FINAL REPORT FOR CONTRACT 52ABNF-6-00092

AERIAL SURVEYS FOR MARINE MAMMALS IN WASHINGTON AND BRITISH COLUMBIA INSIDE WATERS

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FORWARD

This report summarizes information gathered by Cascadia Research under Contract #52ABNF-6-00092 funded by the National Marine Mammal Laboratory (NMML). The primary purpose of this contract was to determine the abundance of harbor porpoise based on aerial surveys in the inland waters of Washington and British Columbia. In addition to this objective, the contract was amended to add an analysis of harbor porpoise distribution in the San Juan Islands in relation to distance from shore and to provide a summary of harbor porpoise sightings and survey effort from previous surveys in 1991 based on international boundaries and new stock definitions contained in the recent harbor porpoise status assessment determination.

In order to promote wide disseminated of these results within the scientific community, we have prepared two manuscripts for submission to peer-reviewed scientific journals. This report includes drafts of both of these manuscripts plus supplemental information that is pertinent to the contract but not considered suitable for publication. In order to improve the manuscripts so that they were complete, we conducted additional analyses that were not originally anticipated. These included:

- A more complete re-analysis of the 1991 survey results. In addition to changes in the study area boundaries, a number of other analysis components needed to be reworked to make them more directly comparable to the 1996 surveys results, including new definitions of distance bins by clinometer angles, the testing of a full range of models for the distance function, use of a new correction factor, and a determination of Dall's porpoise abundance (see below).
- The determination of Dall's porpoise abundance in addition to that for harbor porpoise for both the 1996 surveys as well as the previous 1991 surveys.
- A more complete examination of habitat criteria for harbor porpoise including expanding our evaluation to all region surveyed in 1996 (not just the San Juan Islands) and an evaluation of other habitat criteria including water depth and geographic sub-regions.

This contract report is organized as follows:

- The complete text, tables, and figures of a draft manuscript "Abundance estimates of harbor and Dall's porpoise in Washington and British Columbia inside waters" for submission to the journal *Fishery Bulletin*. This publication includes a summary of survey effort and sightings for both the 1991 and 1996 surveys.
- The complete text, tables, and figures of our draft manuscript "Distribution and habitat preferences of marine mammals in Washington and British Columbia inside waters" for submission to *Fishery Bulletin.*
- A section that contains supplemental information, primarily tables and figures, that are not contained in the above publications. This includes some of the items called for in the contract and amendments including details of the raw data structure and aspects of the habitat analysis in the San Juan Islands.

PART 1

ABUNDANCE ESTIMATES OF HARBOR AND DALL'S PORPOISE IN WASHINGTON AND BRITISH COLUMBIA INSIDE WATERS.

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ABSTRACT

Aerial line-transect surveys were conducted during August 1996 primarily to estimate harbor and Dall's porpoise abundance in five regions, encompassing US and Canadian waters of the Strait of Juan de Fuca, San Juan/Gulf Islands, and Strait of Georgia. A total of 6,263 km (3,382 nmi) of on-transect effort were completed using a twin-engine high-wing aircraft flying at 90 knots and an altitude of 600 feet. Three observers searched for marine mammals through side bubble windows and a downward viewing port. Out of 1,505 groups sighted (3,340 animals) while on-effort, 1,074 were harbor seals, 311 were harbor porpoise, and 76 were Dall's porpoise. We estimate abundance of harbor porpoise and Dall's porpoise using line-transect methods. A re-analysis of aerial surveys conducted in 1991 was also completed to provide a comparable dataset using similar regional boundaries and analysis methods to look at temporal trends. Sighting rates of harbor porpoise differed significantly by region, year, Beaufort sea state, and cloud cover: rates were dramatically lower in the Strait of Georgia than all other regions, they were higher in 1996 than in 1991 for three regions that were surveyed in both years, and rates decreased with increasing Beaufort sea state and cloud cover. Sighting rates of Dall's porpoise varied significantly by Beaufort sea state and cloud cover, but did not show any significant differences by year or region. The Strait of Georgia was excluded from these analysis because no Dall's porpoise were sighted there. Abundance estimates were calculated using only sightings made in calm wind speeds (Beaufort sea state 2 or less) and clear skies (25% or less cloud cover). The abundance of harbor porpoise was estimated as 1,893 (CV=0.45) in the US Strait of Juan de Fuca, 1,239 (CV=0.41) in the Canadian Strait of Juan de Fuca, 1,616 (CV=0.38) in the US San Juan Islands, 745 (CV=0.53) in the Canadian Gulf Islands, and 911 (CV=0.58) in the Strait of Georgia. Total uncorrected Dall's porpoise abundance was lower in 1996 (451, CV=0.23) than 1991 (1,095, CV=0.25) although this differences was not statistically significant. Our best estimate of Dall's porpoise abundance for 1996 was 1,545 (CV=0.43) using a correction factor developed for harbor porpoise.

Keywords: abundance estimation, aerial surveys, harbor porpoise, *Phocoena phocoena*, Dall's porpoise, *Phocoenoides dalli*

INTRODUCTION

A number of marine mammal species of Washington State and British Columbia inside waters are incidentally killed in gillnets (Stacey *et al.* 1990, Gearin *et al.* 1995, Barlow *et al.* 1995a, Pierce *et al.* 1996). The smaller species, such as harbor porpoise (*Phocoena phocoena*) and harbor seals (*Phoca vitulina richardsi*) are the most vulnerable to entanglement, but Dall's porpoise (*Phocoenoides dalli*) mortality is also known to occur (Stacey *et al.* 1990). The National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS) are responsible for reducing human-caused marine mammal mortality below levels deemed to be significant based on population estimates within US waters (Barlow *et al.* 1995b).

Little data exists on Dall's porpoise abundance and estimates of harbor porpoise abundance for inside waters of Washington State and British Columbia are outdated and incomplete (Calambokidis *et al.* 1992, Barlow *et al.* 1995b). Past estimates of harbor porpoise have been made from vessel-based surveys (Flaherty and Stark 1982, Barlow 1988) and aerial-based surveys (Barlow *et al.* 1988, Calambokidis *et al.* 1991, 1992, 1993, Green *et al.* 1992, Osmek *et al.* 1995). With the exception of a 1991 aerial survey (Calambokidis *et al.* 1992), past efforts excluded most of the inside waters of Washington and British Columbia. Dall's porpoise abundance in Washington waters have only been made for one region in Puget Sound (Miller 1990) and off the outer coast of Washington and Oregon (Green *et al.* 1992).

We report the results of aerial surveys for marine mammals that covered the inside waters of Washington and British Columbia including the Strait of Juan de Fuca, San Juan and Gulf Islands, and the Strait of Georgia. The primary objective of this 1996 study was to estimate the abundance of harbor porpoise, and secondarily, Dall's porpoise. We also re-analyze 1991 survey data reported by Calambokidis *et al.* (1992), and compare these estimates to the 1996 results for both species.

METHODS

Study Area

The study area included the inside waters of Washington and British Columbia east of the west entrance to the Strait of Juan de Fuca (Figure 1). The waters of Hood Canal and Puget Sound (south and east of Whidbey Island) were not surveyed because recent surveys had been conducted of these areas and revealed extremely low harbor porpoise densities (Osmek *et al.* 1995). The study area was divided into five separate regions using the international border to separate the US and Canadian Strait of Juan de Fuca and latitude 48° 25' N to segregate the U.S. San Juan Islands and Canadian Gulf Islands from the Strait of Juan de Fuca to the south. The Strait of Georgia was bounded by latitude 49° N and 50° N.

Survey Design and Procedures

A total 6,263 km of on-effort survey tracklines were flown between 7 and 22 August 1996. Surveys were attempted only under favorable weather conditions (light winds and little cloud cover) because past surveys had shown decreased sighting rates of harbor porpoise with increasing Beaufort sea state and cloud cover (Forney *et al.* 1991, Palka 1996, Calambokidis *et al.* 1992). Surveys were also terminated if Beaufort sea state steadily remained above a level 2.

Surveys were flown following saw-tooth transect lines (Cooke 1985) and were designed to provide uniform coverage of each region (Figure 1). Transect lines for each replicate covering the four regions in Strait of Juan de Fuca and the San Juan/Gulf Islands were designed with an effective spacing of about 11 km. For these regions, five unique replicates were designed, each offset approximately 2.78 km (1.5 nmi) from the next closest replicate. Waypoints for the Strait of Georgia were designed with an effective spacing of about 14 km when flown in both directions and only three replicates were flown. This provided about 50% of the coverage (per area) in the Strait of Georgia compared to the other regions.

Flights generally originated and ended at Bellingham International Airport, Washington. The US/Canadian Strait of Juan de Fuca and the San Juan/Gulf Islands were flown during one flight, flying the transects of one region out and the other region back. The flying direction of any given region varied from one survey to another depending on which direction would provide the best combination of visibility conditions for a particular time of day (*e.g.* to reduce sun glare).

Surveys were conducted using a high-wing (*Partenavia* P-68) twin-engine aircraft equipped with left- and right-side bubble windows and a belly window. This arrangement made it possible to observe marine mammals slightly ahead of, to the side, and beneath the aircraft. Three experienced harbor porpoise observers, located at left, center and right positions in the aircraft viewed the water for marine mammals while the aircraft flew at an altitude of 183 m (600 ft) and a speed of approximately 167 km/hr (90 kts). Observers rotated to a new position at the beginning of each flight. Surveys were generally limited to visibility conditions of Beaufort sea state of three or less and cloud cover ≤ 50%. When a transect line was aborted prematurely because of poor visibility conditions or because of airspace conflicts, these lines were flown again when the situation improved.

The data recorder, who also navigated from the copilot's chair, entered survey information using a custom Data Acquisition System (DAS) on a laptop computer that was interfaced with a GPS navigational system. Visibility conditions, and altitude were recorded at the beginning of a transect line and when conditions changed. The date, time, and location was updated automatically by the computer each minute and when other data entries were made. When a marine mammal sighting was made, observers used a clinometer to measure angle from the aircraft to the group of animals as they passed abeam of the aircraft so the perpendicular distance (distance from the survey trackline) could be determined. The species, group size, number of calves, and behavior were recorded along with the observer who made the sighting. A practice flight was conducted on the day prior to the start of the surveys to re-familiarize all members of the team with survey operations, viewing a variety of marine mammals from the air, and recording data.

Data Analysis

Error checks of data were conducted prior to analysis; sequential positions were tested for reasonable speed between one-minute position fixes and tests for reasonable altitudes, clinometer angles, and species codes. Species codes included a designation for probable but not certain species identification as well as codes for unidentified species. Probable sightings were included in the data analyses for that species, but there was no attempt to apportion sightings for which a probable species could not be assigned.

We statistically tested differences in the number of animals seen per kilometer of survey effort among regions, Beaufort sea state, percent cloud cover, and year using an analysis of covariance (ANCOVA) procedure similar to that employed by Forney *et al.* (1991). For this analysis, samples consisted of pooled transect segments from each replicate survey in a region that were conducted under similar visibility conditions. Segments within a replicate and region were categorized into six possible combinations of sea state and cloud cover. These consisted of three Beaufort sea states (0-1, 2, and ≥ 3) and clear (0-25% cloud cover) or cloudy (> 25%) conditions. Beaufort sea state, cloud cover, and year were treated as covariates and region as a categorical variable. Beaufort sea state was treated as a continuous variable; though not strictly true, it does reflect a progression of scaled wind speeds. Because not all combinations of visibility conditions were encountered in a given replicate, only 144 flight segments, or about 60% of the maximum number of combinations, contained survey effort (61 for 1991 and 83 for 1996). All statistical tests were conducted with the significance level of 0.05.

Density and Abundance Calculations

Density and abundance estimates were calculated with the computer program DISTANCE (Laake *et al.* 1993) and the methods described in Burnham *et al.* (1980) and Buckland *et al.* (1993). Regional size (km^2) was calculated using CAMRIS software (Ecological Consulting Inc., Portland, OR). DISTANCE was used to select the best model for the probability density function fit to the perpendicular distances, calculate f(0) and its variance, and to test for relationships between group size and distance from the transect line. Functions used to model the perpendicular distance included the Uniform with either cosine or simple polynomial adjustments, Half-normal with Hermite polynomial adjustments, and Hazard Rate with cosine adjustments (see Laake *et al.* 1993 and Buckland *et al.* 1993). The best model was selected based on Akaike's Information Criterion or AIC scores calculated from the different models tested by the DISTANCE program (Buckland *et al*. 1993, Laake *et al*. 1993). Selected models for the different years and species with their respective estimates are given in Table 1. We also evaluated stratifying f(0) estimates for harbor porpoise by Beaufort sea state but the stratified calculations yielded a higher total AIC score indicating they did not provided a better fit than using the pooled data. The limited sample size with Dall's porpoise led us to evaluate pooling the f(0) calculations for 1991 and 1996. The pooled f(0) calculation yielded a lower AIC score than the separate years (Table 1) and so was used in the analyses.

A few sightings (6 harbor porpoise) were excluded from these model determinations because a clinometer angle had not been recorded. Bin sizes were selected based on distances equivalent to 8 degree clinometer angle reading rather than equal distances because clinometer angle was the measurement unit. Consequently, bin width increases in size with increasing distance from the trackline. Group sizes of harbor or Dall's porpoise did not vary significantly with distance from the trackline (size bias regression in DISTANCE, $p>0.05$) and so the average group size for each region was used in the abundance calculations. Only survey effort and porpoise sightings made during good weather conditions (see Results) were included in the calculation of the sighting function or encounter rate. Abundance was calculated as:

$$\boldsymbol{N_r = \frac{n_r * E(S_r) * f(0) * g(0) * A_r}{2L_r}}$$

where $\mathbf{N_r}$ denotes estimated abundance in a region, $\mathbf{r}$ **=** one of five regions, $\mathbf{n_r}$ denotes sightings in a region, $\mathbf{E(S_r)}$ = group size for that region, **f(0)** = the probability density function at distance zero, **g(0)** = the probability that an animal is detected on the trackline, and $\mathbf{L_r}$ is the distance surveyed in a region, and $\mathbf{A_r}$ is the area of the region. A g(0) of 0.292, (CV=36.6%) was used based on calibration surveys conducted in the San Juan Islands in 1992 (Laake *et al.* 1997) which used the same aircraft and survey procedures employed in this study.

Estimates of variation for the regional abundance estimates were derived using:

$$\boldsymbol{cv(N_r) = \left[\left(cv(n_r)\right)^2 + \left(cv(E(S_r))\right)^2 + \left(cv(f(0)\right)^2 + \left(cv(g(0)\right)^2\right]^{\frac{1}{2}}}$$

The variance for $\mathbf{n_r}$ was calculated based on the five replicate surveys conducted in most areas (Buckland *et al.* 1993, p.90). Pooled estimates of abundance were calculated as the sum of the regional estimates.

Re-analysis of 1991 survey data

We conducted a re-analysis of aerial survey data collected in 1991. These surveys included waters off the coast of Washington and Oregon, as well as some of the inside waters covered by the current surveys (Calambokidis *et al.* 1992). Our re-analysis focused on the portion of those surveys conducted in inside waters and made the following changes to allow a better comparison to the 1996 survey results:

1) Regional boundaries were redefined to make them compatible with those used in the 1996 surveys and to correspond better with the stock definitions employed by NMFS in their stock assessments. New computations were made of survey effort and sightings within these new regions. The 1991 transect lines were generally flown from shore to shore without regard to the international border (Figure 1). To segregate data by region, cut points (the position where a 1991 transects crossed the international boundary) were determined from 1:80,000 scale NOAA Nautical Charts. Effort and sightings were then assigned to the new regional strata based on these cut points.

2) Models for the perpendicular distances were re-computed using bins based on clinometer angles instead of the bins based on equal distance intervals used previously. A more complete set of models for these sighting curves (the same as used for the 1996 data) were computed using the program DISTANCE (Laake *et al.* 1993).

3) The new correction factor for animals missed on the transect line (Laake *et al.* 1997) was used instead of the previous model based on breath rates.

4) Replicates were handled slightly differently in the re-analysis than both the original analysis as well as in the analysis of the 1996 data. In 1996, replicates were well defined and each represented a different set of waypoints. For 1991, there was less coverage, fewer complete replicates, and a less clear definition of where one replicate ended and another began (the same survey waypoints were flown multiple times). To provide a usable number of replicates for 1991, we defined each survey day in a region as a replicate. This yielded from four to six replicates of each region.

Survey coverage in 1991 was not as complete as in 1996. Because a small portion (6%) of the San Juan Island area was not surveyed in 1991, we expanded the regional area to include this segment making it comparable to the 1996 San Juan Island region. Only a small portion of the Gulf Islands and the Strait of Georgia were surveyed in 1991, so they were not compared to 1996 estimates.

RESULTS

A total of 1,505 sightings of 3,340 animals from 9 marine mammal species (plus a river otter) were made during on-effort portions of the surveys (Table 2). An additional 177 sightings were made off-effort or during an initial practice flight. Harbor seals, harbor porpoise, and Dall's porpoise were the most frequently sighted marine mammals and accounted for 97% of the marine mammal sightings. Killer whales, minke whales, gray whales, California sea lions, Steller sea lions, sea otters, and a river otter were also seen during the surveys (Table 2).

Harbor porpoise

A total 382 sightings of 549 harbor porpoise were made during the surveys, with 311 of these sightings made on-effort (Table 2). Group sizes of harbor porpoise ranged from one to three, with the exception of two off-effort sightings of groups of six porpoise, with 66% single animals.

The number of harbor porpoise seen per unit effort on a flight segment (portion of a replicate flown in similar weather conditions) varied significantly by region, year, Beaufort sea state, and cloud cover (Table 3, Analysis of covariance, $p<0.05$ for all variables). The strongest effects were from Beaufort sea state and year ($p<0.000$). There were also significant, but weaker, differences in sighting rates between regions ($p=0.012$) and cloud cover ($p=0.026$). Regional differences in sighting rates were primarily the result of the low sighting rate in the Strait of Georgia, which was first surveyed in 1996. When the Strait of Georgia was excluded from the analysis, sighting rates were not significantly different by region ($p>0.05$), although year, Beaufort sea state, and cloud cover remained significant ($p<0.05$ in all cases).

Survey results from 1996 demonstrated the dramatic effects that weather conditions have on sighting rates of harbor porpoise (Figures 2 and 3). Beaufort sea state was the most dramatic factor and sighting rates showed a steady decline with increasing sea state (Figure 2). Survey effort was very limited at Beaufort sea state of 0, due to the rarity of this condition, and above a Beaufort sea state of 2, because we terminated surveys if such a condition was prevalent. Sighting rates were also lower under cloudy versus clear conditions (Figure 3). There was limited effort above 25% cloud cover because we avoided surveying when cloud cover was heavy.

Based on the relationship between sighting rates and weather found in this study and those reported previously (for example, Forney *et al.* 1991, Forney 1995, Calambokidis *et al.* 1992), we restricted abundance estimation to only the survey segments conducted under optimal weather conditions. Minimum requirements of Beaufort ≤2 and cloud cover ≤ 25% were selected to be consistent with that used in past surveys (Calambokidis *et al.* 1992) as well as the calibration surveys used to estimate the proportion of animals missed on the transect line (Laake *et al.* 1997). The Beaufort sea state limitation does not eliminate the effect of this variable because there is a declining trend in the sighting rate even within the more limited range of sea states. This is primarily a problem if sea state conditions varied widely among years and regions which was not the case (Table 4). Restricting the dataset further based on sea state would eliminate a large portion of the data. Elimination of poor weather using the above restrictions reduced on-effort survey coverage by 28% (from 6,263 km to 4,493 km).

Sighting rates showed a steady decrease with distance from the transect line and a truncation distance of 0.375 km (sightings >64 degrees from vertical) only eliminated two harbor porpoise sightings (Figure 4). The best model for the sighting distances was the Uniform key with one polynomial adjustment (Table 1) and this provided a good match with the observed data (Figure 4). Re-analysis of the 1991 data yielded a slightly different distribution of sightings than for 1996 (Table 1, Figure 5). The Uniform key with one cosine adjustment was the best model chosen based on AIC scores. The corresponding f(0) (5.33, CV=1.8%) estimate was substantially different than from both the 1996 estimate as well as the original estimate from the 1991 analysis using the Hazard rate function (Calambokidis *et al.* 1992). Though use of a 2-term Uniform model (Figure 5) yielded a lower f(0), this model had a slightly higher AIC score and was not chosen.

Estimates of harbor porpoise density and abundance were calculated for each region as well as combinations of regions representing either bodies of water or country boundaries for both 1996 and 1991 (Tables 5 and 6). The total estimated abundance of harbor porpoise in 1996 was 1,870 (CV=0.12), uncorrected for animals missed on the transect line, and 6,404 (CV=0.38), when the correction factor developed by Laake *et al.* (1997) was employed. As revealed by the analysis of harbor porpoise encounter rates, the density was lowest in the Strait of Georgia. Despite the large size of this region (more than double any other region), it contributed less than 1,000 animals (corrected abundance) to this total. Calculated densities in the other regions were fairly similar and contributions to abundance were generally proportional to their areas (Table 5).

The 1991 revised abundance estimates were lower than those found for harbor porpoise in 1996 (Table 6). These surveys did not cover all the regions surveyed in 1996 so abundance for the entire region cannot be compared among the two surveys. For the three regions with comparable coverage in both years, however, the estimated abundance of harbor porpoise were 4% to 51% lower than in 1996. Estimates in the U.S. Strait of Juan de Fuca were most comparable among years while the Canadian Strait of Juan de Fuca showed the greatest difference. The difference in abundance was not as dramatic as the difference in encounter rate because the f(0) was higher in 1991 than 1996 partially compensating for the differences in sighting rates.

Dall's porpoise

A total 97 sightings of 173 Dall's porpoise were made during the surveys, with 76 of these sightings made on-effort (Table 2). Group sizes of Dall's porpoise ranged from one to five animals with 87% of sightings consisting of one or two animals. Dall's porpoise were sighted in all regions except the Strait of Georgia.

The number of Dall's porpoise seen per unit effort by transect segment in 1991 and 1996 varied significantly by Beaufort sea state and cloud cover (Table 3, ANCOVA, $p<0.05$ for both). The relationship was similar to harbor porpoise with the number of Dall's porpoise seen per unit of effort decreasing with increasing Beaufort sea state and cloud cover. As with harbor porpoise, Beaufort sea state had the strongest contribution ($p<0.000$). Unlike harbor porpoise, there was no significant difference by region or year ($p>0.05$). Because sample size was only a quarter of that for harbor porpoise, there was less power to detect differences.

Both current and historical data on the relationship between sighting rate and weather were more limited for Dall's porpoise making selection of weather restrictions more difficult. We chose to use the same weather limitations in the analyses for Dall's porpoise as for harbor porpoise (maximum Beaufort sea state of 2 and 25% cloud cover).

Relative to harbor porpoise, the sighting rate distribution of Dall's porpoise did not decrease as smoothly with distance off the transect line (Figure 6). Because of the smaller sample size for Dall's porpoise, we modeled the sighting function using the combined 1991 and 1996 datasets which yielded a selection of the Uniform key with one polynomial adjustment (Table 1, Figure 6). The distance functions for each separate year did no show as great a difference between years with Dall's porpoise as they did for harbor porpoise (Table 1), therefore even if we had used these separate year f(0) estimates instead of the pooled 1991-96 calculation, it would not have changed the estimate substantially.

The uncorrected estimate of abundance of Dall's porpoise for all regions for 1996 was 451 (CV=0.23). No correction factor for animals missed on the transect line is available for Dall's porpoise. Because of the similarity between Dall's and harbor porpoise in body size, group composition, and breath rate, the proportion of Dall's porpoise missed on the transect line is likely similar to that calculated for harbor porpoise (Laake *et al.* 1997). With this correction factor, the estimated abundance of Dall's porpoise would be 1,545 (CV=0.43). The small sample sizes for Dall's porpoise make the estimates for each region less reliable. Compared to harbor porpoise, Dall's porpoise abundance estimates for 1996 were considerably lower (Table 7).

Unlike harbor porpoise, the abundance of Dall's porpoise was higher in 1991 than 1996 for two of the three regions surveyed in both years (Table 8). Although the overall estimate of abundance was considerably higher in 1991 than 1996, this did not reflect a significant difference in sighting rates because of the small highly variable sample.

DISCUSSION

The surveys in 1996 provide the best estimates of harbor porpoise abundance in the inside waters of Washington and British Columbia due to their greater and better distributed coverage compared to past surveys. These recent surveys have revealed a higher abundance for harbor porpoise than had been estimated for the 1991 survey data (Calambokidis *et al.* 1992, 1993, and this study). This paper also provides the first abundance estimates of Dall's porpoise for these waters. Given the potential risks to harbor and Dall's porpoise from incidental entanglements and the evidence of declines in harbor porpoise in neighboring areas such as Puget Sound, the finding of a larger than expected abundance of harbor porpoise is encouraging.

The significantly higher abundance and sighting rates of harbor porpoise in 1996 compared to 1991 could be the result of a number of factors:

1. **Methodological differences**. Though most survey methods were similar between years (aircraft, flight parameters, and observation methods) there were some differences that could have biased the outcome of the surveys. Total survey effort in the inside waters was lower and a single set of transect lines were flown repeatedly in 1991, compared to 1996 where effort was higher and each replicate was conducted on a different set of lines each flight. Survey coverage in 1991 could have repeatedly sampled some lower density areas compared with the more uniform coverage in 1996.

2. **Observer differences**. Laake *et al.* (1997) showed there can be large differences in the sightings rates of harbor porpoise among observers of different experience levels. Although observers in 1991 and 1996 had similar qualifications and one of the primary observers conducted both surveys, there is the potential that differences among observer contributed to the differences in sighting rates. The difference in f(0) calculations between the two years indicates observers did use slightly different search methods in the two surveys and this brought the abundance estimates somewhat more in line, though still not in agreement.

3. **Movement of animals**. The study areas we defined represent relatively small areas and large numbers of harbor porpoise could move in and out of these regions. Differences in prey abundance and distribution among years could have altered the portion of the entire harbor porpoise population that was present within our study area. Little information exists on harbor porpoise movements in this region and what constitutes a population.

4. **Increased population size**. The changes we observed could reflect in increase in total harbor porpoise populations in this region. Barlow and Boveng (1991) estimated the maximum theoretical reproductive potential for harbor porpoises to be 9.4%. Therefore, it is possible a population increase contributed to the differences we found, but it is unlikely to have solely accounted for the change given the incidental mortality of harbor porpoise known to occur in this region (Stacey *et al.* 1990, Gearin *et al.* 1995, Barlow 1995a, Pierce *et al.* 1996).

Significant changes in harbor porpoise abundance have been found in several other regions in the eastern North Pacific but these have all involved decreases in harbor porpoise abundance. Harbor porpoise were considered common in Puget Sound through the 1940s (Scheffer and Slipp 1948), but more recently, they are rarely seen there (Everitt *et al.* 1980, Calambokidis *et al.* 1985, 1992, Osmek *et al.* 1995). Forney (1995) found a significant decrease in harbor porpoise abundance in some areas along the California coast where harbor porpoise have been killed in gillnets. Declines in harbor porpoise populations have also been reported in other areas including: San Francisco Bay, California (Leatherwood and Reeves 1983), the Baltic Sea (Otterlind 1976), and the Wadden Sea (Wolff 1981).

Our finding of a strong relationship between sighting rates of harbor porpoise and both Beaufort sea state and cloud cover is consistent with other aerial surveys of harbor porpoise (Barlow *et al.* 1988, Forney *et al.* 1991, Calambokidis *et al.* 1992). Harbor porpoise are small and indistinct and tend to surface with only minimal water disturbance. Increasing Beaufort sea states obscures disturbances to the water surface and makes it difficult to see objects below the surface. Increasing cloud cover has a more subtle effect; visibility is reduced below the water's surface by limiting light penetration through the water column and dispersing glare over the entire surface. The sea state and cloud cover limits selected for use with our abundance estimates are similar to those used in past studies (Calambokidis *et al.* 1992) and match the weather criteria used in surveys to derive the correction factor employed in this study (Laake *et al.* 1997).

Although we found dramatic differences in the abundance estimates of Dall's porpoise between 1991 and 1996, these differences were not significant probably because of the small number of sightings in both years. Although lower, the 1996 estimate is better than the 1991 estimate because there was more survey effort and the transect lines covered all inside waters more uniformly (and include the Strait of Georgia). The lack of sightings of Dall's porpoise in the Strait of Georgia is in contrast with the frequent sightings in the rest of our study area (to the south) and their reported common occurrence in the Johnstone Strait area (immediately to the north) (Jefferson 1987). The low sightings of harbor porpoise in the Strait of Georgia suggests a common factor, such as prey, may be responsible for the low numbers of both species.

Although this study provides the first estimate of Dall's porpoise abundance for this region, the use of a correction factor for animals missed on the transect line is problematic. Correction factors for animals missed on the transect are critical for line-transect surveys of marine mammals because of the high proportion of time these species spend underwater and are not viewable (Buckland *et al*. 1993). Our use of the harbor porpoise correction factor is not ideal but probably provides a reasonable estimate for Dall's porpoise because these two species are similar in body size, travel in small groups, and have fairly short similar dive intervals.

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PART II

DISTRIBUTION AND HABITAT PREFERENCES OF MARINE MAMMALS IN WASHINGTON AND BRITISH COLUMBIA INSIDE WATERS

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ABSTRACT

Line-transect aerial surveys for marine mammals of Washington and British Columbia inside waters were conducted during 7-22 August, 1996. Nine different marine mammal species were observed; sighting data for the three most commonly sighted species, harbor seals (n=862), harbor porpoise (n=261), and Dall's porpoise (n=68) were sufficient to determine their habitat preferences related to water depth, distance to shore and sighting rate differences for 352 km^2 geographic cells. These species were found at most water depths, but sighting rates of harbor seals were significantly greater at shallower depths (two-way ANOVA, P=0.010) and Dall's porpoise sighting rates were significantly higher in the deeper waters (P=0.001). Harbor porpoise distribution varied significantly by depth (P=0.013), with more animals occurring in deeper waters of the San Juan/Gulf Island regions. In the Strait of Juan de Fuca, no clear pattern in the depth distribution could be ascertained. The significant regional differences for harbor seal and harbor porpoise were explained by the low sighting rates in the Strait of Georgia, where only these two species were seen. The distance to shore variable was significant for only harbor seals (P<0.000). Because harbor seals and harbor porpoise, the most common species incidentally taken in these waters, ranged widely and were found at all depth and distances to shore, closing specific areas to gillnet fisheries may not be an effective method to reduce take levels.

Keywords: Dall's porpoise, distribution, habitat preference, harbor porpoise, harbor seal, marine mammals, *Phocoena phocoena, Phocoenoides dalli, Phoca vitulina richardsi*, depth distribution, distance to shore.

INTRODUCTION

The inside waters of Washington and British Columbia are highly productive, supporting a rich diversity of marine habitats and animal life, including nine species of commonly occurring marine mammals (Osborne *et al.* 1988, Calambokidis and Baird 1994). Most of the existing information on the distribution of these species is a result of either opportunistic sightings, such as those reported by the public to marine mammal sighting networks (*e.g.*, The Whale Museum, San Juan Island, Washington) or from a number of studies that, by design, covered only a small portion of these waters (*e.g.*, Flarherty and Stark 1982, Raum-Suryan 1995, Suryan 1995, Pierce *et al.* 1996). Everitt *et al.* (1980) provides a description of the geographic distribution of marine mammals for most of these inland waters (with exception to the entire Strait of Georgia), but their effort was unsystematic and non-uniform so sighting rates could not be calculated and used to compare differences between locations. Subsequent aerial surveys of that study area conducted by Calambokidis *et al.* (1992) were systematic and covered the Strait of Juan de Fuca and the San Juan Island regions evenly, but their sightings were limited to these large water bodies and only addressed harbor porpoise.

Three of the marine mammal species that occupy these inland waters, harbor seals (*Phoca vitulina richardsi*), harbor porpoise (*Phocoena phocoena*), and Dall's porpoise (*Phocoenoides dalli*), are abundant in many of the marine waters of the Pacific Northwest. However, the current knowledge about their spatial distribution and habitat preferences throughout their range is fairly limited. Both harbor seals and harbor porpoise are species often associated with coastal and inland marine waters (Reeves *et al.* 1992, Leatherwood and Reeves 1983). Harbor seals are mostly found near shore and use beaches, mud banks and exposed offshore rocks as haul sites. Harbor seals have been recorded foraging mostly at depths of less than 150 m (Stewart and Yochum 1994). Harbor porpoise also are found in relatively shallow marine waters. In the northwest Atlantic, harbor porpoise were encountered most at water depths of 55-130 m (Palka 1995). Throughout their range, herring (*Clupea harengus*) and other small schooling fish species and squid are their predominant prey. In contrast, Dall's porpoise are generally thought of as a pelagic species. The geographic range of Dall's porpoise is broad, extending across most of the northern North Pacific Ocean (Leatherwood and Reeves 1983). This species' range also extends coastally to the inside waters of southern and southeastern Alaska (NMFS 1978), British Columbia (Pike and MacAskie 1969), and Puget Sound (Miller 1989) as well as our study area where it is present year around (Everitt *et al.* 1980, Calambokidis and Baird 1994). Little is known about Dall's habitat preferences, but because their diet consists primarily of prey that inhabit the mesopelagic and epipelagic zones of the ocean, they are generally considered animals of deep water environments (Stroud *et al.* 1981).

We examine the geographic distribution and habitat preference of the common marine mammals encountered throughout the inland waters of Washington and British Columbia using systematic aerial surveys conducted to estimate harbor porpoise abundance (Calambokidis *et al.* In prep.). We also evaluated whether certain areas of high sighting rates might be identified as locations to be avoided by fisheries known to incidentally take marine mammals in their gillnets (see Pierce *et al.* 1996).

METHODS

Study Area

The 1996 study area included the inside waters of Washington and British Columbia, from latitude 47^{o}53' N to 50^o N and east to Tatoosh Island at the western entrance of the Strait of Juan de Fuca, at longitude 124.44^o W (Figure 1). The study area was divided into five separate regions based on water bodies and the international border: (1) US Strait of Juan de Fuca (US Strait) from the (2) Canadian Strait of Juan de Fuca (Canadian Strait), (3) US San Juan Islands, including Admiralty Inlet (San Juans), (4) Canadian Gulf Islands (Gulf Islands) and (5) the Strait of Georgia (SOG)(49^o N to 50^o N). Surveys of Hood Canal and Puget Sound (south and east of Whidbey Island) were not flown because harbor porpoise densities were known to be extremely low (Calambokidis *et al.* 1992, Osmek *et al.* 1995).

Survey Design and Data Acquisition

From 7 to 22 August 1996, a total of 6263 km of aerial line transect surveys were flown following a saw-tooth design (Cooke 1985) from a high-wing (Partenavia P-68) twin engine aircraft flying at an altitude of 183 m (600 ft) and a speed of 167 km/hr (90 kts). Each minute, and whenever a sighting occurred, the aircraft position was automatically recorded on a laptop computer connected to a GPS. Beaufort wind scale (sea state) and percent cloud cover was entered at the beginning of each transect and when visibility conditions changed. Five unique replicate survey lines were flown in all areas except the SOG, where three replicates were flown.

Three observers were positioned at the left or right side bubble windows or the belly window. Sighting data was entered in to the computer by the recorder located in the copilot's seat. Sighting data included species, group size, presence of young animals, and clinometer angle from the aircraft to the group as it passed abeam of the aircraft. This measurement was used to calculate a more accurate position for each sighting so an estimate of its water depth and nearest distance to shore could be obtained. Most groups were sighted within 400 m of the trackline. A complete description of the field methods can be found in Calambokidis *et al.* (In prep.).

Water depth data were determined for all sightings and one-minute aircraft positions using nautical charts published by the U.S. National Oceanic and Atmospheric Administration and Canadian Hydrographic Service, Department of Fisheries and Oceans. Chart scale ranged from 1:40,000 to 1:80,000 in US waters and was 1:80,000 in Canadian waters. Depths were interpolated to the nearest meter or fathom. Due to the large sample sizes of harbor seals (n=863) and aircraft positions (n=1568), every fourth harbor seal sighting and every other aircraft position were measured and subsequently used to calculate mean depth. The one-minute aircraft positions were considered an unbiased estimator of effort because the recorded location was independent of the waypoint positions used to define the flight path. Nearest distance to shore measurements were determined using a computer program that compared all on-effort marine mammal and aircraft positions with a 1:100,000 scale vector file of the study area's land masses (Ecological Consulting Inc., Portland, OR).

Data Analysis

Visibility conditions such as sea state and cloud cover are known to decrease sighting detectability when some marine mammals, such as harbor porpoise, are at or near the water's surface (see Forney 1995, Palka 1996, Calambokidis et al. In prep.). To reduce bias from sighting conditions, observations were restricted to the best conditions of sea state (Beaufort ≤2) and cloud cover (≤25%). A total of 4493 km of total on-effort survey trackline was used for the data analysis reported here (Figure 1).

Geographic cells, measuring 10 minutes latitude (18.5 km) by 15 minutes longitude (19 km)(352 km^2), were defined throughout the study area and sighting rates were computed (groups/100 km). To ensure a sufficient number of sightings per cell, we used a minimum of 40 km of effort for the two porpoise species and 20 km for harbor seals.

A two-way ANOVA was used to analyze sighting rates (animals/km) differences by depth, region, and the depth-region interaction. The same analysis was conducted for distance to shore and region. Samples consisted of pooled transect segments from each replicate survey in a region that were conducted within a specific depth or distance to shore class. Only samples with a minimum of two effort positions (representing an average of at least 5 km) were used in the distance analysis to reduce variation from minimally sampled strata. All statistical tests were conducted with a 0.05 significance level.

RESULTS

Regional Habitat Characteristics

The mean depth and distance to shore as sampled by aircraft positions varied by region (one-way ANOVA, $P<0.000$ for both variables)(Table 1). The deepest mean depth occurred for the SOG (187 m), but the Canadian Strait had the greatest mean distance to shore (5.5 km). The lower mean distance in the SOG was influenced by the narrow passages and a few small islands in the north. Smith Island, located in the east end of the US Strait, had a similar influence on this region by lowering the mean distance calculations to shore (Figure 1).

Habitat Preferences and Geographic Distribution

A total of nine marine mammals species were sighted during the two week survey period. The three most common species were harbor seals, harbor porpoise, and Dall's porpoise, accounting for 71%, 22% and 6% of all sightings, respectively. No marine mammals other than harbor seals and harbor porpoise were sighted in the SOG.

Other species sighted under acceptable visibility conditions were killer whales (n=8)(*Orcinus orca*), gray whales (n=3)(*Eschrichtius robustus*), minke whales (n=2)(*Balaenoptera acutorostrata*), Steller sea lions (n=3)(*Eumetopias jubatus*), California sea lions (n=1)(*Zalophus californianus*), and sea otters (n=3)(*Enhydra lutris*)(Figure 2). Several distribution patterns and sightings of these marine mammals were of interest: (1) sea otters were sighted along Dungeness Spit, Washington, further east in these inland waters than had previously been described (Kenyon 1969), (2) a California sea lion was sighted during August when this species is usually absent from this area (Steiger and Calambokidis 1986, Calambokidis and Baird 1994), (3) killer whales were widely dispersed within the Strait of Juan de Fuca, but no animals were sighted in Haro Strait or the adjacent area of the San Juans and Gulf Islands where they are usually found during summer (Ford *et al.* 1994). As expected, the distribution of gray whale and sea otter sightings were near shore.

Harbor Seals

Harbor seal sightings were common and occurred throughout the study area in the narrow passages as well as in open water (Figure 3). A total of 862 groups (974 seals, including 20 pups) were observed at sea, while 26 groups (1,159 animals) were hauled out at various land sites. Most pups (85%) were sighted close to shore in the vicinity of the San Juan and Gulf Island regions. Sighting rates were highest in these island regions (29.5-33.7 groups/100 km) and similar in the others (13.1-16.4 groups/100 km)(Table 2).

Out of a total of 38 geographic cells, 37 contained at least one harbor seal sighting; rates varied greatly from 3 to 59 groups per 100 km of effort (Figure 4). The highest rates (31-59 groups/100 km) were found in two clusters of cells encompassing: (1) the northern Gulf Islands and (2) northeast of Orcas Island. The sighting rates adjacent to these cell clusters were also high (21-29 groups/100 km) and comparable to the eastern Strait of Juan de Fuca near western Whidbey Island and around Protection and Smith Islands, well established haul sites (Huber 1995). The highest rates in the SOG were for two cells (21-29 groups/100 km): (1) between Hornby and Texada Islands and (2) near the Fraser River mouth and Roberts Bank, an alluvial sand bar that is extensively used to haul out.

Although harbor seals were sighted most often near shore in the shallower waters of each region (Table 1), this species could be found at all depths and distances to shore. Harbor seal sighting rates varied significantly by both water depth (P=0.01) and region (P=0.049, Table 3). Except for the Canadian Strait where sighting rates were highest at depths of 51-150 m, harbor seals were more prevalent in shallower water (Figure 5). Although this region also had the lowest sighting rate, it but was similar to the SOG. For all regions combined, the inverse relationship of decreasing numbers with increasing depth was more apparent (Figure 6). Harbor seal sighting rates also varied significantly by distance to shore and region (two-way ANOVA, P=0.001 for both distance and region) with the highest sighting rates closest to shore.

Harbor Porpoise

Harbor porpoise occurred throughout the study area with few breaks in their geographic distribution. A total of 261 porpoise sightings (364 porpoise and including 16 calves) were seen (Figure 7). Calves were seen in all five regions and there was no significant difference in the proportion of calves seen versus the expected proportion (Chi-square goodness of fit analysis, P=0.479). Sighting rates for harbor porpoise were highest in the Canadian Strait and San Juans (8.0-8.1 groups/100 km) and lowest in the SOG (1.9 groups/100 km)(Table 2).

Harbor porpoise sightings occurred in all 19 cells; rates ranged from 1 to 21 sightings per 100 km (the SOG was unrepresented for both porpoise species because effort there was mostly less than 40 km per cell). Sighting rates were highest (21 groups/100 km) northwest of Orcas Island and rates were also high (15-16 groups/100 km): (1) west of Whidbey Island, (2) off Victoria, British Columbia, and (3) in the central US Strait (Figure 8).

Harbor porpoise distribution, like that of harbor seals, varied significantly with water depth (Table 3). However, unlike seals, an opposite pattern of increasing sightings with increased depth was apparent in the island regions (Table 1); no clear pattern was detectable for the three other regions alone (Figure 9) or all regions combined (Figure 6). Sighting rates also varied significantly by regions and by the interactive effect of region and depth (Table 3). The regional significance was due to a low sighting rate in the SOG (Table 2), while the interactive significance is due to the differences in the depth distribution pattern by region. The regional significance is verified by Calambokidis *et al.* (In prep.) who used an analysis of covariance test. No meaningful statistical relationship could be determined for distance to shore (P=0.196).

Dall’s Porpoise

Dall’s porpoise were more clumped in their distribution than either harbor seals or harbor porpoise. The overall distribution of 68 group sightings (119 Dall’s, including 7 calves) shows few sightings occurred east of the transboundary waters of Haro Strait and immediately west of Whidbey Island in the Strait of Juan de Fuca (Figure 10). The sample size of calves was too low to be of much value, except that they appeared to be distributed uniformly with the other Dall’s porpoise sightings. Sighting rates in the regions where Dall’s porpoise occurred varied little; the Gulf Islands were higher (2.2 groups/100 km) than the Canadian Straits (1.4 groups/100 km)(Table 2).

Almost a third of the geographic cells had zero sighting rates (Figure 11). Dall’s porpoise sighting rates in the remaining cells ranged from 1-5 groups/100 km. The exception was for one cell encompassing northern Haro Strait/Boundary Pass and the Canadian Gulf Islands which was dramatically higher (13 porpoise/100 km). This relatively high rate was a result of 11 Dall’s porpoise groups that were seen over several minutes during a single replicate survey. This was an atypical event for this species.

Most Dall’s porpoise were seen in deeper waters (Tables 1-3); only one group was seen in water less than 25 m (Figure 12). With the SOG excluded (because of the lack of sightings), there were no differences in sighting rate by region (Figure 12, two-way ANOVA, Table 3). The animal’s distance to shore was a poor indicator of their distribution (two-way ANOVA, P=0.498).

DISCUSSION

Regional Differences

It is suspected that the distribution and habitat preferences of marine mammals is affected largely by prey availability, especially for those smaller species with high energetic demands (Morejohn 1979). The waters of the San Juan and Gulf Islands, and in particular the transboundary waters of Haro Strait/Boundary Passage and near northwest Orcas Island, had either first or second highest sighting rates of harbor seals, harbor porpoise, and Dall's porpoise, both with respect to region and the geographic cells. The Haro Strait vicinity is unique in that this channel has comparable depths to the western Strait of Juan de Fuca (> 300 m), even though it divides the two shallowest regions in the study area (Table 1). Currents in this area commonly exceed several knots, especially along the adjacent island areas (NOAA Tidal Current Tables 1995). Along with these strong currents are distinct tide rips, zones of mixing which were more consistent and prominent there than the other regions we sampled. Shore- and vessel-based studies have associated greater concentrations of these species with tide rips (harbor seals: Suryan 1995; Dall's porpoise: Miller 1989; and harbor porpoise: Everitt 1980, Flaherty and Stark 1982, Raum-Suryan 1995). These authors and Read (1983), who observed harbor porpoise foraging on herring at rips near the surface, believe these aggregations of marine mammals are related to greater prey abundance. Herring, a important prey species for these marine mammals (Cowan 1944, Pike and McAskie 1969, Stroud 1981), especially during summer (Everrit *et al.* 1980, Gearin *et al.* 1994), are associated with areas of such mixing because of zooplankton concentrations along these convergence zones (Battle *et al.* 1936). These higher aggregations of prey and the possible action of current upwellings transporting herring to the water's surface may lead to increased foraging efficiency (Watson 1976).

Other than harbor seals and porpoise, the lack of marine mammal sightings in the SOG was surprising because this region had next to the highest amount of effort (Table 2). The absence of other marine mammal sightings there may be related to either animals temporarily leaving this region or a general avoidance of this region. Because this is the first study to systematically survey these waters, no marine mammal sighting data are available for comparison with other seasons or years. The lack of Dall's porpoise sightings in the SOG is consistent though with Cowan (1944) and Pike and McAskie (1969), who report that Dall's porpoise rarely occur in this region. These two accounts also describe Dall's porpoise as common immediately north (also see Jefferson 1987) and south of SOG (Everitt *et al.* 1980, Calambokidis *et al.* 1992).

Habitat Preferences

Harbor Seals

The significant relationship of higher sighting rates in the near shore shallow waters provides some insight to the strong association that harbor seals have with their haul sites. The geographic cells that had the highest sighting rates were either in the island regions or had large haul sites nearby. Harvey (1987) found that 24 tagged harbor seals off coastal Oregon spent most (92%) of their time within 8 km of their haul site. Huber (1995) found that molting harbor seals of Smith and Protection Island spent over half of their time ashore during July and August (approximately when this study was conducted). Radio-tagging studies of seals in the San Juan and Gulf Islands and Boundary Bay have also indicated though that seals occasionally move among haul sites and across the international border (Huber *et al.* 1995). Harvey (1987) reported two tagged seals moving 250 and 280 km from their haul site.

Other than traveling, the relatively long-distance movements off shore may be related to feeding on a variety of prey throughout the inland waters, including benthic and other small schooling fishes (Brown and Mate 1983, Harvey 1987). Studies of harbor seals tagged with satellite linked transmitters show that harbor seals dove almost continually while at sea and were presumably foraging at a wide range of depths from 10-446 m (Stewart and Yochum 1994). The greatest depth in the SOG exceeds 400 m, but is still within the diving capabilities of harbor seals.

Harbor Porpoise

The highest sighting rate was the cell northwest of Orcas Island, an area where several other studies had been conducted because this species is more consistently abundant there (Calambokidis *et al.* 1992, Raum-Suryan 1995). The cell off Victoria, British Columbia, also had a high rate of harbor porpoise sightings. This area is transited on a regular basis during summer by vessels of a variety of sizes, from pleasure boats to larger ferries and freighters. Raum-Suryan (1995) noted that there was a correlation between the presence of small boats and lower harbor porpoise sighting rates in the study area, but the extent to which they avoided the area was undetermined.

Harbor porpoise of the inland waters of Washington and British Columbia exploit a variety of depths by region and no clear pattern of use is evident for all regions combined. Raum-Suryan (1995) also found that harbor porpoise off Orcas Island were distributed over all water depths, except she reports that their distribution was distinct with a higher proportion of sightings (relative to effort) at depths greater than 125 m and significantly less in depths shallower than 75 m. Her results, correspond closely with our results for the US San Juan Islands (Figure 9), the region including her study area. Other studies also indicate that there is tendency of higher sighting rates at depths from about 50 to 200 m (Smith and Gaskin 1983, Watts and Gaskin 1985, Palka 1995). But even in those areas of the northwest Atlantic, as well as off the northwest coast of Washington, harbor porpoise can frequently be found foraging on herring at much shallower depths of less than 25 m (Gearin *et al.* 1994). Westgate *et al.* (1995) determined, through the use of time-depth recorders attached to 7 harbor porpoise, that mean dive depths ranged from 14 m ± 16 (SD) to 41 m ± 32 m, and that animals were feeding in the water column well above the maximum depth of their study area (230 m). Because harbor porpoise generally feed on small schooling prey (Gearin *et al.* 1994) that are not usually associated with the bottom, the significant relationship of harbor porpoise presence and water depth maybe due to the affect of bottom structure on currents and other oceanographic conditions that influence prey distribution.

Dall's Porpoise

Dall's porpoise were not uniformly distributed, geographically or with respect to water depth. Their preference for deeper waters of this study area is expected for a species commonly associated with the pelagic environment. Loeb (1972) suspected that the areas of steep bottom slopes in Monterey Bay, California, not unlike the steep slopes of the Haro Strait vicinity, were favored by Dall's porpoise because foraging there allowed them to remain over, or in close proximity to, preferred depths while taking advantage of the shallower more varied feeding areas. Similarly, Miller (1989) noted that Dall's porpoise, at her Puget Sound study site, prefer areas of steep bottom topography such as the bank edge off the south tip of Whidbey Island (35-150 m deep).

Evaluation of Areas to be Avoided by Fisheries

Although there were significant patterns in the distribution of the three species tested, these patterns may not be dramatic enough to be of great value to management in reducing incidental take levels in gillnet fisheries. The two species incidentally taken most often in the US San Juans, harbor seals and porpoise, were present in most all of the geographic cells as well as the depth and distance to shore classes. Patterns of occurrence by depth and or distance to shore also varied among regions. Consequently, significant reductions in take, through regional or habitat closures, would be difficult.

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Figure 12. Effort corrected sighting rates by depth and region for Dall's porpoise. No Dall's porpoise were seen in the Strait of Georgia.

Part III

SUPPLEMENTAL MARINE MAMMAL INFORMATION FROM AERIAL SURVEYS OF WASHINGTON AND BRITISH COLUMBIA WATERS

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INTRODUCTION

The purpose of this section of the final report is to provide NMML with supplementary information that is not appropriate for inclusion in the preceding draft manuscripts for publication. Two progress reports were also provided to NMML during earlier stages of the project and some of the relevent information from those reports is also included here.

1996 AERIAL SURVEYS

Practice Flight

On 6 August a practice flight was conducted along the northern US San Juan Islands because these waters were known to have high densities of many marine mammal species, especially harbor porpoise. This 1.4 hour flight yielded 83 group sightings of 5 marine mammal species, including 54 sightings of 59 harbor seals, 23 sightings of 38 harbor porpoise, 2 sightings of 2 Dall's porpoise, 3 sightings of 3 killer whales and one sighting of a California sea lion. Some of these groups were observed more than once during this practice flight. Those sightings and effort were treated as off-effort and not included in the abundance and habitat manuscripts.

Flight Operations and Time Expenditures

Surveys were based out of Bellingham, Washington, because of its central location. However, the airports at Port Angeles, Friday Harbor, Powell River, Sekiu, and Qualicum Beach were sometimes used because of constraining weather conditions or fuel needs. For 23 flights, 61.5 hours of survey time was expended (Table 1). Total aircraft time was 72.9 hours including 3.5 hours of aircraft taxi time on the ground and 7.9 hours of one-way ferry time bringing the aircraft to the region. During the surveys, 6,263 km of effort was completed over water on-effort in all five regions. Areas receiving the most effort were the Strait of Georgia (1,798 km) and the U.S. Strait of Juan de Fuca (1,774 km). U.S. waters received a total of 2,725 km of effort and Canadian waters 3,539 km. This excludes over land coverage, but is not adjusted to exclude poor weather conditions. Most transect legs were flown as originally intended (Table 2). On several occasions, however, transect legs were unexpectedly truncated or our flight path rerouted because of airspace conflicts near airports (primarily at Victoria, Vancouver, and Whidbey Is.). These instances were few and this effort was made-up at a later time. Coordinates for the waypoints used for all 5 replicates (3 replicates for the Strait of Georgia) are given in Table 3.

Sighting Conditions

Sighting conditions over the 12 day survey period were generally favorable and allowed flights on most days with the exception of five consecutive days of poor weather in the middle of the study (Table 2). This allowed completion of all survey lines and replicates in all five regions. Weather conditions deteriorated or were less than ideal during a few flights. The primary weather criteria was Beaufort sea state; Beaufort 3 conditions were flown for short periods, usually to see if conditions would improve. Cloud cover was also used as a weather selection criteria. Most surveys were conducted when cloud cover was 25% or less. During the last two days of the surveys, cloud cover did exceed 50% within the Strait of Juan de Fuca. However, this was generally when the cloud layer was light and the sun could be seen reflecting off the water's surface.

Marine Mammal Sighting and Habitat Data

Other marine mammal sighting data

Of the nine marine mammal species observed only two (harbor seals and porpoise) were sighted in the Strait of Georgia. The distribution and habitat data (mean depth and mean distance to shore) data for the 6 less common species are provided in Table 4; the on-effort aircraft tracklines and the one-minute aircraft positions are presented in Figure 1. For all regional sighting rate (groups/km) data combined, there was a declining trend with distance to shore for harbor seals, an increasing trend with distance to shore for Dall's porpoise, and no clear trend for harbor porpoise and distance to shore (Figure 2). By region, harbor seal distribution by distance to shore was significant, but was insignificant for the porpoise species (Table 5). Figures 3-5 illustrates this variation for each species by region. Codes for all of the raw data collected in the field on the computer with the DAS (data acquisition system) is provided in Table 6.

Harbor Porpoise of the US San Juan Islands

We investigated the distribution and habitat preference of harbor porpoise in the US San Juan Islands. This region was analyzed more thoroughly because most harbor porpoise of inland Washington waters are killed in gillnets set for sockeye salmon, *Oncorhynchus nerka*, and this information might prove valuable to mitigate take rates there. The objective of this study was to determine if excluding fishing activities from certain distances to shore or water depths might be effective in eliminating harbor porpoise mortality, which was recently estimated at a rate of 15 animals per year. This study was conducted during August, the same month that the sockeye salmon fishery generally operates in these waters.

Harbor porpoise occurred at all distances to shore and depth classes, but tended to favor areas further from shore and deeper water (Figures 6 and 7). The proportion of sightings for distance to shore ($P<0.001$) and depth ($P<0.001$) varied significantly from that expected based on effort (Chi-square goodness of fit test). However, no clear distance to shore or water depth strata are evident that, if avoided by fisheries, would dramatically reduce the likelihood of harbor porpoise/fishery interactions.

Regional Differences In Depth and Distance to Shore

Regional differences by distance to shore and water depth was determined using all of and one-half of (respectively) the on-effort one-minute aircraft positions. Depth measurements were determined for each position from NOAA and Canadian nautical charts and the nearest distance to shore was calculated by a computer program (HABITAT) which uses CAMRIS formatted vector-file data (Glen Ford, Ecological Consulting Inc., Portland OR). Mean values for these variables are presented in Table 4. The Strait of Georgia had the greatest mean depth, but this region did not have the greatest mean distance to shore as one would expect. Mean distance to shore was lowered substantially by the narrow passages and the islands in the northern two-thirds of the region. The proportion of measurements made at various distances to shore (0.5 km bins) are presented in more detail for each region in Figure 8.

REANALYZES OF THE 1991 SURVEY DATA

The 1991 study area of Calambokidis et al. (1992) included the waters of Oregon, Washington, and southern British Columbia. For this analysis, however, we were primarily interested in those waters of inland Washington and inland British Columbia. Two survey blocks were originally designated for these inland waters: (1) the Strait of Juan de Fuca and (2) the San Juan Islands, including the southern Canadian Gulf Islands. As a basis for apportioning sighting data and aerial survey effort, we further subdivided these 2 waterbodies in to 6 regions (Figure 9).

Area calculations for the different subregions were determined using CAMRIS. Stock boundaries were defined and entered into CAMRIS. These areas were used to calculate the region's size; total water area was calculated by excluding all land areas within the defined block. The area calculations used for the original 1991 data analysis were estimated using nautical charts and an assortment of measurements. Nonetheless, the results of the two methods are very similar. The small differences in area may be the result of two factors: (1) we included waters of a small region of U.S. waters north of the San Juans that was considered outside the study area in 1991 but is clearly within the new stock boundary, and (2) the current CAMRIS analysis included some inlets off the main bodies of water that were not included previously.

LIST OF FIGURES