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FINAL REPORT

HARBOR PORPOISE DISTRIBUTION AND ABUNDANCE OFF OREGON AND WASHINGTON FROM AERIAL SURVEYS IN 1991

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EXECUTIVE SUMMARY

Aerial surveys were conducted off Oregon and Washington in the summer of 1991 to help determine the current abundance of harbor porpoise (*Phocoena phocoena*) in these waters. Effort in 1991 was increased from that in previous years' surveys to reduce the coefficient of variation around the estimated abundance and to cover regions that had not been surveyed in 1990. Several new regions including the entire Strait of Juan de Fuca, the waters around the San Juan Islands, Puget Sound, and the coastal embayments of the southern Washington coast were surveyed for the first time in 1991.

The study area was surveyed along transect lines following a saw-tooth survey design. Surveys of all areas except Puget Sound and the coastal embayments were conducted from a twin-engine, high-wing aircraft (Partenavia P-68) outfitted with bubble windows for side observation and a belly window to search below the aircraft. Surveys were flown at 600 ft at 90-100 kts. Surveys of Puget Sound and the coastal embayments were conducted primarily to verify that few harbor porpoise occurred in these areas and were conducted with a single-engine aircraft.

A total of 1,236 sightings of 4,816 marine mammals were made during the surveys including 579 sightings of 913 harbor porpoise (not including the calibration experiment). A total of 501 sightings of 782 harbor porpoise were made on-effort during transects. Highest sighting rates were in Oregon and southern Washington. No harbor porpoise were seen in Puget Sound (south of Admiralty Inlet), Hood Canal, or coastal embayments of the Washington coast (including Columbia River).

Sighting rates declined with increased Beaufort sea state and cloud cover. Statistical tests of the sighting rate by survey line confirmed the effect of both Beaufort sea state and cloud cover and that these were not the by-products of regional differences. Given this finding, density and abundance estimates were conducted using only surveys conducted during Beaufort sea state of 2 or less and cloud cover of 25% or less. A total of 2,387 of the 3,658 nm survey effort (on transect) fell within the acceptable weather criteria.

A primary goal of the analysis of the land calibration experiment was to determine the proportion of harbor porpoise groups being missed by the aircraft. This was complicated by the high density of harbor porpoise in the sample area; 522 harbor porpoise sightings were made from land and 259 sightings from air during the 5 hour experiment. A more general analysis of the calibration data was conducted for the primary viewing area directly north of the land site. We compared the total

number of harbor porpoise groups seen by aerial and land teams along a 500 ft. strip to either side of the aircraft path. This revealed that aerial observers were seeing a maximum of 40%-45% of the sightings along the transect line; a figure consistent with the correction factor we used in the current study that is based on breath rates summarized by Barlow et al. (1988).

We estimate total abundance to be just under 30,000 harbor porpoise for Oregon and Washington. This includes a correction factor for animals missed because they were underwater. We estimated just over 13,000 harbor porpoise for coastal Oregon and just over 13,000 along the outer coast of Washington. The highest densities were found along the central and southern Washington coast accounting for high abundance for this region. As in previous years, a low number of harbor porpoise (under 1,000) was found on the northern Washington coast where harbor porpoise are caught incidentally. The abundance estimates for the Strait of Juan de Fuca and the San Juan Islands totaled just over 3,000. Comparison of the abundance estimates reported here with those made previously revealed good agreement with past estimates in some areas and disagreement in others. Where they disagreed, the current estimates were higher than previously calculated.

Coefficients of variation for the different regions were below the target of 0.30. To achieve these coefficients of variation we pooled some areas for analysis, such as the waters around the San Juan Islands and the Strait of Juan de Fuca, and 1990 and 1991 data for the low density northern Washington coast. The density estimates for the samples pooled were nearly identical.

Harbor seals were the most numerous marine mammal seen and were encountered in all regions except the limited effort in offshore waters. A total of 76 sightings of 154 Dall's porpoise were made during the surveys, primarily in the Strait of Juan de Fuca. Other marine mammals sighted included California and northern sea lions, sea otters, northern right-whale dolphins, killer whales, gray whales, minke whales, and a humpback whale.

The surveys in 1991 met the objectives of providing suitable abundance estimates for harbor porpoise in Washington and Oregon. The principal weakness of the abundance estimates is the absence of a tested correction factor with known variance for harbor porpoise missed on or near the transect line. Until this is developed a true minimum abundance must be based on the uncorrected abundance estimate. Given the importance of this factor in accurately assessing the true abundance of harbor porpoise, it warrants more effort than this question has been afforded to date.

INTRODUCTION

Harbor porpoise (*Phocoena phocoena*) along the northern coast of Washington have been killed incidentally in a set net fishery for salmon (Gearin et al. In press). The impact of this mortality on harbor porpoise populations is dependent upon the abundance of harbor porpoise and their movements. Aerial surveys (Turnock et al. In press, Calambokidis et al. 1991) were conducted in 1989 and 1990 and vessel surveys (Calambokidis, In press) were conducted in 1989 to estimate abundance in this region.

Harbor porpoise have been eliminated or their number greatly reduced from several regions including Puget Sound (Everitt et al. 1980, Calambokidis et al. 1985), the Baltic Sea (Otterlind 1976), the Wadden Sea (Wolff 1981) San Francisco Bay (Leatherwood and Reeves 1986), and portions of the east coast of North America (Prescott and Fiorelli 1980). Causes of theses declines are not well understood. Harbor porpoise are killed through net entanglement which has resulted in the death of hundreds of harbor porpoise annually along the California coast (Diamond and Hanan 1986, Hanan et al. 1986). Evaluation of the impacts of mortality off Washington requires an understanding of the abundance and distribution of this species.

The primary objective of the research reported here was to obtain a minimum abundance estimate for harbor porpoise in Washington and Oregon that had a coefficient of variation of 0.30 or less. An accurate minimum abundance estimate is needed for management of this species as required by regulations under the Marine Mammal Protection Act. These surveys were undertaken in conjunction with other research to determine the abundance of other marine mammal species subject to fishery-related mortality (Ferrero and Fowler, In Press). Secondary objectives of this research were to examine the distribution and preferred habitats of harbor porpoise and to evaluate the proportion of harbor porpoise not seen during aerial surveys.

METHODS

Study Area

The study area for aerial surveys was expanded from previous years to include the inland waters of Washington State as well as coastal Oregon which were not surveyed in 1990. The study area was divided into blocks to stratify the transect lines and calculate initial density and abundance estimates (Figures 1-3). Boundaries for these blocks were determined as follows:

1 - Coastal waters (out to 50 fathoms) off Oregon (including a small portion of northern California) from 41°43'N to just south of the Columbia River mouth at 46°13'N. The area around Heceta Bank was also included.

2 - Coastal waters (out to 50 fathoms) off southern Washington from 46°13'N, just south of Columbia River mouth to 47°45'N (just south of Hoh Head).

3 - Coastal waters (out to 50 fathoms) off northern Washington from 47°45'N (just south of Hoh Head) to 48°23'N (Cape Flattery).

4 - Southern side of the Strait of Juan de Fuca from Pillar Pt. west to the entrance of the Strait of Juan de Fuca encompassing waters from the shore out to the inbound traffic lane (subarea of Block 5).

5 - Strait of Juan de Fuca (including block 4 above) extending from Swiftsure Bank to Whidbey Island and including Admiralty Inlet.

6 - Waters around the San Juan Islands extending north from 48°25'N to 49°00'N and including a portion of the Strait of Georgia.

7 - Offshore lines at selected locations to examine offshore distribution. Only a single transect line was flown in this region.

8 - Major coastal embayments including Grays Harbor, Willapa Bay, and Columbia River.

9 - Puget Sound and Hood Canal.

Transect Design

A saw-tooth survey design, which has gained popularity in recent years (Cooke 1985, 1986), was used for sampling the study area (Figures 1-3). The transects covered the study area systematically. In areas where survey coverage was similar to 1990, such as the northern Washington coast, the same lines were used in 1991.

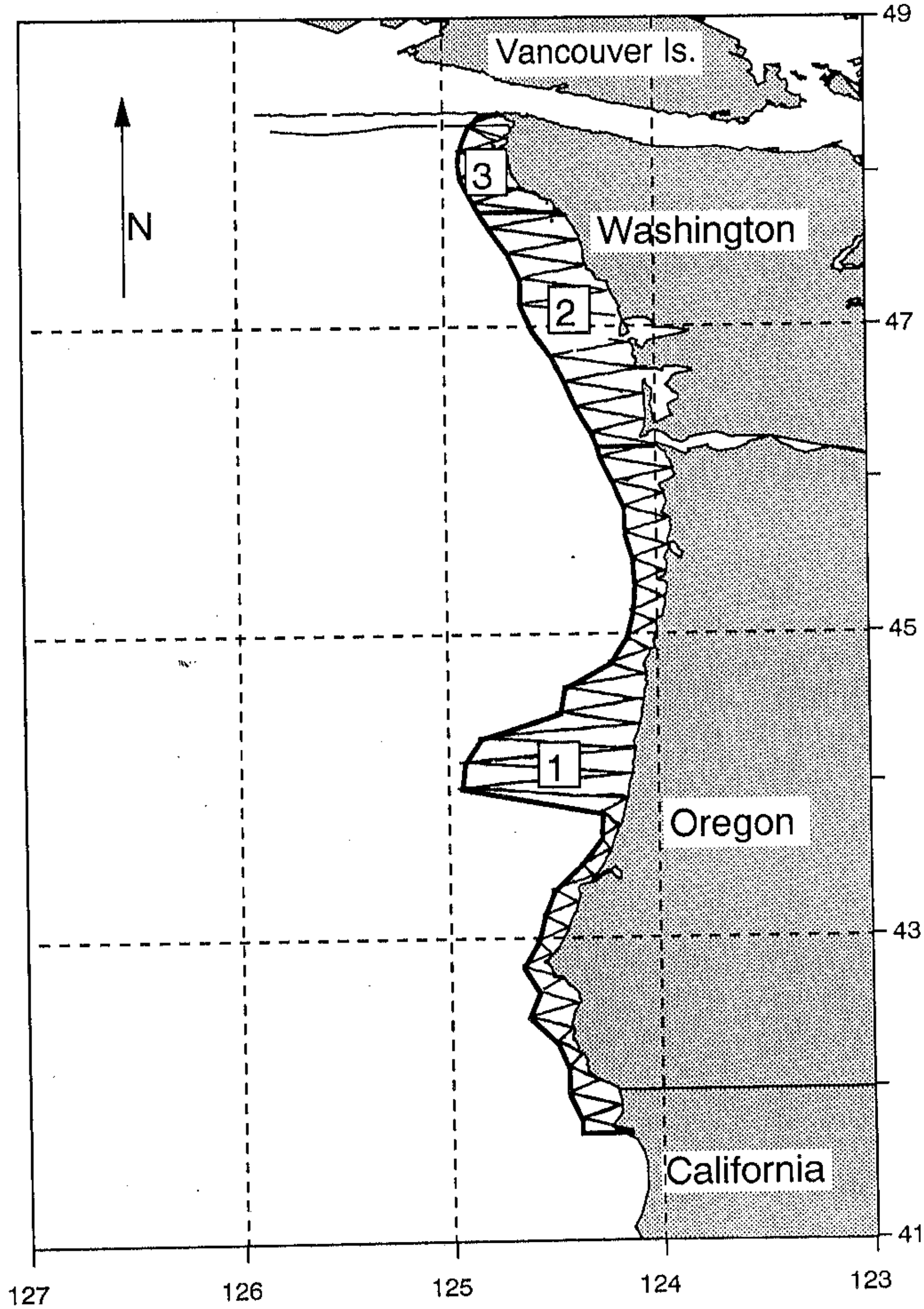

Figure 1. Study area and transect lines flown off Oregon and Washington. Numbers refer to study regions as described in text.

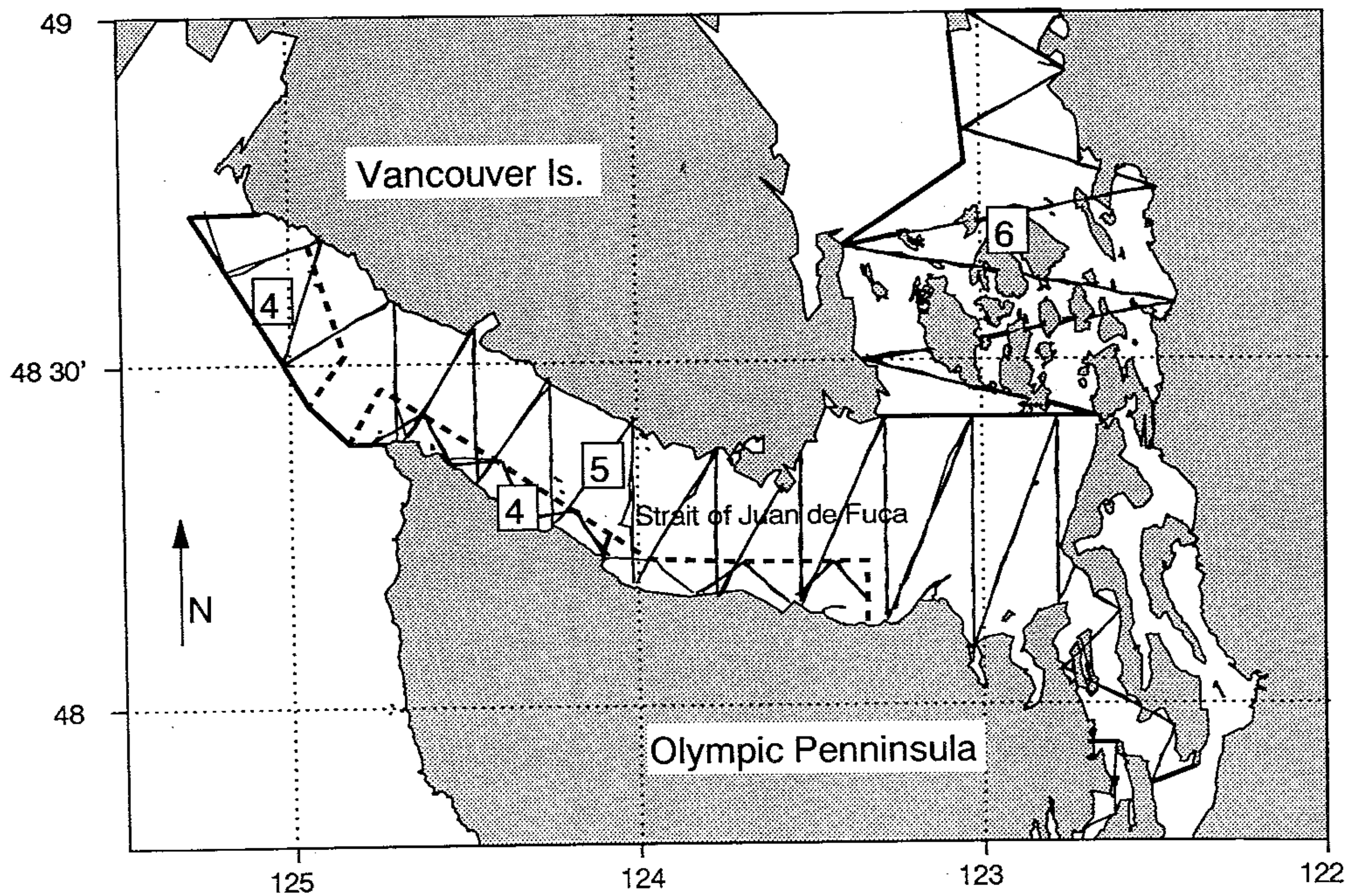

Figure 2. Study area and transect lines flown in the Strait of Juan de Fuca and San Juan Islands area. Numbers refer to study regions as described in text.

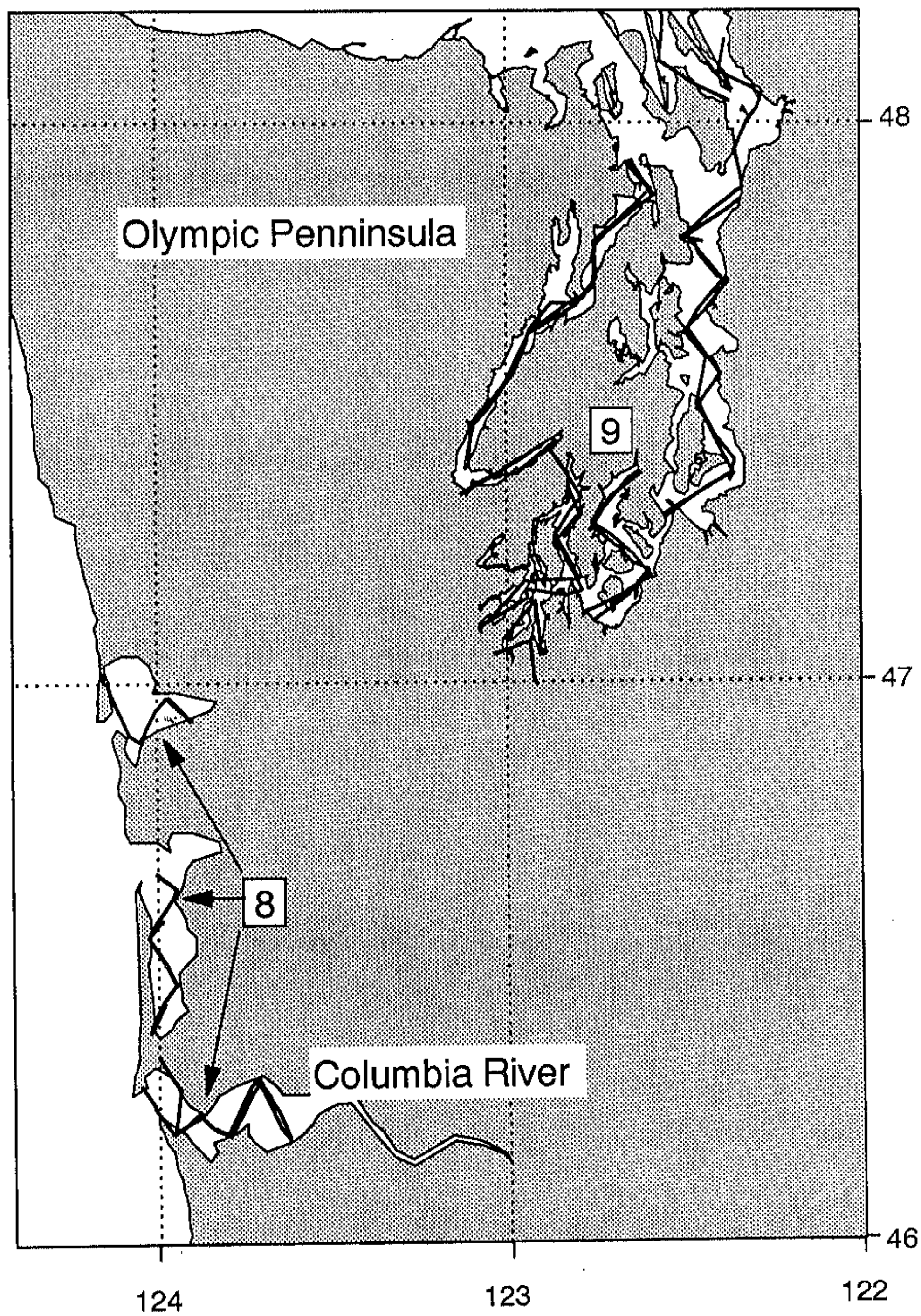

Figure 3. Study area and transect lines flown in Puget Sound, Hood Canal, and coastal embayments (including the Columbia River). Numbers refer to study regions as described in text.

Survey Design and Procedures

Two types of surveys were conducted in 1991. Areas 1-7 were surveyed with a twin-engine aircraft using standard line-transect methodology and procedures similar to those employed in previous years. Areas 8 and 9, Puget Sound and the coastal embayments, were surveyed with a single-engine aircraft.

Surveys of coastal Washington and Oregon

Surveys of areas 1-7 were conducted from a twin-engine, high-wing aircraft (Partenavia P-68) outfitted with bubble windows for side observation and a belly window to search below the aircraft. Three observers (left, right and belly) searched for animals while a fourth person, in the copilot seat, recorded data and navigated. Surveys were flown at 600 ft altitude and at an air speed of 90 kts. Data were recorded with a laptop computer that received data directly from the LORAN. Surveys were limited to good weather and were generally terminated when sea state consistently exceeded Beaufort 3 or overcast greater than 50%.

A summary of aircraft effort and the flight itinerary for the surveys with the Partenavia are provided in Table 1. Approximately 119 flight hours in total were expended between 7 July and 22 September 1991. Of these just over 40 hours were on-effort along 3,658 nm of transect lines. The remaining hours were used in transit to areas or to refuel, surveys canceled due to weather, taxi at airports, or in conducting other experiments like the calibration surveys described below.

Surveys of Puget Sound and coastal embayments

Puget Sound and the coastal embayments (Areas 8 and 9) are regions where few harbor porpoise were expected (Everett *et al.* 1980, Calambokidis *et al.* 1985). Abundance estimates were not expected to be possible in these areas due to the small numbers of harbor porpoise encountered. The single-engine surveys in Puget Sound and the coastal embayments were conducted to verify that harbor porpoise density in these regions were so low that they would not contribute measurably to the overall abundance estimates.

Transect lines flown during these surveys are shown in Figure 3. These followed a sawtooth pattern from shoreline to shoreline. Surveys were flown on 4 days (12 and 14 July, 4 August, and 5 September 1991). A total of 5.9 hours were conducted on-effort totaling 532 nm. This coverage allowed most areas to be covered twice and some three times.

Table 1. Summary of flights and intinerary for surveys.

Day	Mon.	Take-off		Landing		Blocks	Hours
7	July	HQM	10:40	HQM	13:57	3-all,2-N	3.3
8	July	HQM	11:32	BLH	15:10	6-all	3.6
8	July	BLH	17:04	HQM	19:19	5-Adm	2.3
11	July	HQM	08:10	BFI	08:50	Ferry to Boeing	0.7
11	July	BFI	09:35	HQM	13:35	1-N,2-S	4.0
11	July	HQM	14:45	EVT	18:40	2-mid,2obs,5-E,Adm	3.9
11	July	EVT	19:11	BFI	20:00	Transit	0.8
12	July	OLY	12:24	OLY	14:33	Puget Sound (part of N. HC)	2.1
14	July	OLY	13:50	OLY	16:47	Puget Sound (part of N. HC)	2.9
17	July	BFI	11:06	HQM	11:52	Ferry	0.8
17	July	HQM	16:06	HQM	18:31	1-NN(53-5),2-S(56-61)	2.4
18	July	HQM	10:32	CRC	12:48	Aborted (bad weather)	2.3
18	July	CRC	13:47	HQM	16:17	Transit	2.5
19	July	HQM		BFI		Transit	0.8
21	July	BFI	09:30	PA	12:10	5-E	2.7
21	July	PA	13:55	BFI	17:38	6-all	3.7
21	July	BFI	18:28	OLY	18:50	Transit	0.4
21	July	OLY	19:07	NB	20:43	Transit	1.6
22	July	NB	10:15	AST	11:48	Aborted (bad weather)	1.5
22	July	AST	12:23	PA	15:30	2-N, 3-S	3.1
22	July	PA	16:38	HQM	20:00	4-all,5-W	3.4
23	July	HQM	15:15	PA	19:06	Maint.,2-N(63-),3-all,4-all	3.8
23	July	PA	19:47	HQM	20:26	Transit	0.7
24	July	HQM	11:30	BFI	12:20	Ferry	0.8
28	July	BFI	09:45	PA	12:43	Abort-5, 6-all	3.0
28	July	PA	13:14	BFI	13:50	Transit	0.6
30	July	BFI	08:54	ORC	10:37	Calibration	1.7
30	July	ORC	11:33	ORC	13:36	Calibration	2.0
30	July	ORC	15:32	ORC	18:06	Calibration	2.6
31	July	ORC	15:43	BFI	16:21	Engine prob., transit	0.6
4	Aug.	OLY	11:15	OLY	13:30	Single-eng. Hood Canal	2.3
10	Aug.	BFI	10:10	OLY	10:39	Transit	0.5
10	Aug.	OLY	10:56	HQM	11:44	Abort Block 3 due to cl. cov.	0.8

Table 1. Continued

Day	Mon.	Take-off		Landing		Blocks	
10	Aug.	HQM	14:15	PA	17:49	All 3 (some poor) and Offsh.	3.6
10	Aug.	PA	18:15	BFI	18:46	Transit	0.5
11	Aug.	BFI	09:07	NPT	10:35	Transit	1.5
11	Aug.	NPT	14:32	NBE	15:17	Transit	0.8
12	Aug.	NBE	09:50	HQM	11:38	Transit (aborted)	1.8
12	Aug.	HQM	14:30	BFI	15:20	Transit	0.8
13	Aug.	BFI	09:59	SEK	10:47	Transit	0.8
13	Aug.	SEK	11:20	PA	14:28	Lines 124-133 and back	3.1
13	Aug.	PA	16:06	ORC	18:00	S San Juans	1.9
13	Aug.	ORC	18:15	BEL	19:13	Rest of San Juans	1.0
13	Aug.	BEL	19:41	PA	20:45	Transit	1.1
14	Aug.	PA	13:14	SEK	14:46	E Block 4 done twice	1.5
14	Aug.	SEK	15:01	BFI	15:57	Transit	0.9
15	Aug.	BFI	11:03	PA	14:34	W strait (Bl 5), All 4	3.5
15	Aug.	PA	16:07	SEK	17:16	Aborted Bl 4 attempts	1.2
15	Aug.	SEF	17:39	BFI	18:24	Transit	0.8
17	Sep.	BFI	13:23	NEW	15:12	Transit to OR	1.8
18	Sep.	NEW	09:00	NB	12:48	Block 1 surveys	3.8
18	Sep.	NB	15:00	NEW	16:45	Block 1 surveys	1.7
21	Sep.	NEW	09:34	NEW	12:52	Block 1 surveys	3.3
21	Sep.	NEW	15:18	CRC	16:32	Block 1 surveys	1.2
22	Sep.	CRC	08:47	NB	10:58	Block 1 surveys	2.2
22	Sep.	NB	12:05	CRC	12:55	Block 1 surveys	0.8
22	Sep.	CRC	13:39	BFI	16:28	Transit back to BFI	2.8
						Taxi time	5.7
						SWFC surveys of OR	10.0
Total hours for twin-engine aircraft							119.0
Total hours for single-engine aircraft							7.3
Total hours for all aircraft							126.3

Land calibration

An aerial survey was conducted on 30 July 1991 in conjunction with land observations to examine the proportion of harbor porpoise groups that were being missed during aerial surveys. Transects were flown in an east-west direction off the northwest end of Orcas Island. These surveys were separate from the abundance surveys and were not included in the calculation of sighting functions, density estimates, or distribution. A total of 7 flight hours was expended completing approximately 5 hours of transect surveys.

A five-person land observation team made observations of harbor porpoise from Pt. Doughty at the northwest corner of Orcas Island that provides a view of waters from the northeast to the west (Figure 4). Observers sighted harbor porpoise with reticle/compass binoculars and noted the compass readings and angle below the horizon or background land to each sighting. A single observer with a theodolite obtained more accurate positions when possible. Groups of harbor porpoise were followed by individual observers and were given the same alpha-numeric designation for as long as observers were confident they were tracking the same group.

Positions were calculated using the bearing and angle measurements from the theodolite and binoculars. Because reticle readings from the binoculars were only in relation to the horizon or land behind the sighting, the distance to land was calculated for each observation direction and used to calculate the distance to harbor porpoise groups. Because tide affected the height of the observation platform above the water, the value for the height of the platform was adjusted during analysis from that measured in the field based on changes in tidal elevation.

Aerial surveys for the calibration were conducted with the Partenavia in an identical fashion to the line-transect surveys used to assess population abundance. Radio contact with the land site was used to make adjustments to the survey route to insure that land and aerial observers were examining the same areas. A total of 117 transects were flown from along an East-West past off the land site (Figure 4).

Data Recording

Effort, weather and sea conditions, and sighting data were recorded during surveys. Effort and position readings were made at least with every start and stop of transect lines or when weather conditions, observers, or aircraft course changed. With computer-recorded surveys, positions were noted every minute. Distance off the

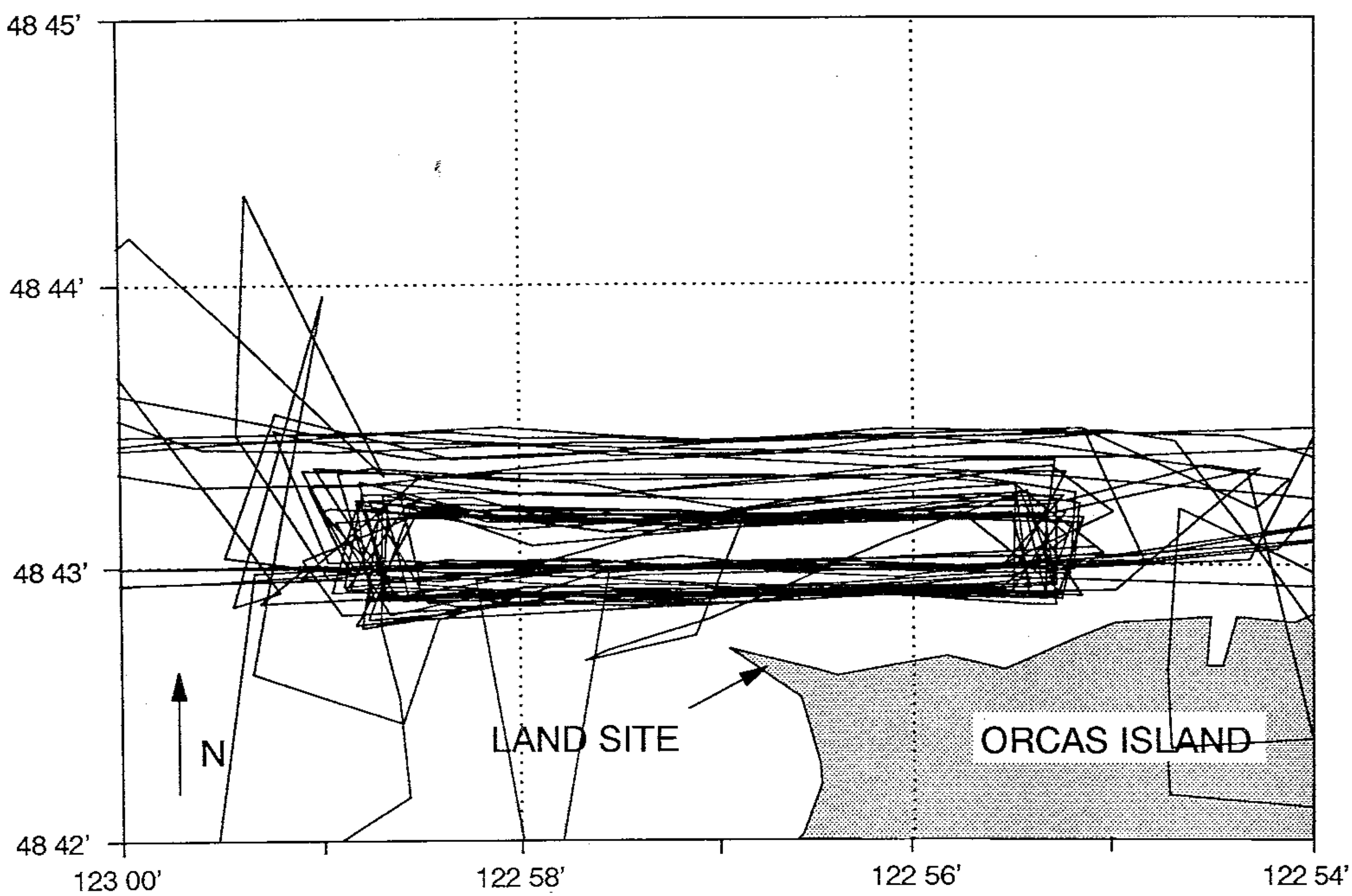

Figure 4. Study area for calibration surveys used to evaluate harbor porpoise missed by aerial observers. Location of land observation site on Orcas Island and survey lines flown on 30 July 1991 by aircraft are shown.

transect line (perpendicular sighting distance) for sightings was calculated from the clinometer-measured angle from the horizon of the sighting as it passed abeam the plane and the aircraft altitude. Position of the observer making the sighting was also noted. The observer's subjective evaluation of visibility quality (including sea state, glare, surface penetration, etc.) and glare intensity were noted. Number of porpoise that were adults and calves were recorded.

Error checks of the data were conducted prior to analysis. This included checking all sequential positions for reasonable speed between points and valid locations to find potential errors in computer entry. In addition to the 510 sightings of harbor porpoise, five entries were made in the field as harbor porpoise? (considered likely harbor porpoise but observers were not confident of the identification) and 12 entries were codes as unidentified small cetaceans (not considered likely harbor porpoise). For the analysis, all five tentative sightings were treated as harbor porpoise but none of the unidentified small cetaceans was treated as a harbor porpoise. Regardless of interpretation, the small number of questionable sightings has little impact on the results.

Analysis of Sighting Rates

Sighting rates of harbor porpoise were calculated and compared for different visibility conditions including Beaufort sea state, percent cloud cover, observer visibility quality, and glare. Sighting rates were calculated as number of animals seen on transect per nautical mile (nm) of transect effort. In order to statistically test the sighting rates by weather conditions, summaries were prepared by transect line of sighting rates, average sea state, and cloud cover.

The effects of Beaufort sea state and cloud cover were tested with multiple regression. An analysis of covariance was used to test the effect of these factors by region. The above analysis for Beaufort sea state was somewhat unconventional because we treated Beaufort sea state as a continuous measurement variable. This violation was considered acceptable because Beaufort sea state does reflect a progression of scaled estimates of wind speeds. Testing sighting rates using only complete transect lines avoids the problem of non-independence of harbor porpoise sightings created by the often clumped nature of sightings along a transect line.

Density Calculations

Density and abundance calculations were made following the methods described by Burnham et al. (1980). Line-transect calculations were conducted both for all data and excluding all effort and sightings during sea state conditions worse than Beaufort 2 or cloud cover greater than 25%. As explained in the results, effort in poorer conditions yielded lower sighting rates. A truncation point of 1,200 ft was used in the calculation which resulted in the exclusion of less than 5% of sightings. A model of the sighting frequency versus perpendicular distance off the track-line was fitted (Figure 5) with the Fourier Series using formulas given in Burnham et al. (1980) and the Hazard-rate model using the program HAZARD (Buckland 1985).

The Hazard-rate model was selected for use in the abundance estimates primarily because this was the model used in previous abundance estimates of harbor porpoise. The Hazard-rate appeared to more accurately model the limited deterioration of sighting frequency at distances closest to the transect line (Figure 5). Chi-square values that compared the observed and expected (modeled) number of sightings in each distance category were similar between the Fourier and Hazard models (Chi-square values of 10.2 and 10.3, respectively). Use of the Fourier model would have increased the abundance estimates by about 20% reflecting the higher f(0) obtained from the Fourier model.

Variances for the density estimates were computed by several techniques to allow comparison between some of the methods employed in past surveys. In all cases, the variance for f(0) was computed from the program HAZARD (Buckland 1985). The variance for the number of sightings, however, was computed by two methods.

First, variance was estimated using each line through a region as a replicate and calculating the variance for the number of sightings using the following formula from Burnham et al. (1980):

$$Var\ (n) = L * \frac{sum(l_i[n_i/l_i - n/L])}{R - 1}$$

Where: l_i and L are the replicate and total transect lengths
n_i and n are the replicate and total number of sightings
R is the number of replicate lines in the sample

The variance of D was calculated as follows:

$$Var\ (D) = D^2 * [cv(n)^2 + cv(f(0))^2 + cv(G)^2]$$

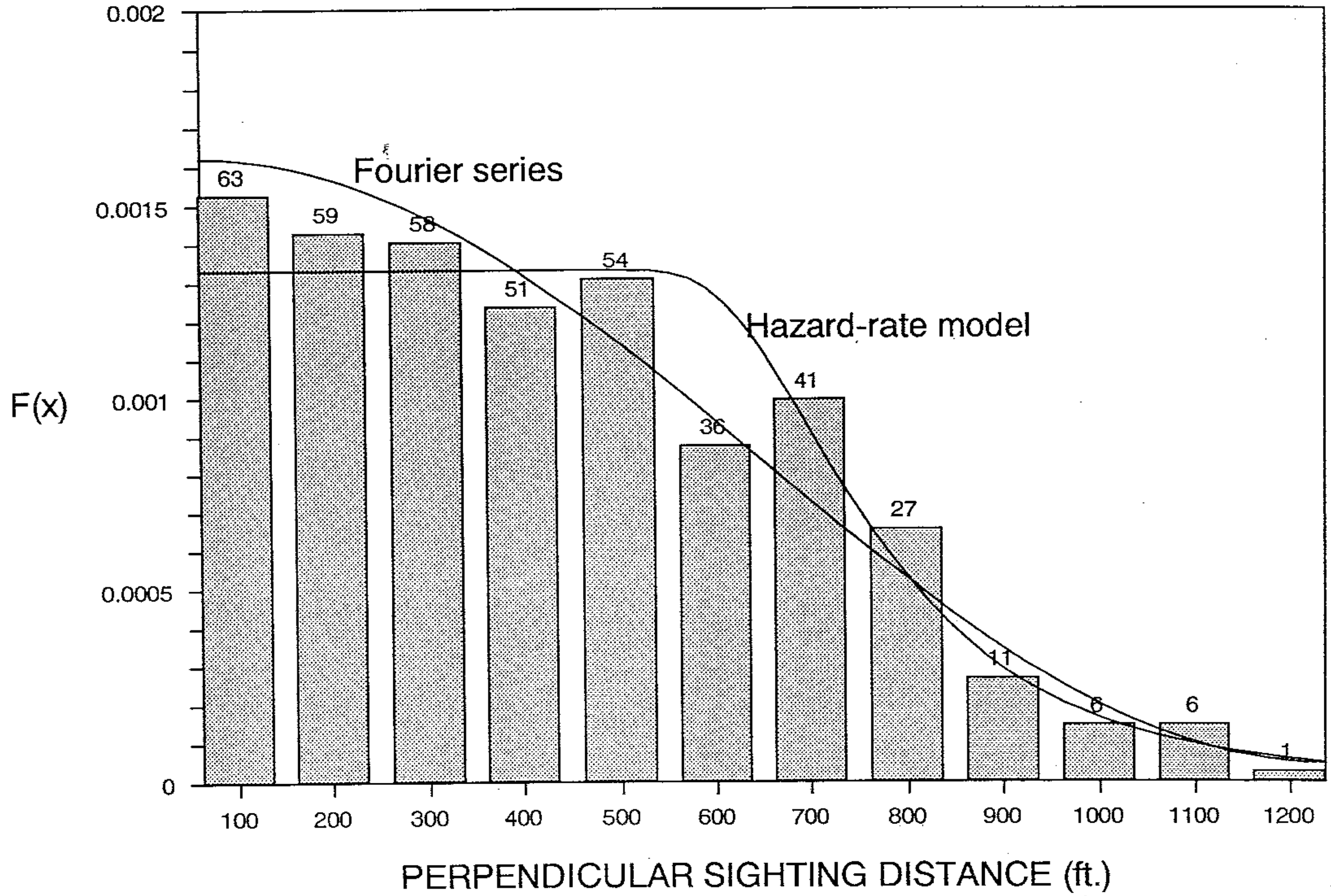

Figure 5. Distribution of perpendicular sighting distances and fitted models. Numbers above bars show the number of sightings.

Where cv(n), cv(f(0)), and cv(G) are the coefficient of variation for the number of sightings, f(0), and group size, respectively. Coefficients of variation were calculated as the square root of the variance divided by the estimate for that parameter (i.e. $cv(n)=Var(n)^{1/2}/n$). Group size was estimated using all on-effort harbor porpoise sightings and the cv calculated using the standard error of the mean of group size.

Second, we determined variance of the number of animals seen on each survey line using bootstrap procedures described in Barlow (1988). Because number of animals was used instead of number of sightings, this avoids the need to calculate a separate variance for group size.

Correction for Animals Missed on Transect

Though most terrestrial line-transect surveys rely on the assumption that all animals on the transect line are detected (Burnham et al. 1980), this is clearly not the case with harbor porpoise and other marine mammals that elude detection underwater. An estimate of the animals missed while underwater is required. Three approaches were considered to evaluate the proportion of harbor porpoise groups that were not detected by the aerial surveys: 1) we examined the correction factors developed in other aerial line-transect surveys of harbor porpoise (Barlow et al. 1988), 2) we examined the ability of the aircraft observers to detect harbor porpoise groups being tracked from a land observation site, and 3) we conducted some limited experiments on whether harbor porpoise seen by the recorder or a second rear observer were also seen by the primary observers.

For the abundance estimates, we used the correction factor for harbor porpoise missed by aerial surveys developed by Barlow et al. (1988). The calculation was based on the breath rates of harbor porpoise and assumed all animals along the transect line on the surface when the aircraft passes were seen. This correction factor (3.2) was also used in the abundance estimates from the 1989 aerial surveys off Washington and Oregon (Turnock et al. In press). We were not able to calculate an additional correction factor for animals missed while at the surface. Sightings made by a recorder or a second rear observer were difficult because of the limited visibility of observers not using the single bubble windows on each side of the aircraft.

RESULTS AND DISCUSSION

Number and Locations of Sighting

A total of 1,236 sightings of 4,816 marine mammals were made during the surveys. Of these, 579 sighting of 913 animals were of harbor porpoise (not including the calibration experiment). Locations of the 501 sightings of 782 harbor porpoise made on-effort by the primary observers during transects are shown in Figures 6 and 7.

Sightings were frequent throughout coastal Oregon especially near the California border. Harbor porpoise were also frequently seen in the offshore areas that were surveyed near Heceta Bank. Southern Washington sightings were most frequent between Grays Harbor and Hoh Head where some of the highest densities seen during the surveys were encountered on several survey lines. Sightings off northern Washington were less common despite the higher coverage of this region.

During surveys throughout the inland waters of Washington State, sightings were only made in the Strait of Juan de Fuca and the San Juan Islands area. Sightings in the Strait of Juan de Fuca were dispersed throughout the region including the shallow as well as deeper waters in the central part of the Strait. Sightings off the San Juan Islands were most common in the northern portions of the study area.

Surveys throughout Puget Sound confirmed the absence of harbor porpoise south of Admiralty Inlet in the Puget Sound Basin and Hood Canal. Though some harbor porpoise may have been missed in the Puget Sound surveys (conducted with a single-engine aircraft), the absence of sightings indicate that if present, porpoise numbers were extremely low. Similarly, surveys of the coastal estuaries did not yield any harbor porpoise sightings.

Effort-corrected sighting rates by region are shown in Figure 8. These show that the highest sighting rates were off southern Washington followed by Oregon. Sighting rates in northern Washington, Strait of Juan de Fuca, and waters around the San Juan Islands were all considerably lower than Oregon and southern Washington.

Depth and Offshore Distribution of Sightings

The depth at which harbor porpoise were seen varied significantly among the study regions (ANOVA, $p<0.001$). These mean water depths for sightings ranged from

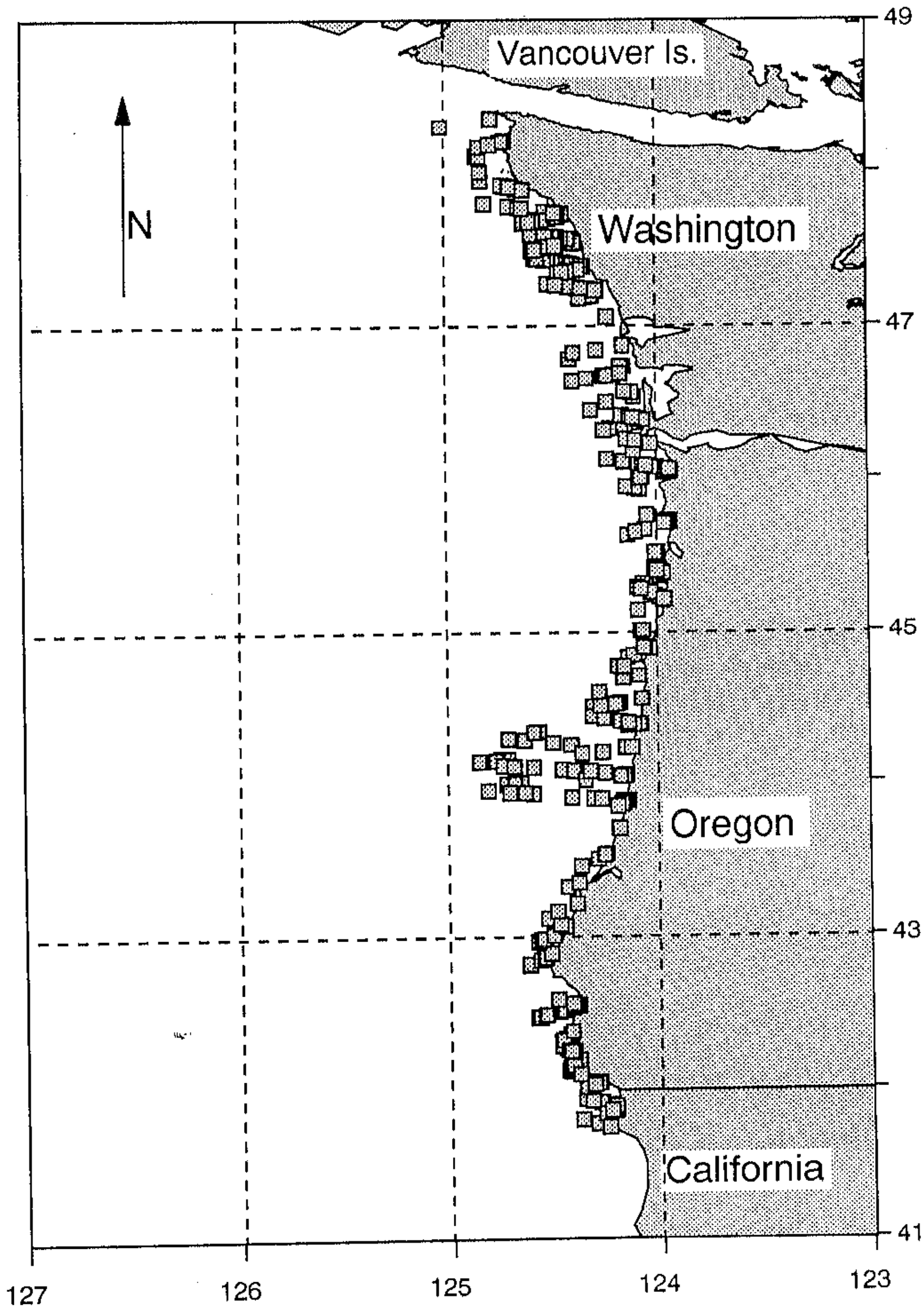

Figure 6. Locations of on-effort harbor porpoise sightings off Washington and Oregon.

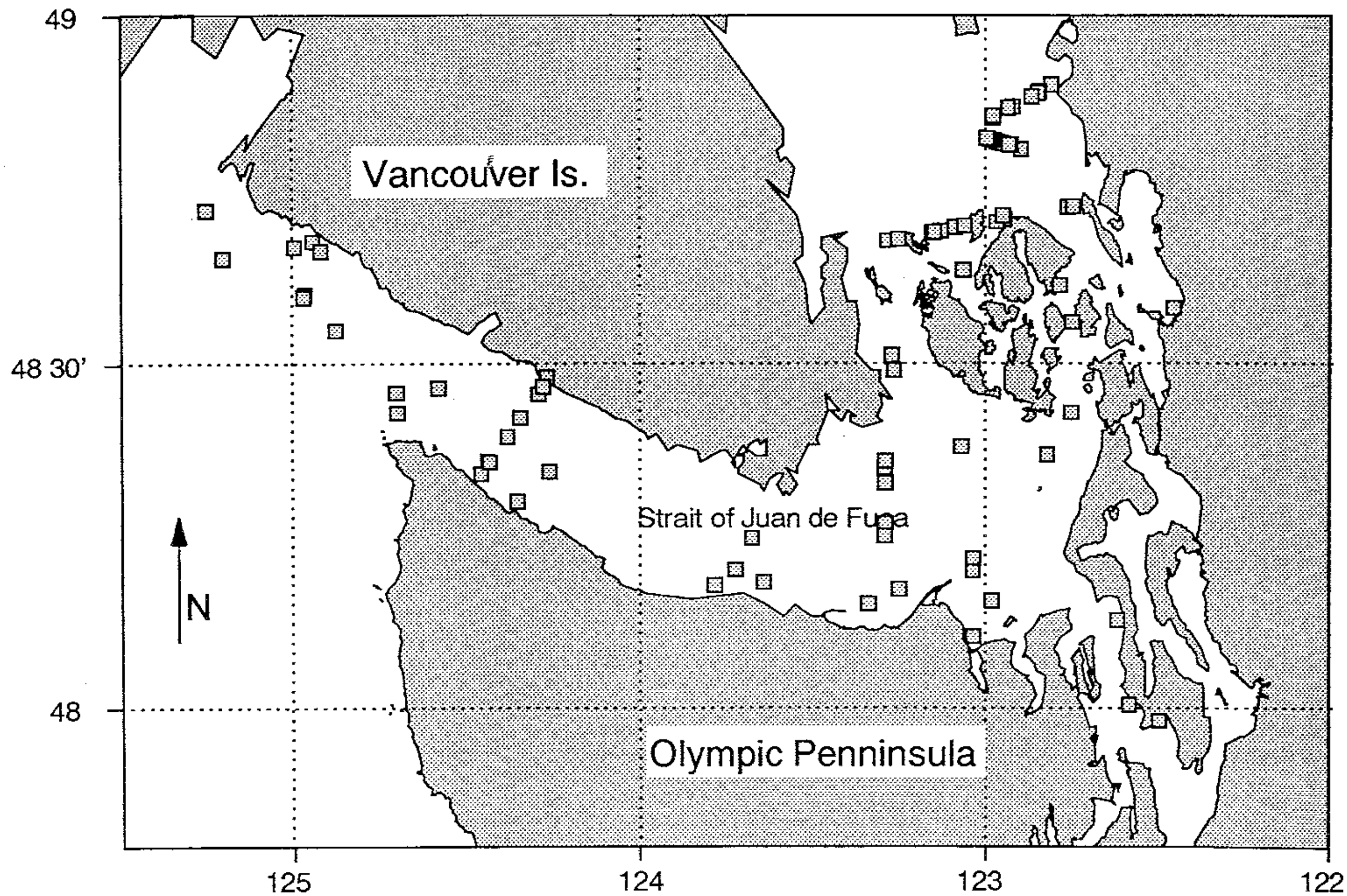

Figure 7. Locations of harbor porpoise sightings in the Strait of Juan de Fuca and waters around the San Juan Islands.

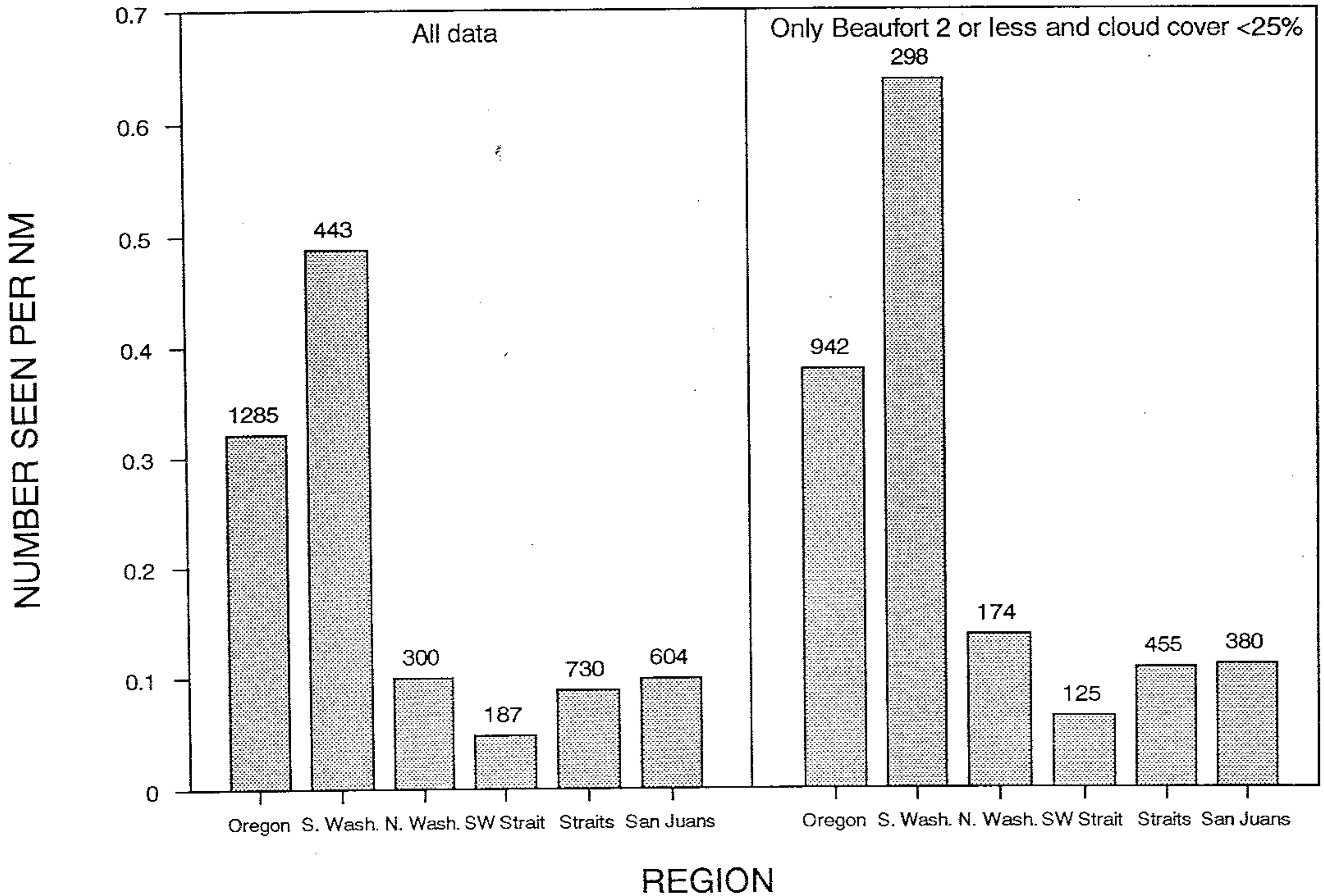

Figure 8. Numbers of harbor porpoise seen per nm of survey effort by region. Numbers above bars show the number of nm of survey effort.

a mean of 16 fathoms (n=35, SD=7.6) off the southern Washington coast to 62 fathoms (n=37, SD=44) in the San Juan Islands area. These depth differences only partly reflect the differences in the amount of effort conducted at different depths among regions. The number of sightings in depth classes was significantly different than expected from the distribution of effort by depth class for all of the principal study regions (Chi-square test, $p<0.001$ for the three coastal regions and $p<0.05$ for both the Strait of Juan de Fuca and San Juan Island areas).

Effort-corrected sighting rates for the three coastal regions revealed that sighting rates were generally highest in shallower waters (Figure 9). Off both Oregon and southern Washington, the sighting rates were highest in waters less than 20 fathoms. In both regions more than 50% of the sighting were made in waters shallower than 20 fathoms. Sighting rates in the limited coverage of waters deeper than 50 fathoms were low. Because waters deeper than 50 fathoms were generally excluded from the surveys, this effort was primarily conducted in areas of offshore banks, such as around Heceta Bank, where transect lines crossed deeper waters to access shallower offshore areas.

Though there were significant differences in the depth distribution of sightings in the San Juan Islands and the Strait of Juan de Fuca these did not follow as clear a pattern as those the coasts of Washington and Oregon (Figure 10). Sighting rates in the Strait of Juan de Fuca were generally highest between 10 and 40 fathoms, though sighting rates were also relatively high in waters deeper than 100 fathoms. In the San Juan Islands area sighting rates were highest in water depths deeper than 50 fathoms. The San Juan Island area is characterized by steep depth contours with deep water areas often close to shore.

Examination of the proportion of sightings and sighting rates in relation to distance offshore revealed similar patterns to those found for water depth. This would be expected because of the general correlation between depth and distance from shore. In all regions most sightings were made within 6 nautical miles of shore (Figure 11). In the San Juan Islands area, 76% of sightings were within 2 nm of shore, largely because with the numerous islands in this area, most of the area surveyed was close to land. Effort-corrected sighting rates were also highest within 6 nm of shore (Figure 12).

Sightings of Calves

Of the 795 harbor porpoise seen while conducting transects, 54 or 7% were judged to be calves by the observers. The proportion of calves did not vary significantly

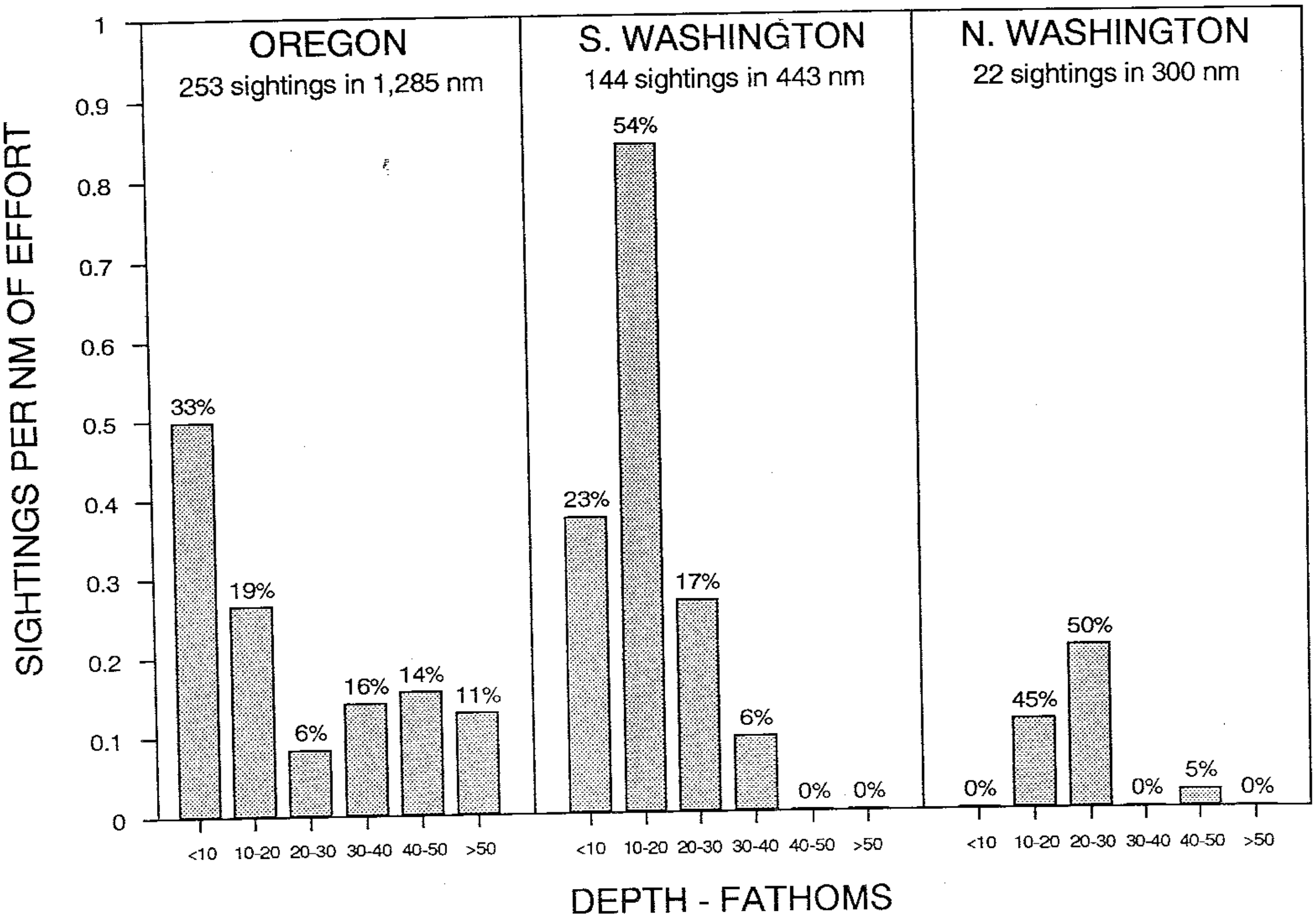

Figure 9. Sightings of harbor porpoise per nm of survey effort by water depth for the coasts of Oregon and Washington. Numbers above bars show the percent of total sightings made in that depth class.

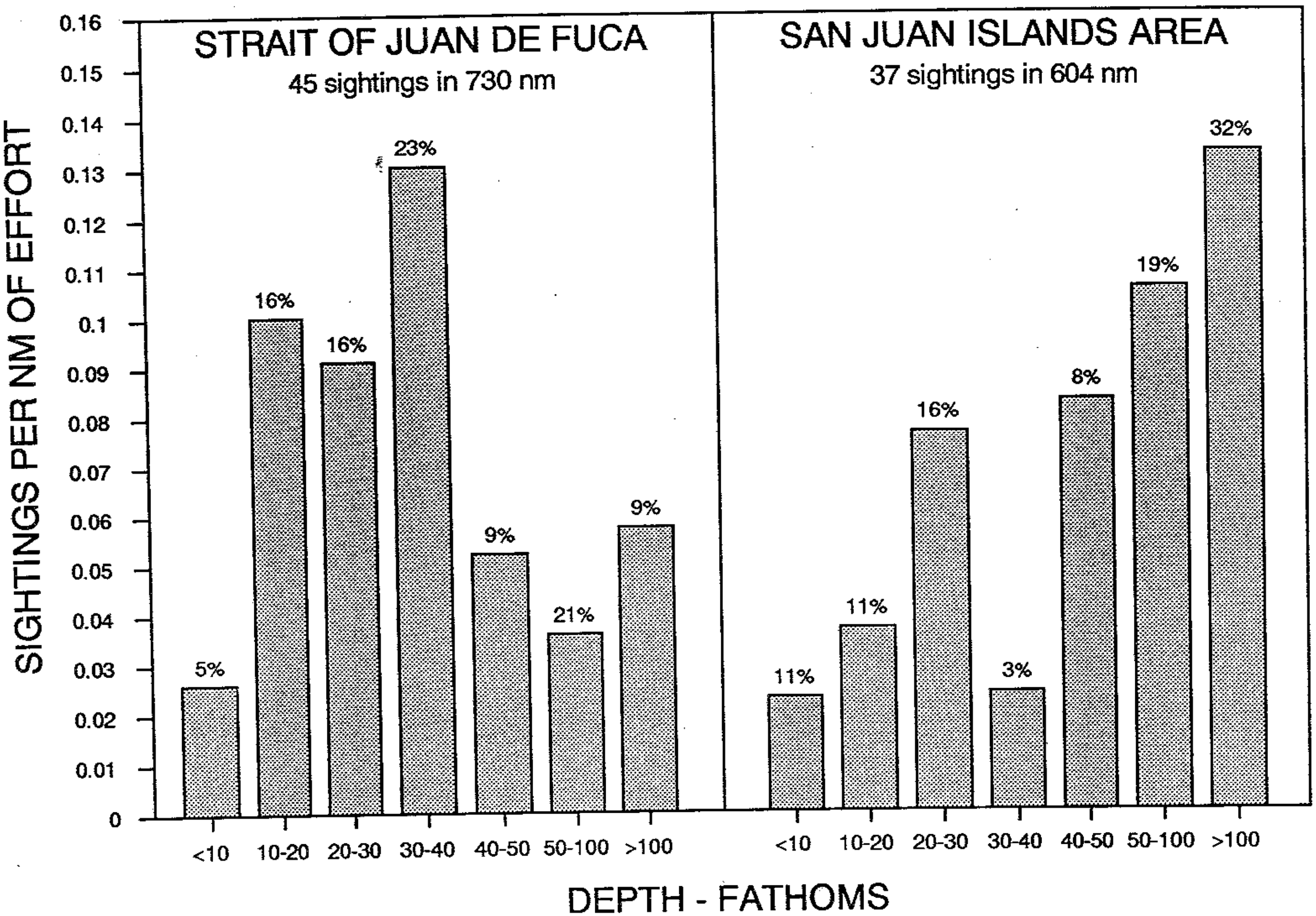

Figure 10. Sightings of harbor porpoise per nm of survey effort by water depth for the Strait of Juan de Fuca and San Juan Islands area. Numbers above bars show the percent of total sightings made in that depth class.

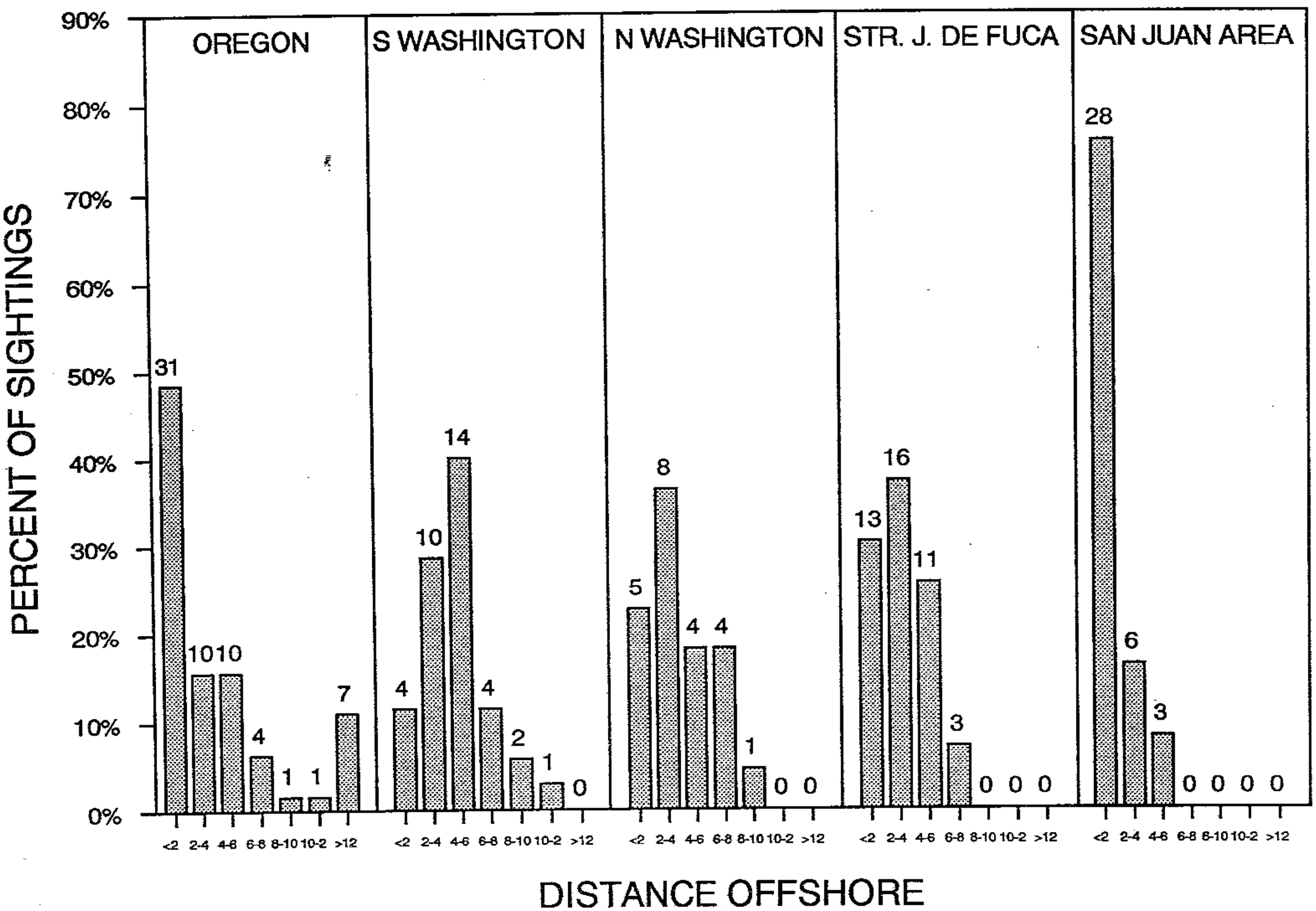

Figure 11. Percent of harbor porpoise sightings made at different distances from shore for each survey area. Numbers above bars show number of sightings.

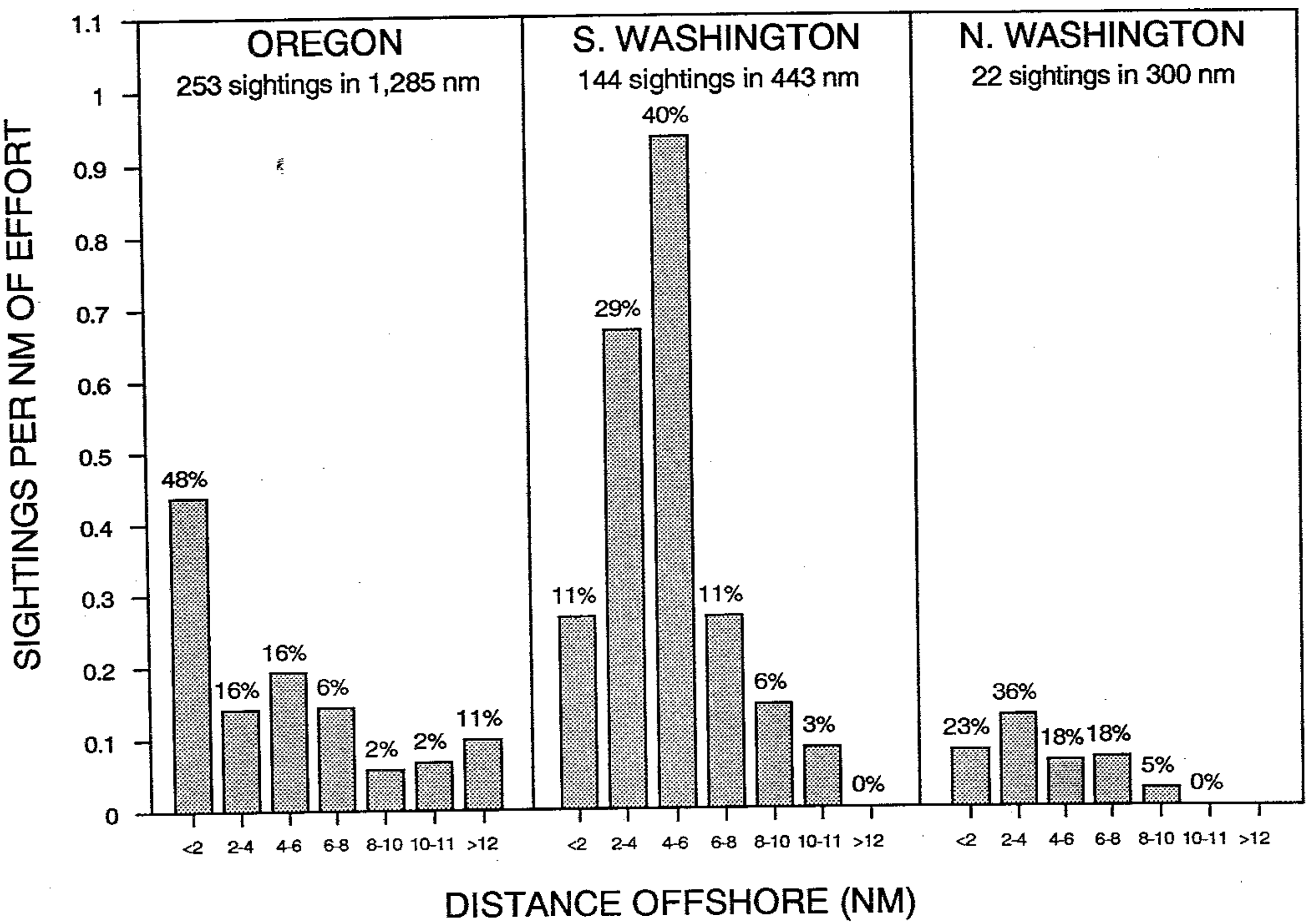

Figure 12. Sightings of harbor porpoise per nm of survey effort by distance offshore for the coasts of Oregon and Washington. Numbers above bars show the percent of total sightings made at that offshore distance.

among regions (Chi-square test, $p>0.05$). The observed proportion of calves is similar to the gross annual recruitment rate reported for harbor porpoise in the Bay of Fundy (Gaskin *et al.* 1984).

Harbor porpoise calves were distributed throughout the study regions and showed no distinct difference from the distribution of overall sightings (Figures 13-14). There was not a significant difference in the distance offshore for porpoise groups containing calves compared to those without calves (ANOVA, $p>0.05$). Average depth of sightings of calves was different than sightings without calves (ANOVA, $p=0.02$), however, this difference was not significant when region was included as factor (two-way ANOVA, $p>0.05$).

Factors Affecting Sighting Rates

Two factors, Beaufort sea state and cloud cover, were found to alter the sighting rate of harbor porpoise. This is consistent with findings from past years. The number of animals seen per nautical mile surveyed declined with increasing Beaufort sea state and increasing cloud cover (Figure 15). The sample size for sea state conditions of Beaufort 3 and higher and cloud cover greater than 50% was limited because we generally terminated surveys when conditions consistently reached these levels.

Statistical tests of the sighting rate by survey line confirmed the effect of both Beaufort sea state and cloud cover. Simple regressions were significant between sighting rates and both sea state ($p=0.002$) and cloud cover ($p=0.008$). When considered simultaneously, multiple regression indicated sighting declined significantly with both increasing cloud cover and sea state ($p<0.001$ for both factors). The significance of these effects remained even if regional differences were included in the model with an analysis of covariance. Forney *et al.* (1991) found that both sea state and cloud cover significantly influenced harbor porpoise sighting rate based on multi-way ANOVA.

Based on the examination of sighting rates given different sighting conditions, we decided to accept survey effort for density and abundance analysis only if conducted in conditions of Beaufort 2 or calmer sea state and overcast of less than 25%. Eighteen percent (651 nm) of the survey effort had cloud cover greater than 25% and 19% (693 nm) of effort was in sea state greater than Beaufort 2. A total of 2,387 of the 3,658 nm survey effort (on transect) fell within the acceptable weather criteria and was used for the abundance estimates. This effort was distributed throughout the study area.

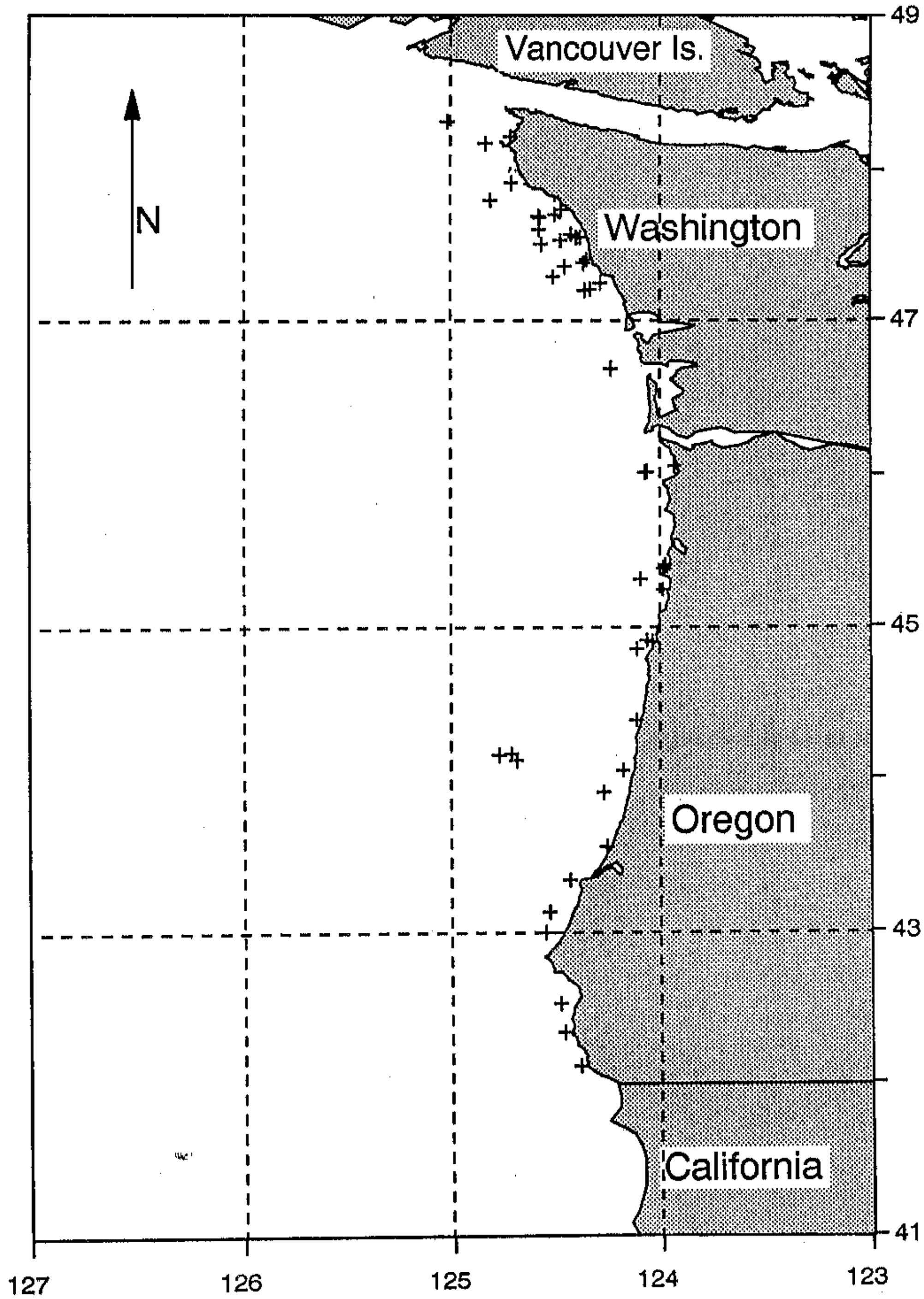

Figure 13. Locations of sightings of harbor porpoise mothers and calves in the Strait of Juan de Fuca and the San Juan Islands area during aerial surveys.

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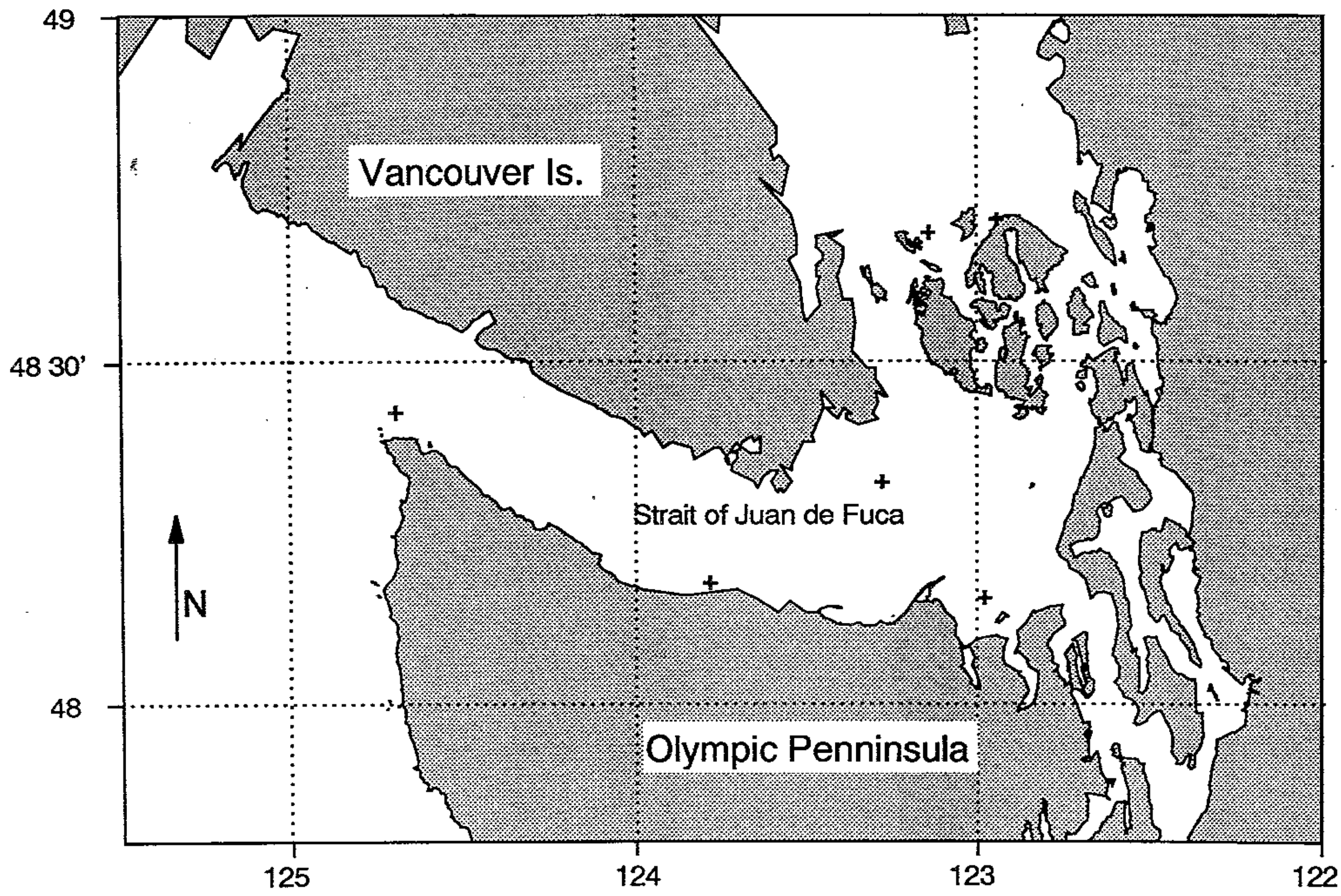

Figure 14. Locations of sightings of harbor porpoise mothers and calves along the coasts of Oregon and Washington made during aerial surveys.

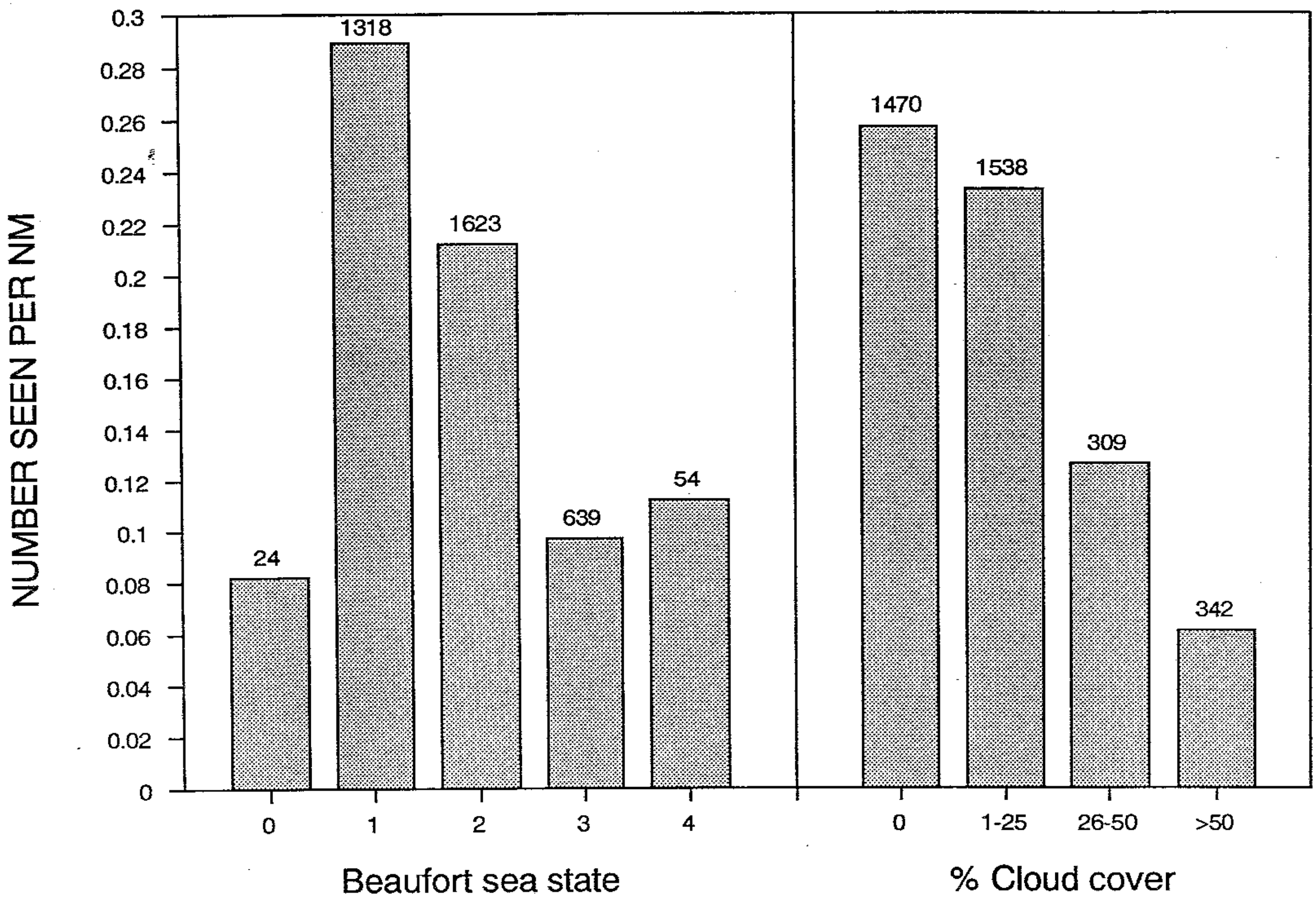

Figure 15. Number of harbor porpoise seen per nm of survey effort by Beaufort sea state and cloud cover. Numbers above bars show nm of survey effort.

Land Calibration

Though the land calibration experiment was conducted on only a portion of a single day, both the land and aerial observers sighted large numbers of harbor porpoise. The land observation team obtained positions on 522 sightings of harbor porpoise and the aerial observers made 259 sightings of harbor porpoise. Locations of the harbor porpoise groups sighted by the two teams were similar (Figure 16). The high number of sightings reflected the extremely high density of harbor porpoise in this area.

A primary goal of the analysis of the calibration data was to determine if harbor porpoise groups being tracked by land near the path of the aircraft were successfully sighted by aircraft observers. This was not possible because the relatively inaccurate position fixes obtained with the reticle binoculars and the high density of harbor porpoise groups made verifying whether a specific group had been seen by the land and the aerial crews impossible.

A more general analysis of the calibration data was conducted for the primary viewing area directly north of the land site. We compared the total number of harbor porpoise groups seen by aerial and land teams along a 500 ft. strip to either side of the aircraft path. This revealed that in the primary viewing area the land team saw 89 harbor porpoise groups within 2 minutes of the aircraft pass and within a 500 ft. zone on either side of the transect line. A total of 89 harbor porpoise groups were being tracked by land observers within this zone immediately before or after the aircraft passed. The aircraft, however, only saw a maximum of 41 or 46% of these groups. This is a maximum because additional harbor porpoise groups may have been present and seen by the aircraft that were not being tracked by the land team. The impact of this bias was limited by not counting aircraft sightings above the number being tracked by land. A more restrictive analysis, using only transect lines flown when land observers were tracking two or more groups within the flight zone, yielded a slightly lower sighting rate with a maximum of 18 groups seen by the aircraft out of the 45 (40%) being tracked from land.

Unfortunately this experiment fell short of providing a new quantitative correction factor. The maximum sighting rates of 40% and 45%, however, are not out of line with the correction factor being employed based on Barlow et al. (1988) which assumes 31% of groups along the transect line are seen. The primary difficulty with the calibration experiment was the extremely high density of harbor porpoise in the area.

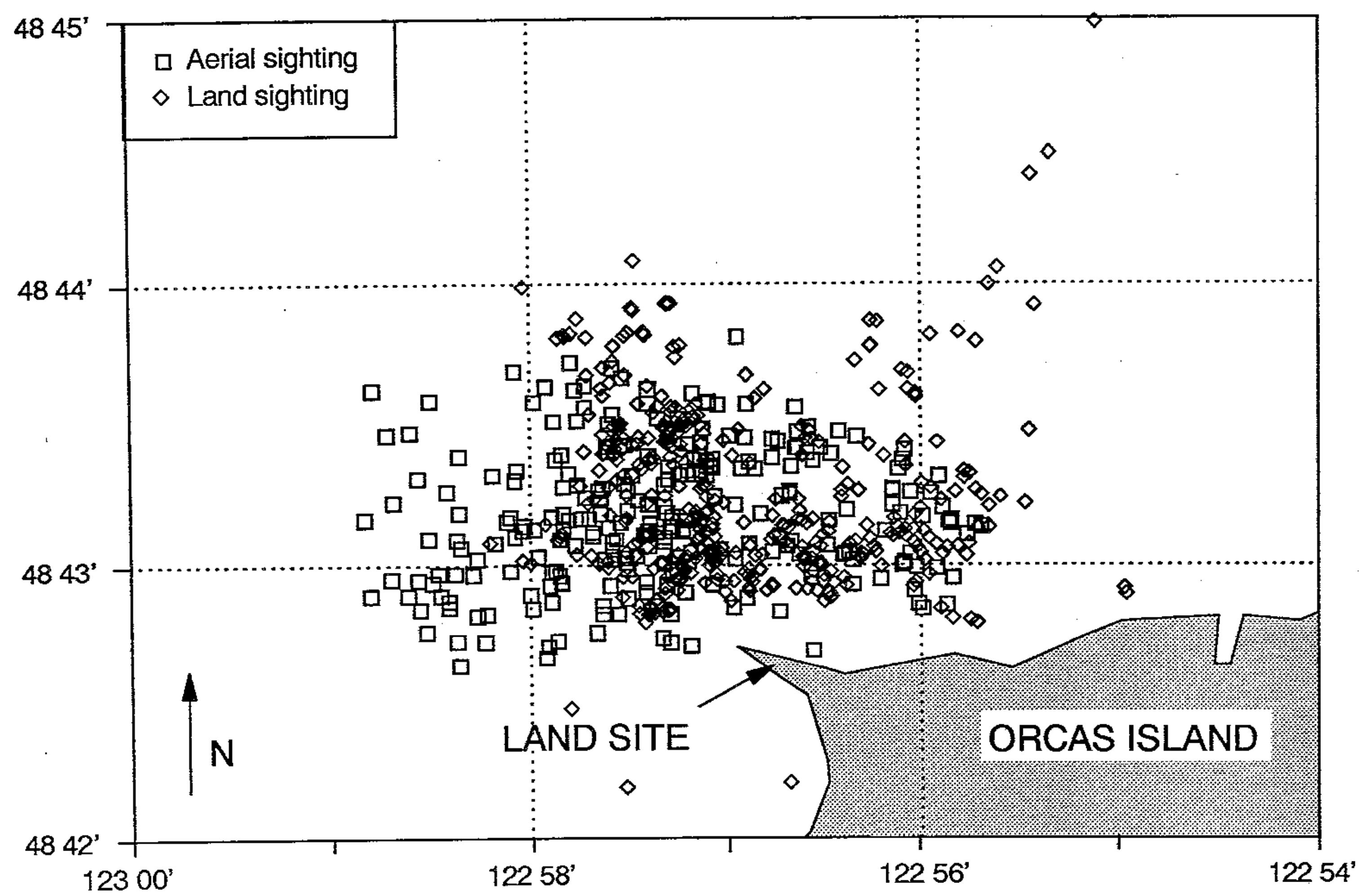

Figure 16. Locations of harbor porpoise seen from land and air during the land calibration experiment off of Orcas Island on 30 July 1991.

Group size

Group size of harbor porpoise sighted during transects averaged 1.56 (n=500, sd=0.79). The majority of the sightings (56%) were of single animals. Group sizes of 4 or greater made up only 2% of the sightings and the largest group size was eight. There were no significant differences in group size by region, or weather condition (p>0.05 in all cases). There also was not a significant difference in the mean distance to sightings in relation to group size (p>0.05), an important consideration for the line transect estimates. Based on the similarity in group sizes among regions and the absence of a significant group size difference, group sizes were pooled among regions for the line-transect estimates.

The group size of harbor porpoise in 1991 was significantly greater (t-test, p<0.05) than the 1.33 (n=73, sd=0.498) group size during the 1990 aerial surveys (Calambokidis et al. 1991). The 1991 group size is more consistent, however, with the larger groups sizes noted in the 1989 vessels surveys and land observations.

Density and abundance estimates

Harbor porpoise density and abundance estimates based on the 1991 surveys conducted at Beaufort 2 or calmer sea states and cloud cover of 25% or less are shown in Table 2. Highest densities of harbor porpoise were seen off southern Washington. Densities in this region were almost double that in Oregon and more than four times higher than any other area off Washington. Lowest densities were in the inland marine waters of Washington.

As discussed previously, a correction factor for animals on the transect line has not been tested with harbor porpoise. The correction factor included in Table 2 is that used by Barlow et al. (1988) and has no variance associated with it. The CVs presented in Table 2 are therefore only valid for the density and uncorrected abundance estimates. If true minimum abundance estimates with known CVs are sought, therefore, the uncorrected abundance estimate should be used. For the sake of discussion in this report, however, we will be referring to the corrected abundance estimates that are comparable to estimates made in 1989 and 1990.

The two alternate methods of calculating CVs for the abundance and density estimates yielded similar results though the bootstrap method was consistently slightly higher. Overall, the differences in the methods is of little consequence, except where the different estimates yielded values that fell above and below the target CV of 0.30. This is the case with the unpooled estimates for the Strait of

Table 2. Harbor porpoise abundance estimates for Oregon and Washington in 1991. Based on only effort in good weather. Area designated "N WA (exten.)" includes portions of the Straits and Switfrtsure Bank and is only for comparison to previous years.

Location	Oregon	S WA	N WA (base)	N WA (exten.)	Straits	S. Juans	Straits & S. Juans
Effort - nm	945	297	176	315	456	377	833
Replicates	91	25	21	48	43	21	64
Sightings	220	125	17	24	34	25	59
Number	357	190	24	35	49	37	86
F(0) - Hazard	8.08	8.08	8.08	8.08	8.08	8.08	8.08
Density (groups)	0.94	1.70	0.39	0.31	0.30	0.27	0.29
Group size	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Density (animals)	1.47	2.65	0.61	0.48	0.47	0.42	0.45
Area (nm^2)	2,870	1,420	379	613	1,480	668	2,148
Uncorrected abundance	4,211	3,767	231	294	696	279	959
Confidence limit (±)	1,015	1,480	161	165	426	167	412
Correction factor	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Corrected abundance	13,477	12,055	738	942	2,226	893	3,069
Confidence limit (±)	3,248	4,735	514	527	1,363	533	1,318
CV CALCULATIONS							
cv F(0)	0.031	0.031	0.031	0.031	0.031	0.031	0.031
cv R (bootstrap)	0.119	0.198	0.354	0.284	0.311	0.303	0.217
cv Density (bootstrap)	0.123	0.200	0.355	0.286	0.313	0.305	0.219
cv N (replicates)	0.114	0.164	0.304	0.223	0.259	0.242	0.186
cv Group size	0.023	0.023	0.023	0.023	0.023	0.023	0.023
cv Density (replicates)	0.120	0.168	0.306	0.226	0.262	0.245	0.190

Juan de Fuca and the San Juan Islands. In these cases it is probably more appropriate to use the higher CV estimate because of the tendency for most variance estimates to be underestimates.

A total of just over 30,000 harbor porpoise were estimated for Oregon and Washington. Abundance estimates for coastal Oregon and Washington were similar despite the smaller area of coastal Washington. The pooled abundance estimate for the Strait of Juan de Fuca and the San Islands totaled just over 3,000. These are the first comprehensive surveys to estimate harbor porpoise abundance in these areas. Flaherty and Stark (1982) made some rough estimates of several hundred harbor porpoise for the San Juan Islands.

Abundance estimates for northern Washington have been of particular interest because of the incidental catch of harbor porpoise in this area (Gearin et al. In press). We estimated 824 harbor porpoise in this region based on the 1991 surveys, however, the CV is greater than 0.30 due to the limited number of sightings in this area. Several alternate estimates are summarized in Table 2 and 3. We calculated an abundance estimate for this region by including Swiftsure Bank and the southwest portion of the Strait of Juan de Fuca in the study area as had been done by vessel and aerial surveys in 1989 and 1990 (Calambokidis et al. 1991, Calambokidis In press). This increases the sample size enough to achieve a CV below 0.30 and also allows easier comparison to the results of the 1989 and 1990. We also calculated an abundance estimate for the northern Washington coast by pooling 1990 and 1991 aerial survey data (Table 3). These conformed well in terms of f(0) and overall sighting rate. These estimates also provide a CV of well below 0.30.

Comparison of the abundance estimates reported here and those that have been made previously are summarized in Table 4. Most of these compare favorably given the high variances associated with most of these estimates. In some cases, such as the northern Washington coast, the agreement is far better than would be expected. The total estimate of approximately 30,000 harbor porpoise in coastal Washington and Oregon is in surprisingly close agreement with Barlow's (1988) estimate from ship surveys.

Despite the areas of agreement, several dramatic differences among the abundance estimates are also apparent. The 1991 estimates for southern Washington and Oregon are substantially higher than the estimates in 1989 for these areas (Turnock et al. In press). This may partially reflect differences in methodology including absence of a third belly observer and less stringent weather criteria for the 1989

Table 3. Harbor porpoise abundance estimates for N. Washington using both 1990 and 1991 data. Group size and f(0) are based on 1991 data.

Location	N. Wa. only	N. Wa. + Swiftsure & SW Straits
Effort – nm	374	774
Replicates	46	112
Sightings	31	59
Number	43	81
F(0) – Hazard	8.08	8.08
Density (groups)	0.33	0.31
Group size	1.56	1.56
Density (animals)	0.52	0.48
Area (nm^2)	379	613
Uncorrected abundance	198	295
Confidence limit (±)	100	105
Correction factor	3.2	3.2
Corrected abundance	634	943
Confidence limit (±)	320	337
CV CALCULATIONS		
cv F(0)	0.031	0.031
cv R (bootstrap)	0.256	0.18
cv Density (bootstrap)	0.258	0.183
cv N (replicates)	0.22	0.152
cv Group size	0.023	0.023
cv Density (replicates)	0.223	0.157

Table 4. Comparison of 1991 abundance estimates for Oregon and Washington with those obtained previously.

Report	Platform	Year	Region: N. Wa. (extended)	S. Wa.	All Wa.	Oregon	Comments
Barlow (1988)	Vessel	1984–6			9,808	21,523	Oregon only S to Cape Blanco
Calambokidis (In Press)	Vessel	1989	848				
Turnock et al. (In Press)	Aerial	1989		7,961		5,215	
Brueggeman (1991, draft)	Aerial	1989–90			-----8,762----		Oregon & Wa. total for summer
Calambokidis et al. (1991)	Aerial	1990	837	5,250			
This report	Aerial	1991	942	12,055	12,997	13,477	

surveys. Preliminary abundance estimates of harbor porpoise during summer months made by EBASCO (Brueggeman 1991) were also dramatically lower than those we obtained for 1991 or other years. EBASCO's estimates included correction factors to account for both animals missed underwater as well as on the surface. For other seasons besides summer, the EBASCO estimates were considerably higher and therefore in closer agreement with our estimates.

Primarily as a tool for providing abundance estimates with lower CVs, we also calculated abundance estimates using all survey data regardless of weather state. Only a minority of survey effort fell outside the optimal conditions of Beaufort 2 or less and cloud cover of 25% or less, because surveys were generally terminated if conditions were consistently outside this range. The use of all weather data results in a downward biased density and abundance estimate but a lower variance due to larger sample size. We recommend use of only the good weather data despite its higher variance because it is less biased.

Other Marine Mammals

Tables 5 and 6 summarize the sightings of other marine mammals made during the surveys. Harbor seals were the most numerous marine mammal sighted and were encountered in all regions except the limited effort in offshore waters. Sightings of harbor seals included single seals in the water and large groups hauled out on rocks near shore. Occasional sightings were also made of California sea lions and northern sea lions, with northern sea lions being more common. Sightings of sea otters were only made along the northern Washington coast.

A total of 76 sightings of 154 Dall's porpoise were made during the surveys. More than half these sightings were made in the Strait of Juan de Fuca. Dall's porpoise were as common as harbor porpoise in this region and were frequent enough that it would be possible to estimate abundance. Dall's porpoise were also seen occasionally off Oregon, in the San Juan Islands, and in Puget Sound.

Killer whales were seen off northern Washington, in the Strait of Juan de Fuca, and the San Juan Islands. Gray whales were seen along outer coast of Oregon and northern Washington, in the Strait of Juan de Fuca, and in Puget Sound around Whidbey Island. A single humpback whale was encountered during the one set of offshore lines flown off of Cape Flattery. Four sightings of lone minke whales were made off Oregon, southern Washington and in Admiralty Inlet.

Table 5. Number of sightings of marine mammals other than harbor porpoise by region on and off-effort. See text for region details.

	Region									
	1	2	3	4	5	6	7	8	9	Total
	OR	S WA	N WA	SW St	Straits	S.J.	Offsh.	P.S.	Emb.	
Dall's porpoise	10	1	0	2	47	8	0	0	7	75
N. right-whale dolphin	1	0	0	0	0	0	0	0	0	1
Killer whale	0	0	3	0	5	1	0	0	0	9
Unid. small cetacean	4	1	1	0	7	0	0	0	0	13
Harbor seal	24	57	28	4	98	205	0	17	52	485
Northern sea lion	13	0	3	1	1	0	0	0	0	18
California sea lion	7	1	0	0	0	0	0	0	0	8
Unid. pinniped	4	1	0	0	0	0	0	0	0	5
Gray whale	5	0	4	2	2	0	0	0	1	14
Humpback whale	0	0	0	0	0	0	1	0	0	1
Minke whale	2	1	0	0	1	0	0	0	0	4
Sea otter	0	0	8	0	0	0	0	0	0	8

Table 6. Number of marine mammals other than harbor porpoise seen by region on and off-effort. See text for region details.

	Region									
	1	2	3	4	5	6	7	8	9	Total
	OR	S WA	N WA	SW St	Straits	S.J.	Offsh.	P.S.	Emb.	
Dall's porpoise	24	1	0	4	100	13	0	0	11	153
N. right-whale dolphin	1	0	0	0	0	0	0	0	0	1
Killer whale	0	0	4	0	20	3	0	0	0	27
Unid. small cetacean	13	1	2	0	8	0	0	0	0	24
Harbor seal	77	2,506	198	4	197	494	0	19	58	3,553
Northern sea lion	18	0	7	8	7	0	0	0	0	40
California sea lion	9	1	0	0	0	0	0	0	0	10
Unid. pinniped	13	1	0	0	0	0	0	0	0	14
Gray whale	8	0	4	2	2	0	0	0	1	17
Humpback whale	0	0	0	0	0	0	1	0	0	1
Minke whale	2	1	0	0	1	0	0	0	0	4
Sea otter	0	0	52	0	0	0	0	0	0	52

RECOMMENDATIONS

The surveys in 1991 provided improved abundance estimates for harbor porpoise in Washington and Oregon. Based on the results of these surveys and those from previous years, we make the following recommendations:

1) Abundance estimates for harbor porpoise off Washington and Oregon have been established with a reasonable level of variance. Future surveys need only be conducted if estimates are needed for smaller geographic areas than employed in this study or to monitor annual or seasonal differences in abundance.

2) A principal weakness of the abundance estimates remains the unknown portion of animals missed by the surveys. Relatively minimal effort has been dedicated to this objective given its importance. Directions for improvement of correction factors include double-observer experiments to determine the portion of animals missed at the surface, additional modeling of surfacing rates to estimate the portion of animals missed because they are underwater, and land calibration efforts such as that conducted for this study. Until these correction factors are refined and variance estimates determined, minimum abundance estimates should be based on uncorrected calculations that assume 100% of animals on the transect line are seen.

3) Information on stock structure and interchange between regions will be critical to interpreting the abundance estimates in relation to specific locations where mortality occurs. The results of these surveys indicates a relatively small number of harbor porpoise in the immediate region of incidental mortality but large numbers of animals outside this region.

ACKNOWLEDGMENTS

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