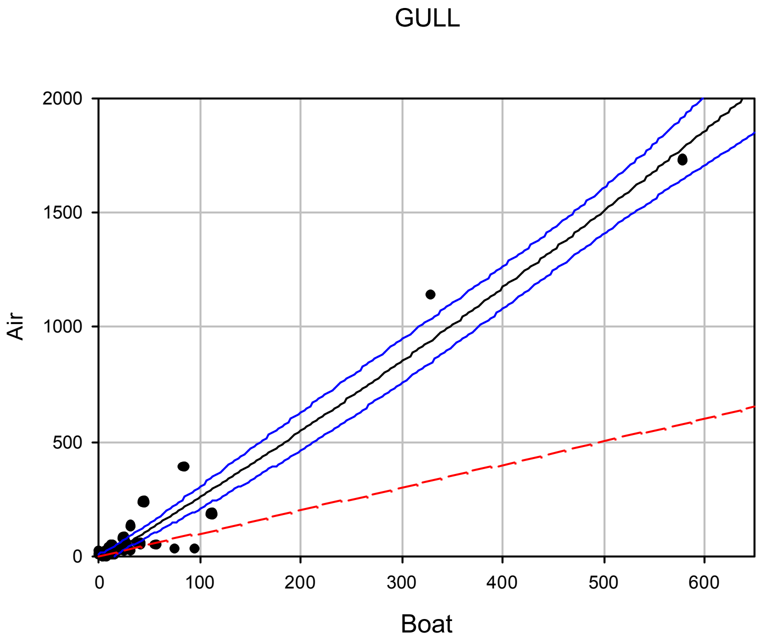


Figure 9. Polynomial regressions of aerial vs. boat-based density estimates of all birds (top) and Marbled Murrelet (bottom). Red dashed lines are expected 1:1 ratio; blue lines are 95% confidence limits.



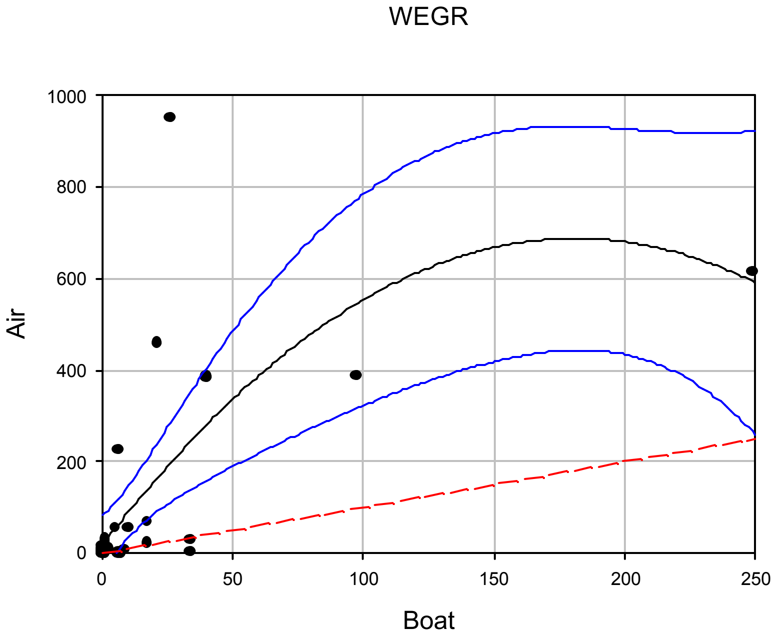


Figure 10. Polynomial regressions of aerial vs. boat-based density estimates of all gulls (top) and Western/Clark's Grebe (bottom). Red dashed lines are expected 1:1 ratio; blue lines are 95% confidence limits.

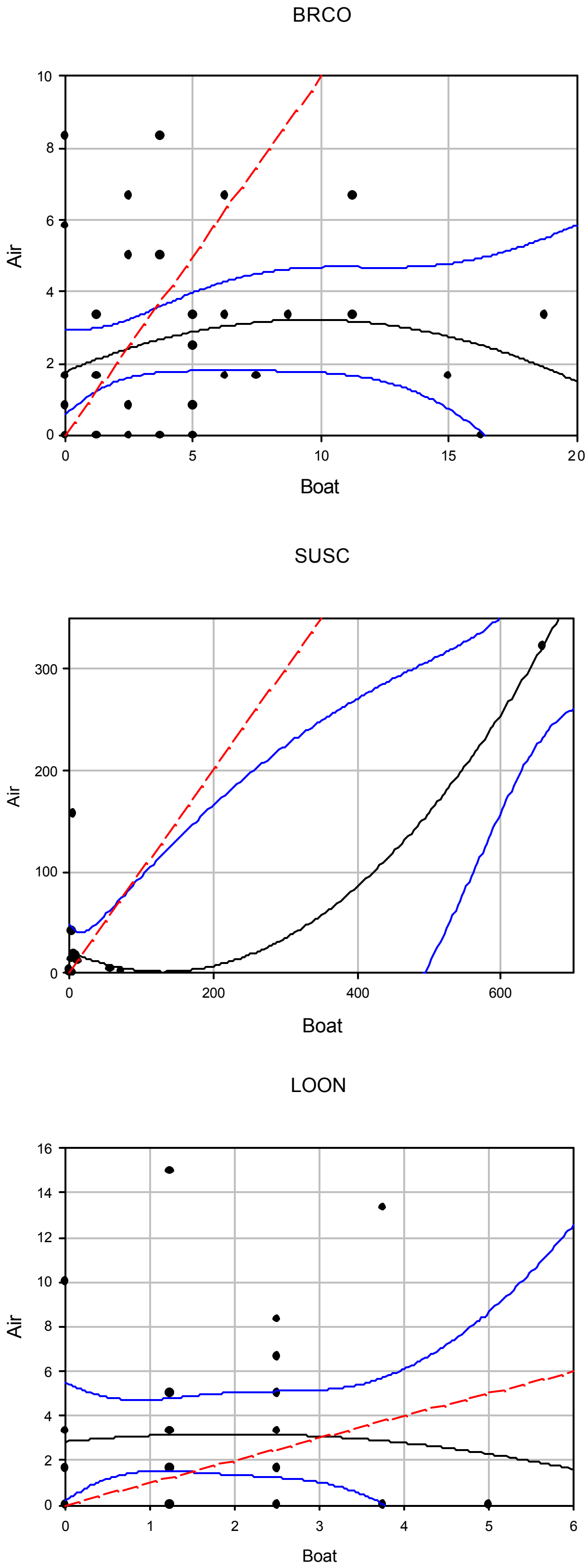


Figure 11. Polynomial regressions of aerial vs. boat-based density estimates of Brandt's Cormorant (top), Surf Scoter (middle), and all loons (bottom). Red dashed lines are expected 1:1 ratio; blue lines are 95% confidence limits.

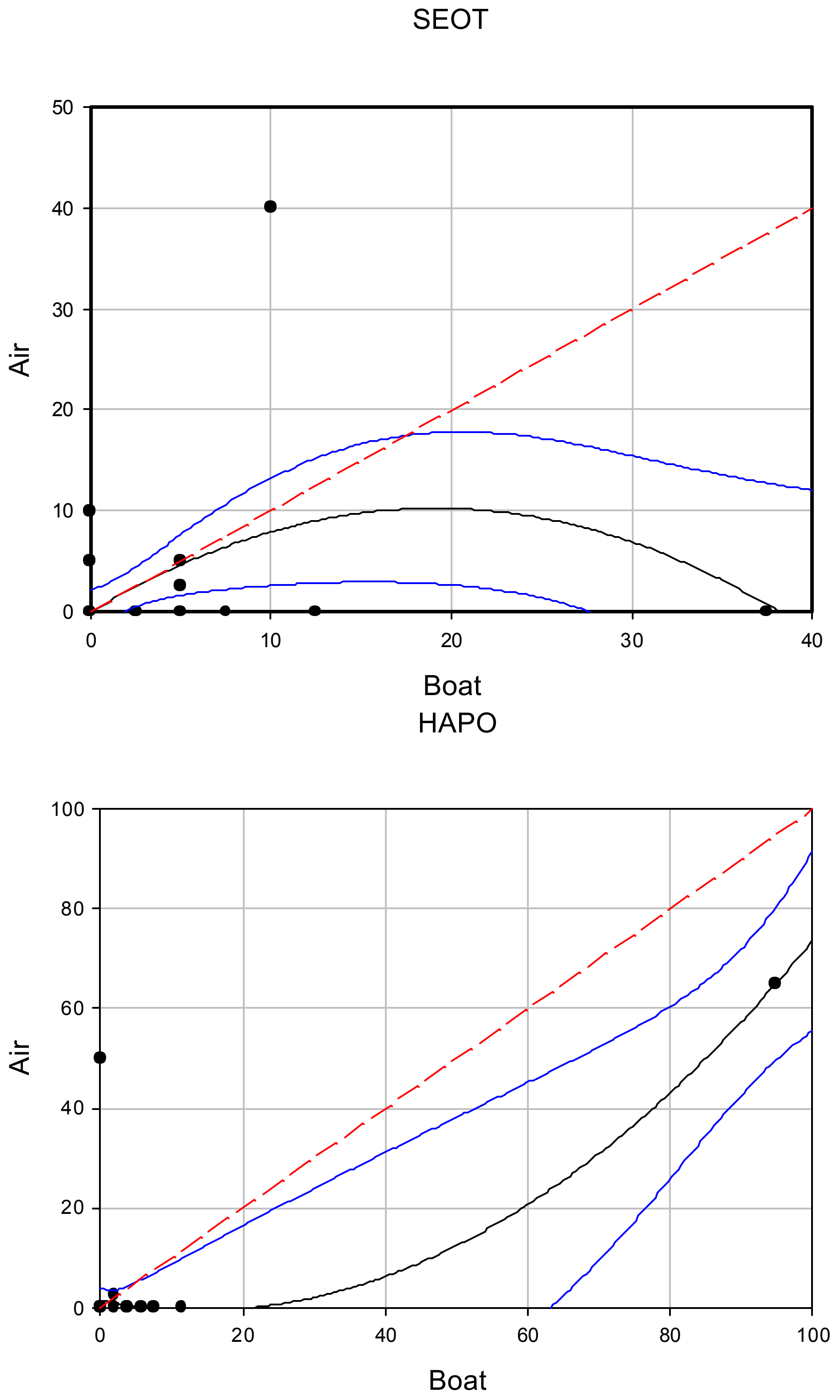


Figure 12. Polynomial regressions of aerial vs. boat-based density estimates of sea otter (top) and harbor porpoise (bottom). Red dashed lines are expected 1:1 ratio; blue lines are 95% confidence limits.

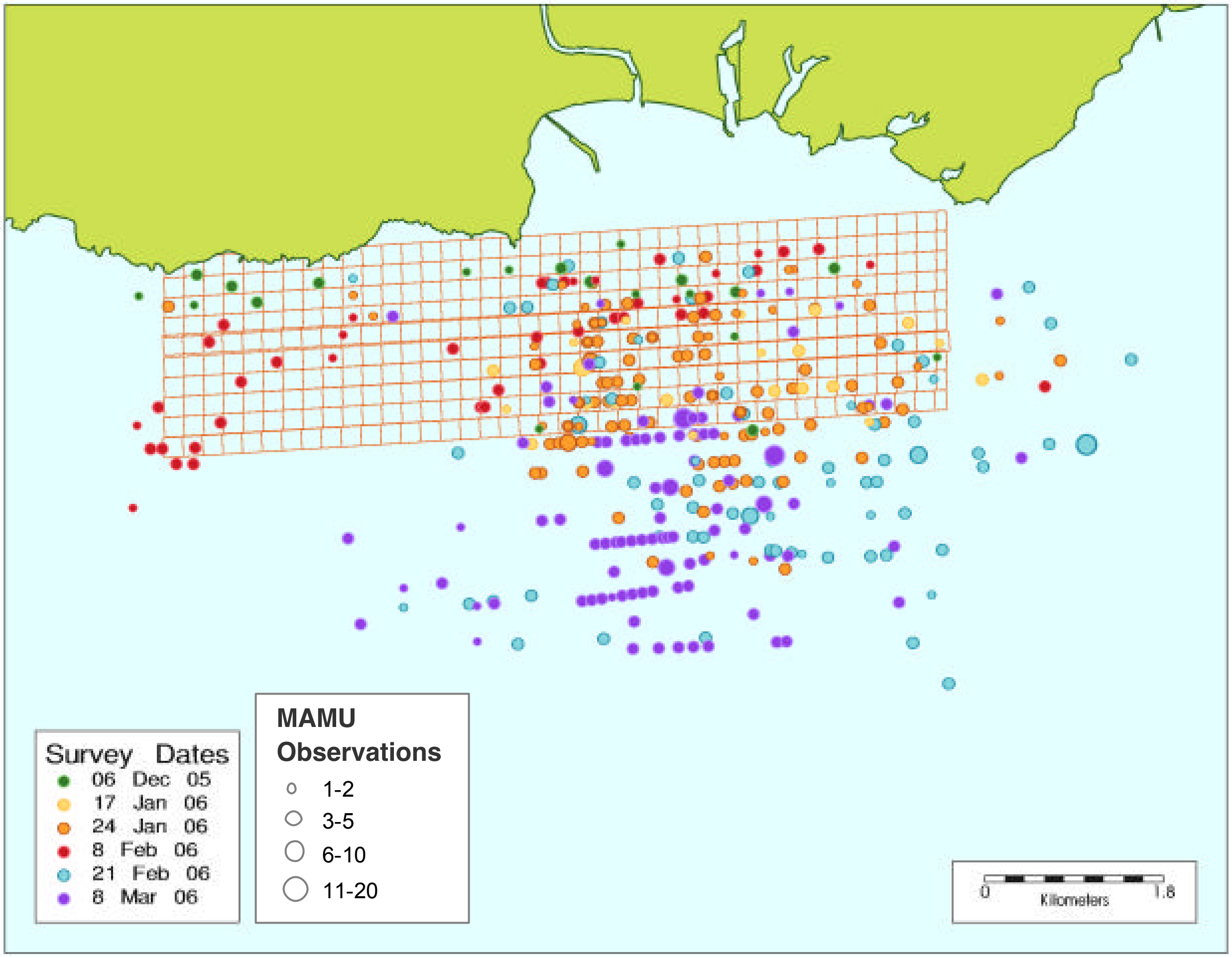


Figure 13. Distribution of all Marbled Murrelet sightings on-transect in the northern portion of the study area, including ad-hoc transects up to 4 km offshore.