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FINAL REPORT

ABUNDANCE ESTIMATES OF HARBOR PORPOISE IN WASHINGTON AND OREGON WATERS

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EXECUTIVE SUMMARY

Numerous surveys have been conducted in recent years to estimate harbor porpoise abundance for Washington and Oregon. The primary goal of this study was to evaluate the past data on harbor porpoise abundance and develop a revised abundance estimate the data from these data.

To this end, we evaluated the suitability and comparability of past surveys. Four data sets from different surveys were selected for development of a revised abundance estimate:

1) Vessel surveys dedicated to harbor porpoise estimation conducted in 1989 off the northern Washington coast (Calambokidis *et al.* In press),
2) Aerial surveys dedicated to harbor porpoise estimation conducted in 1989 off the coasts of Oregon and Washington (Turnock *et al.* In press),
3) Aerial surveys dedicated to harbor porpoise estimation conducted in 1990 off the coast of Washington (Calambokidis *et al.* 1991), and
4) Aerial surveys dedicated to harbor porpoise estimation conducted in 1991 off the coasts of Oregon and Washington and in Washington inland waters (Calambokidis *et al.* 1992).

The methods used in the dedicated harbor porpoise aerial surveys conducted in 1990 and 1991 were identical and these data were pooled for analysis. Abundance estimates from the dedicated aerial surveys and vessel surveys conducted in 1989 were analyzed separately and then averaged (weighed by the inverse of variance) with the 1990-1991 dataset.

Revised abundance estimates for the different data sets were usually similar to the original estimates. The only exception was the revised estimate of the 1989 dedicated aerial survey data which differed substantially from the original estimates. This was primarily the result of the different detection function we used in the analysis which excluded consideration of the area closest to the transect line. The area closest to the transect line had low sighting rates because of the absence of a center observer.

Revised abundance estimates using all the survey data yielded estimates of 13,014 harbor porpoise off the coast of Oregon (including Heceta Bank), 10,074 off the southern Washington coast, 634 off the northern Washington coast, and 3,298 for the Strait of Juan de Fuca and San Juan Islands area. For the first time revised coefficients of variation (CV) for these estimates included the variance contributed by the correction factor for animals missed on the transect line. These CVs varied between 0.18 and 0.26 for the above estimates.

All the surveys of Oregon and Washington coastal waters used in the revised abundance estimates covered waters out to a water depth of 50 fathoms (91 m). The revised abundance estimates are therefore only valid for the portion of the population inhabiting these waters. Surveys conducted by Ebasco Environmental for the Minerals Management

Service surveyed waters much farther offshore for marine mammals and marine birds (Green *et al.* 1992). Though these surveys were not considered suitable for use in the abundance estimates (partly because of a much lower survey altitude) they did provide information on the proportion of harbor porpoise that occurred within and outside the study area covered by the dedicated surveys. A total of 24% of harbor porpoise sightings made during their systematic survey legs, extending from the coast to up to 100 nm offshore, were outside the area covered by the dedicated surveys used for the revised abundance estimate. This would result in a correction factor of 1.31 to adjust our abundance figures to cover the animals missed outside the study area.

INTRODUCTION

Under the 1988 amendments of the Marine Mammal Protection Act (MMPA) of 1972, abundance estimates of marine mammal species taken incidentally in fisheries are needed. Assessment effort have been undertaken with several species of marine mammals, including harbor porpoise, in Oregon and Washington waters to meet this requirement of the MMPA (Ferrero and Fowler 1992). Estimates of harbor porpoise are needed to aid in the management of this species and the fisheries that cause their mortality.

A number of surveys have been conducted since 1984 that have provided estimates of harbor porpoise off Washington and Oregon (Barlow 1988, Barlow et al. 1988, Green *et al.* 1992, Turnock *et al.* In press, Calambokidis *et al.* 1991, 1992, In press). The 1991 aerial surveys sponsored by the National Marine Mammal Laboratory provided comprehensive estimates of harbor porpoise abundance (Calambokidis *et al.* 1992). These surveys were comprehensive and used methods specifically aimed at assessing harbor porpoise abundance. The incorporation of information from past surveys, however, could improve these most recent estimates. Additionally, it would be clearer for management purposes to have a single estimate utilizing all relevant data, rather than several separate estimates.

A crucial element of past harbor porpoise abundance estimates has been the correction factor for animals missed along the transect line. Because harbor porpoise are inconspicuous, spend extended periods out of view underwater, and occur in small groups, a large proportion of the animals along the transect are likely not seen by observers. Past surveys have relied on a correction factor based on the diving behavior of harbor porpoise (Barlow *et al.* 1988). New information has become available to calculate the proportion of animals missed based on a series of calibration flights (Calambokidis *et al.* 1993) and was used here.

We examined and compared the existing data available on harbor porpoise abundance in Oregon and Washington waters. The primary goal was to develop the best estimate of current harbor porpoise abundance using all relevant survey data.

METHODS

General approach

Our approach to develop a revised estimate of harbor porpoise abundance was to examine all past relevant surveys and determine their suitability for developing the best current estimate of harbor porpoise abundance. Past survey data were classified in three categories: 1) suitable for pooling into a single data set for analysis, 2) suitable as an independent abundance estimate to average with other estimates, or 3) not suitable for use in a revised abundance estimate.

To achieve the objectives of the project, we conducted the following steps:

Evaluation of data from previous surveys: The National Marine Mammal Laboratory, Ebasco Environmental, and Southwest Fisheries Center (SWFC) generously provided copies of the data they had gathered on harbor porpoise. Data were already available for the surveys conducted jointly by the National Marine Mammal Laboratory (NMML) and Cascadia Research. The SWFC and NMML surveys were conducted cooperatively with Washington Department of Wildlife and Oregon Department of Fish and Wildlife. Table 1 describes the past surveys that were evaluated.

Determination of data compatibility: Using the data and the reports from previous analyses, we determined which data sets could be pooled together or averaged. Criteria considered in evaluating survey data are detailed in the next section.

Pooling of survey data: We pooled the data from surveys that were deemed to be effectively similar and therefore able to be analyzed together.

Reanalysis of pooled survey data: The pooled data set was reanalyzed to determine harbor porpoise abundance and a variance estimate. Procedures included generating and modeling the sighting function, determining the amount of effort by region during acceptable weather conditions, determining the number of harbor porpoise sightings during acceptable weather by region, calculating average group sizes, determining the area of the study region, and computing a density and abundance estimate.

Averaging estimates from incompatible data sets: Some data sets, such as those from vessel surveys, were not compatible to combine with the larger pooled data set from aerial surveys. In order to develop a single estimate of abundance with the lowest possible variance, we averaged the estimates from different data sets together

Table 1. Analysis of important factors to be considered relative to specific surveys

Reference	Years	Season	Design	Regions	Platform	Observers	Transect	Alt.	Weather	Correction factors
Barlow (1988)	1984-85	Sept.	Parallel to shore along 10 fathom line	OR and WA outer coasts	52m ship	5 covering right, left and center	Line transect	-	Beauf 0-2	Depth distribution modeled, correction for 22% missed on trackline based on experiment
Barlow *et al.* (1988)	1984-85	Sept.-Oct.	Parallel to shore at .33 and 1 nm.	OR and WA coast	Single and twin-engine aircraft	2 covering right and left sides	strip transect	700 ft 213 m	Beauf 0-1 & cl. cov. < 25%	No attempt to determine abundance or overall density, corrected for 69% of animals missed because they were underwater
Turnock *et al.* (in press)	1989	July-Aug.	Saw-tooth out to 50 fathoms	WA & OR coast	Twin-engine aircraft	2 covering right and left sides	Line transect	600 ft 183 m	Beauf 0-2, cl. cov. < 50%, & observer vis. codes	No acceptable coverage of N WA., no center observer, used Barlow's estimate of 69% missed
Calambokidis *et al.* (in press)	1989	July-Aug.	Saw-tooth out to 50 fathoms	N WA only	Small vessel	3 covering right, left and center	Line transect	-	Beauf 0-2	Correction for 50% missed based on breath rate and calibration
Calambokidis *et al.* (1991)	1990	July-Aug.	Saw-tooth out to 50 fathoms	WA coast	Twin-engine aircraft	3 covering right, left and center	Line transect	600 ft 183 m	Beauf 0-2 & cl. cov. < 25%	Corrected using Barlow's estimate of 69% missed
Calambokidis *et al.* (1992)	1991	July-Sept.	Saw-tooth out to 50 fathoms	OR & WA coast and inland waters	Twin-engine aircraft	3 covering right, left and center	Line transect	600 ft 183 m	Beauf 0-2 & cl. cov. < 25%	Corrected using Barlow's estimate of 69% missed
Green *et al.* (1992)	1989-90	All seasons	East-west from shore out to 1,000m depth, some to 100 nm	OR & WA coast and offshore	Twin-engine aircraft	2 mammal, 1 seabird observer (bird obs. used for porpoise)	Strip transect	200 ft 61 m	Beauf 0-2 & good vis.	Both uncorrected and corrected for submerged animals

weighted by the inverse of the variance of each estimate. A combined variance was determined for the averaged estimate.

Study area

Regional boundaries used in this report for the revised abundance estimates (Figures 1 and 2) were as follows:

Oregon: Coastal waters out to 50 fathoms and including a small portion of northern California from 41°43'N to 46°13'N (Columbia River mouth). The area around Heceta Bank was treated as a separate area because it was excluded from one set of surveys.

Heceta: The area around Heceta Bank off central Oregon.

Southern Washington: Coastal waters out to 50 fathoms from 46°13'N (Columbia River mouth) to 47°45'N (just south of Hoh Head).

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

Strait of Juan de Fuca: All water depths for the entire Strait extending from Swiftsure Bank to Whidbey Island and including Admiralty Inlet.

San Juan Islands: Surrounding waters extending north from 48°25'N to 49°00'N and including a portion of the Strait of Georgia.

No harbor porpoise were sighted in other regions surveyed in 1991 (Calambokidis *et al.* 1991), including Puget Sound south of Admiralty Inlet, Hood Canal, and Washington coastal embayments, and so these areas were not considered in the revised abundance estimates.

Factors considered to compare and evaluate surveys

In the comparison of the different survey designs, we evaluated a number of criteria to determine the suitability of a particular survey for use in the revised abundance estimate. Some of these factors and how they applied to different surveys are summarized in Table 1. The importance of these factors and how they differ among surveys are summarized below:

Years conducted: The years in which surveys were conducted affected their suitability for use in a current abundance estimate of harbor porpoise. This is primarily an issue with the two surveys in 1984-85 (Barlow 1988, Barlow *et al.*

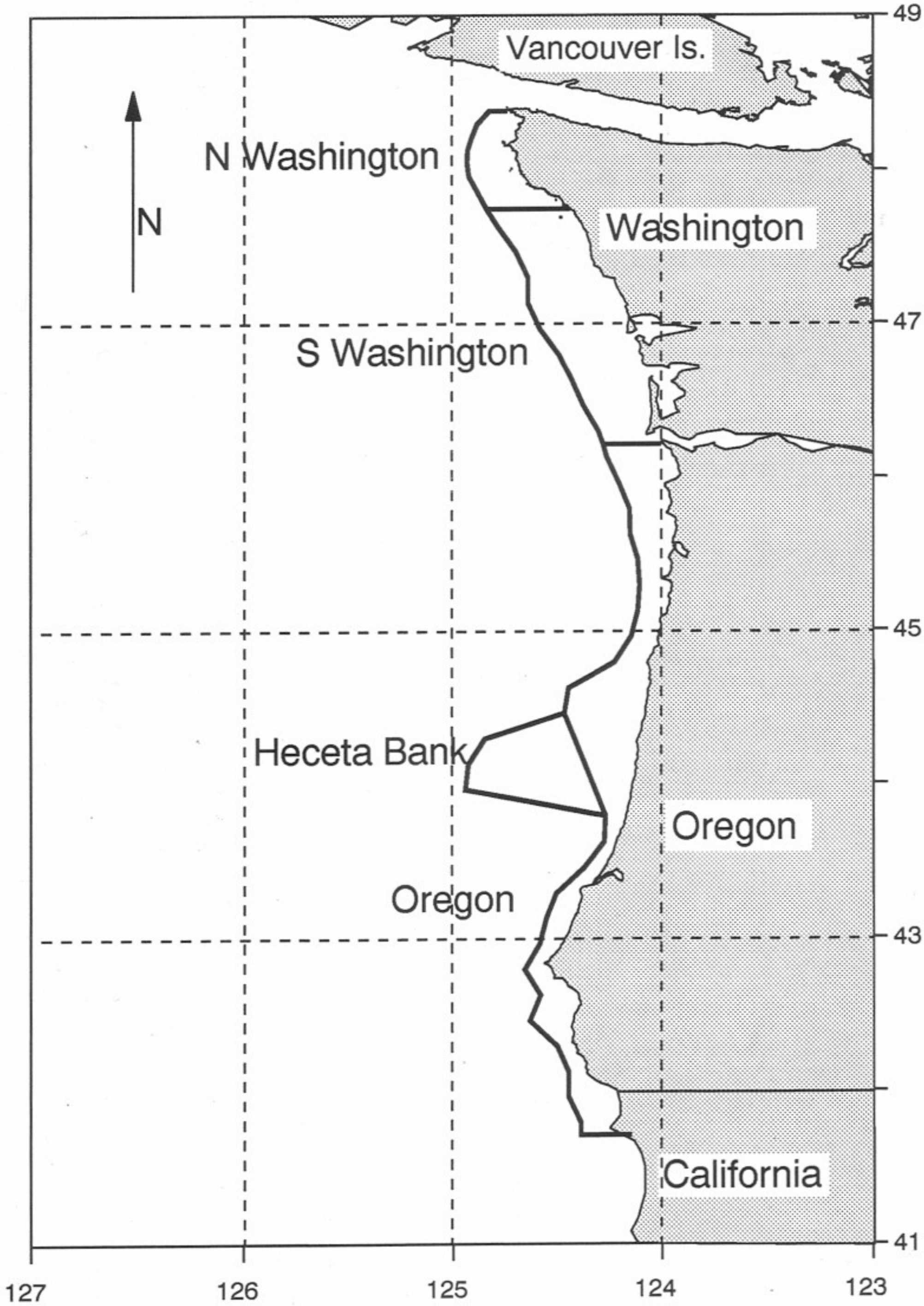

Figure 1. Study area off Oregon and Washington showing boundaries for regions described in text.

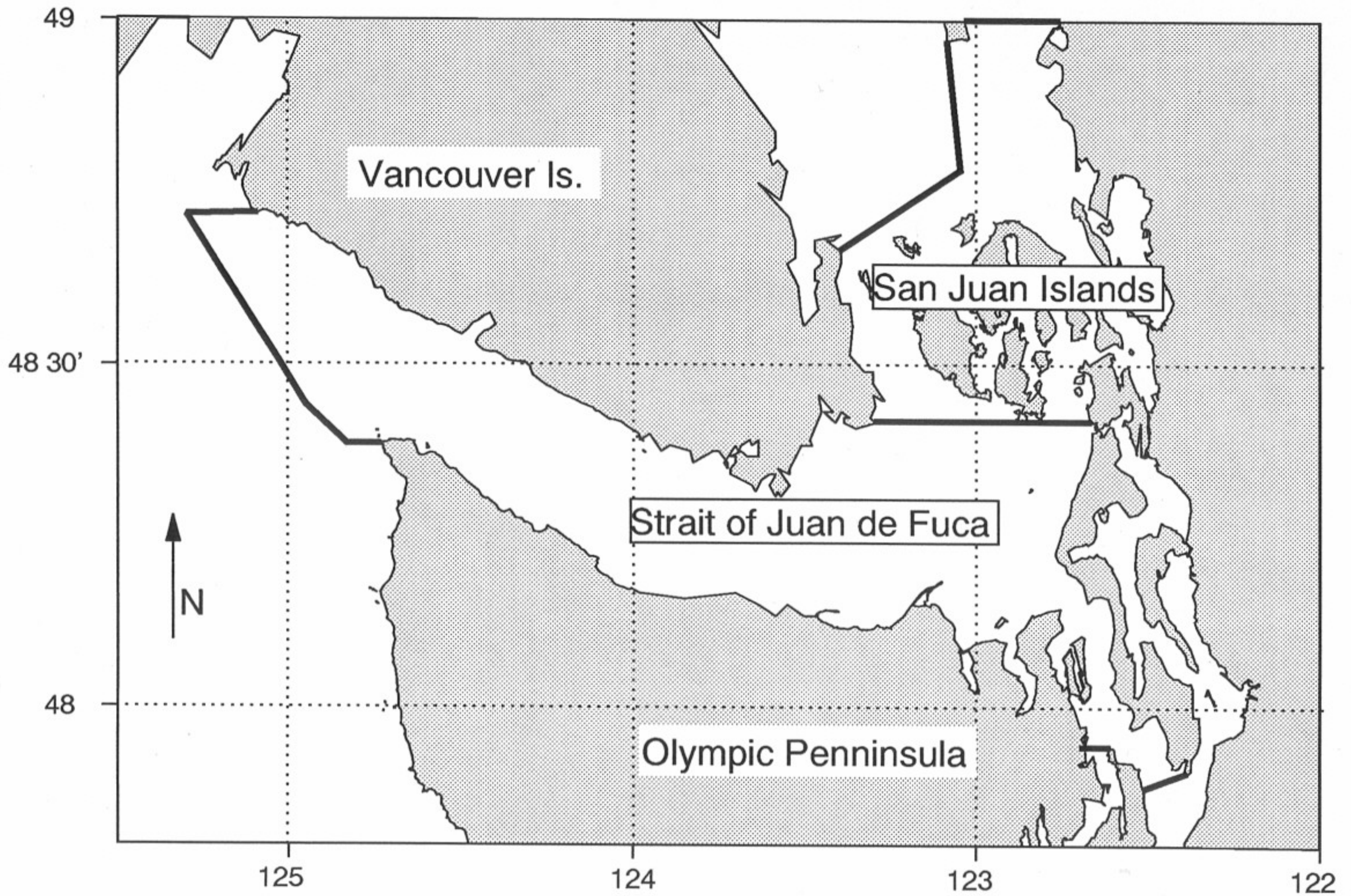

Figure 2. Study area in the inland waters of Washington State showing boundaries for regions described in text.

1988). These two surveys predate other survey efforts by 5 years and therefore were not be pooled or averaged with more current results.

Season: The season that surveys were conducted could affect the abundance estimate. Fortunately, most of the surveys were conducted in the late summer and early fall (July to September) (Table 1). The seasons were considered primarily for the surveys reported by Green *et al.* (1992) that were conducted year-round and obtained very different results by season.

Transect design: The designs used to survey the study areas varied among the surveys (Table 1). More than half the surveys used saw-tooth or lines perpendicular to shore extending from shore out to 50 fathoms. The most significant divergence from this design were the surveys reported by Barlow (1988) and Barlow *et al.* (1988) that surveyed parallel to shore. To estimate abundance from these surveys requires assumptions be made about the depth distribution of harbor porpoise. The study conducted for Minerals Management Service (Green *et al.* 1992) were the only surveys that covered waters deeper than 50 fathoms and, although they report lower sightings in offshore waters, there were a substantial number of sightings in waters deeper than 50 fathoms.

Strip or line transect: Past survey methods primarily used line transect methods as summarized in Table 1. The transect design is particularly important because strip and line transects need to employ very different correction factors for their results to be comparable. An uncorrected abundance from a strip transect assumes that all animals within the entire strip are seen while line-transect methods assume all the animals on the transect line are seen but sighting rate decreases with distance off the line (Burnham *et al.* 1980).

Regions covered: This was a limitation in the comparison of the existing survey results. The boundaries of the study areas used were not the same for all studies. Only the 1991 surveys (Calambokidis *et al.* 1992) provided coverage of major portions of the inland waters of Washington (including portions of British Columbia).

Vessel or aerial platform: Vessel and aerial surveys, even where both use the same transect design, would achieve very different estimates of uncorrected abundance because of the different proportion of animals missed.

Number of observers/positions: The number of observers influences the comparability of some of the similar survey types. The aerial surveys in 1989 (Turnock *et al.* In press) differed from those in 1990 and 1991 (Calambokidis *et al.* 1991, 1992) in that the 1989 surveys did not use a center observer. This dramatically altered the sighting function which has a direct bearing on the abundance estimate obtained.

Altitude: Survey altitude is primarily a concern related to the surveys reported by Green *et al.* (1992) that were flown at 200 ft (61 m) (a third of the height of the other aerial surveys). This dramatically alters the effective survey zone, the length of time observers see harbor porpoise, and the proportion of harbor porpoise missed by observers.

Weather conditions: Almost all aerial surveys have found a strong influence of weather on sighting rates. Recent surveys have shown that Beaufort sea state and cloud cover exert independent effects on sighting rates (Forney *et al.* 1991, Calambokidis *et al.* 1991, 1992). Most of the recent aerial surveys have therefore utilized only survey effort conducted when Beaufort sea state was 2 or less and cloud cover was less than 25%. The surveys reported by Green *et al.* (1992) evaluated the effect of Beaufort sea state but not cloud cover on sighting rates.

Correction factors computed or used: The correction factors employed to adjust the abundance estimates for animals missed either on the transect line or within the survey strip (for strip transects) have differed among surveys. Most of the aerial surveys, however, have at least included a correction factor for animals missed because they were underwater based on breath rate data (Barlow *et al.* 1988).

Selection of data sets for analysis

Based on evaluation of the above criteria, four data sets were selected for development of the revised abundance estimates (Table 2). These included:

1) Vessel surveys dedicated to harbor porpoise estimation conducted in 1989 off the northern Washington coast (Calambokidis *et al.* In press),
2) Aerial surveys dedicated to harbor porpoise estimation conducted in 1989 off the coasts of Oregon and Washington (Turnock *et al.* In press),
3) Aerial surveys dedicated to harbor porpoise estimation conducted in 1990 off the coast of Washington (Calambokidis *et al.* 1991), and
4) Aerial surveys dedicated to harbor porpoise estimation conducted in 1991 off the coasts of Oregon and Washington and in Washington inland waters (Calambokidis *et al.* 1992).

Analytical procedures

Density and abundance calculations were made following the methods described by Burnham *et al.* (1980). Where possible, the program DISTANCE (Laake *et al.* In prep.) was used to conduct the analyses.

Table 2. Preliminary evaluation of the utility of different data sets for abundance estimates of harbor porpoise.

Reference	**Primary limitations**	**Use in revised estimate**
Barlow (1988)	5-7 years previous to other studies, relies on depth distribution model	Not used
Barlow *et al.* (1988)	5-7 years previous to other studies, no abundance estimate	Not used
Turnock *et al.* (In press)	Lack of center observer	Averaged uncorrected estimate w/ 1990-91 for Oregon and S. Washington
Calambokidis *et al.* (In press)	Only N WA covered, based on vessel rather than aerial	Averaged corrected estimate for N. Washington
Calambokidis *et al.* (1991)	No coverage of OR	Pooled with 1991 for new estimate
Calambokidis *et al.* (1992)	-	Pooled with 1990 for new estimate
Green *et al.* (1992)	Flown at 200 ft (61 m), lack of center obs., different weather criteria	Not used for abundance estimate. Used to evaluate porpoise distribution farther offshore than covered by dedicated harbor porpoise surveys.

Line-transect calculations were conducted using only effort and sightings made during excellent sighting conditions. For aerial surveys, effort was used only during Beaufort sea state conditions of 2 or less and cloud cover of less than 25% (Calambokidis *et al.* 1992). For vessel surveys, only surveys conducted when Beaufort sea state was 2 or less were used (Calambokidis *et al.* In press).

Sighting functions

Models of the sighting frequency versus perpendicular distance off the track-line were fitted using the program DISTANCE (Laake *et al.* In prep.). Models tested included the Hazard rate, Fourier (Uniform), half-normal, and negative exponential. The model and number of terms used in the analysis were selected based on the lowest Akaike Information Criterion (AIC) score. The truncation point for aerial surveys was 1,200 ft (366 m) and for vessel surveys it was 500 m. For both survey types, these truncation distances resulted in the exclusion of less than 5% of sightings.

Results of the 1990 and 1991 aerial surveys were pooled for calculations of abundance. A single estimate of f(0) and of group size was calculated using data from all regions in both years. The model with the lowest AIC score that was used in the analysis was the Hazard-rate with one cosine adjustment term (Figure 3).

The 1989 aerial surveys were conducted without a center observer and so were not pooled with the 1990-1991 data. The absence of a center observer resulted in a sighting detection curve that increased with distance from the transect line out to 200-300 ft (61-91 m)(Figure 4). This reflected the natural tendency of side observers to concentrate their sighting effort to either side of the transect line rather than directly downward to the transect line. Surveys in 1991 demonstrated that the center observer is critical to maximizing the number of sightings made on the transect line (Figure 4). We used the program DISTANCE (Laake *et al.* In prep.) to estimate f(0) excluding consideration of the first 200 ft (61 m) on either side of the transect line (Figure 5). The 1991 survey data showed that the influence of the center observer primarily occurred out to 200 ft (61 m).

For the 1989 vessel surveys, sightings in all regions including those at Swiftsure Bank and a portion of the Strait of Juan de Fuca were used to calculate the sighting function (Figure 6). A half-normal sighting function provided the lowest AIC score and was used.

Variance for density estimates

The variances for the density estimates were computed by separately calculating the variance for f(0), the number of sightings, and the average group size. The variance for f(0) was computed from the program DISTANCE. Group size was estimated using all on-effort harbor porpoise sightings and the CV (Coefficient of Variation) calculated using the standard error of the mean of group size.

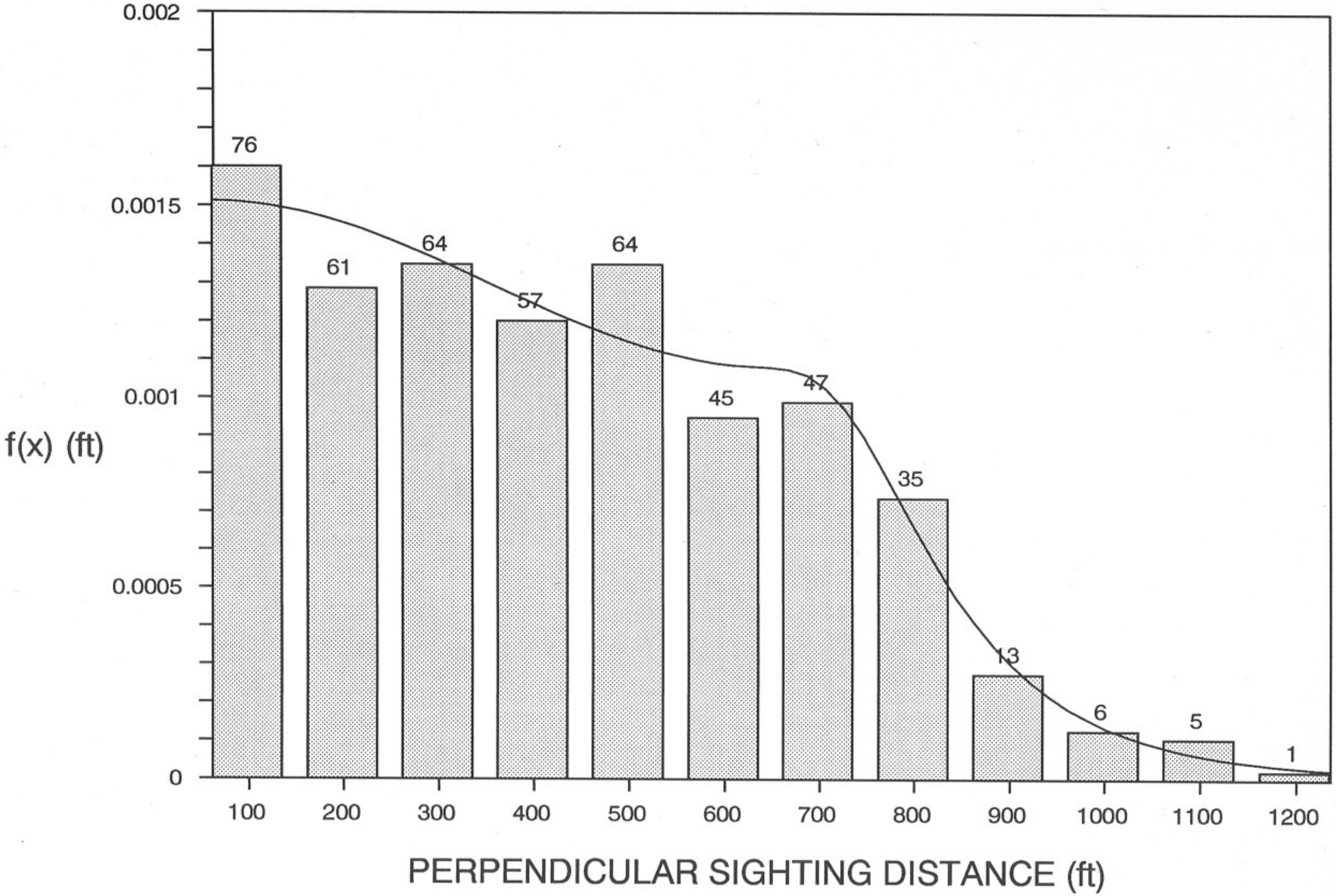

Figure 3. Perpendicular sighting distances for pooled 1990 and 1991 aerial survey data. Fitted Hazard-rate model is shown. Numbers above bars show the number of sightings.

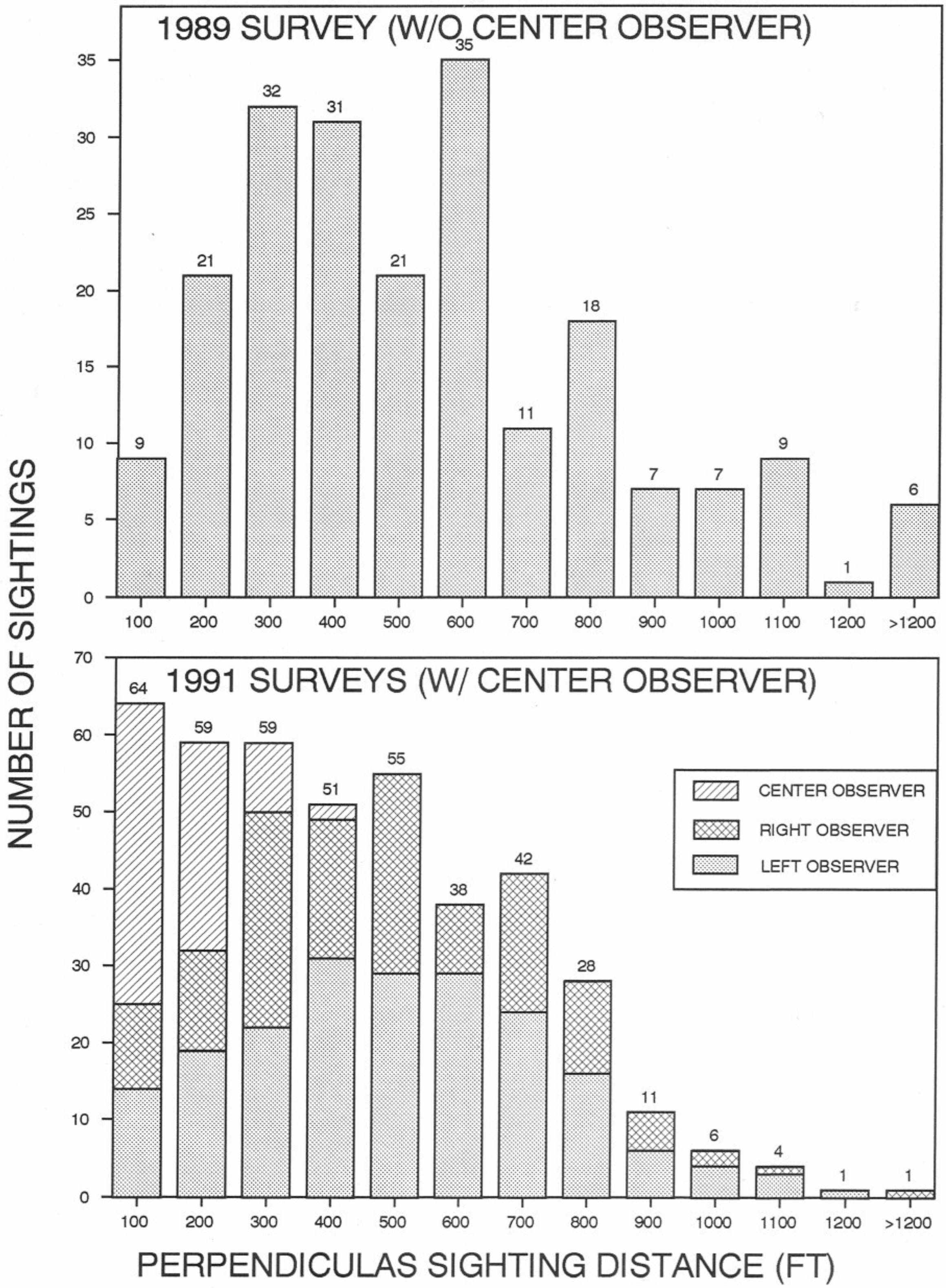

Figure 4. Perpendicular sighting distances for the 1989 (Turnock *et al.* In press) and 1991 (Calambokidis *et al.* 1992) aerial surveys showing the contribution of the center observer.

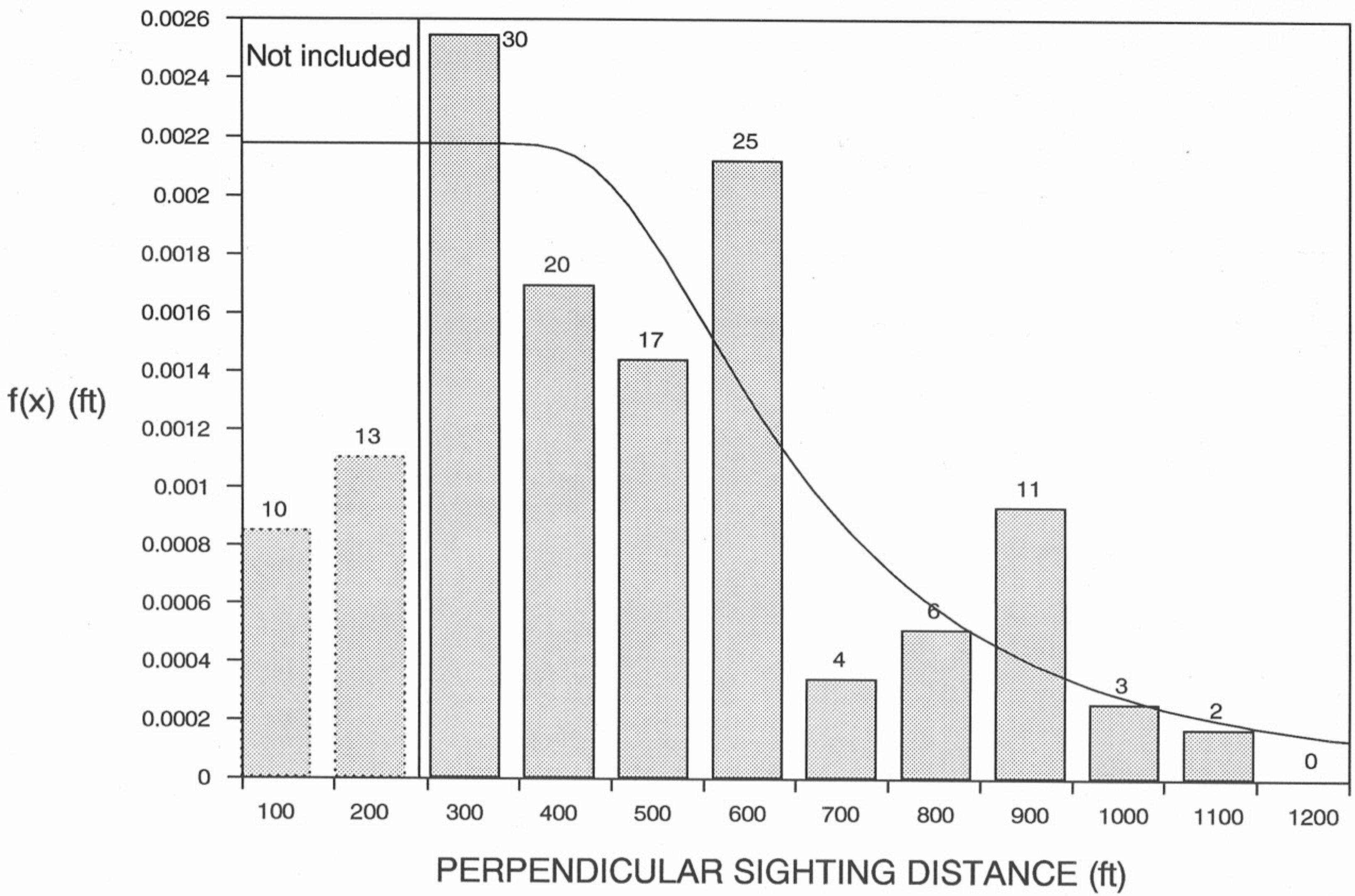

Figure 5. Perpendicular sighting distances for 1989 aerial survey (Turnock *et al.* In press). Sightings out to 200 ft (61 m) were excluded from the calculations and the fitted Hazard-rate model. Numbers above bars show the number of sightings.

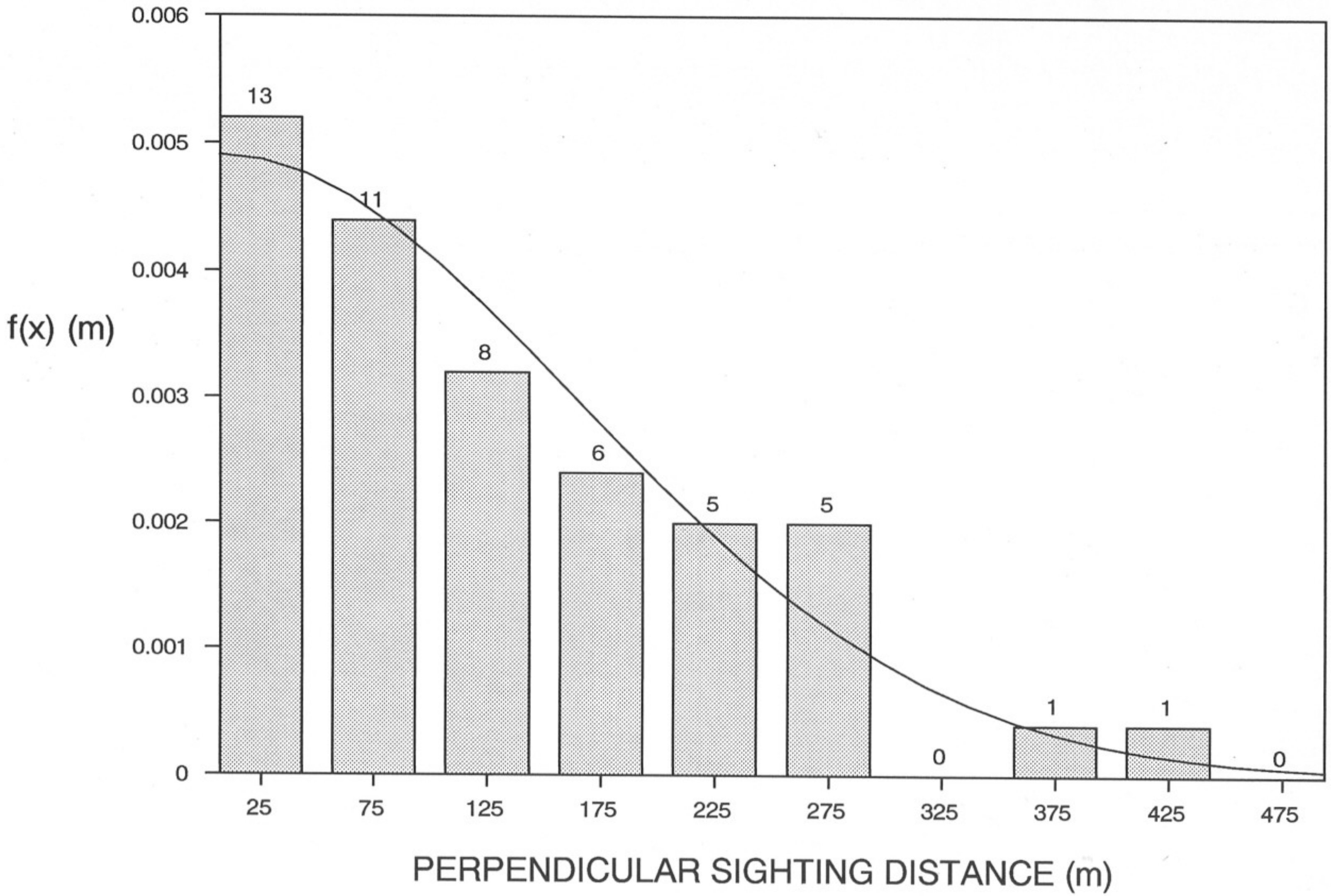

Figure 6. Perpendicular sighting distances for 1989 vessel survey (Calambokidis In press). Fitted Half-normal model is shown. Numbers above bars show the number of sightings.

The variance for the number of sightings was estimated using both replicate passes and replicate lines through a study region. A replicate line consisted of one transect line extending from shore out to the boundary of the study area (usually the 50 fathom line). For aerial surveys, a replicate pass consisted of all effort in a region on a day. Vessel surveys were conducted in two different directions through each region and sometimes took several days to complete. Each set of lines in one direction was considered a survey pass and effort was pooled between days when they represented the completion of a single pass through a region. When fewer than four replicate passes were completed (which only was the case with the 1989 aerial surveys), variance was calculated using only survey lines as replicates. The variance for the number of sightings was calculated using the following formula (Burnham et al. 1980 Equation 1.23):

$$Var(n) = L * \frac{\Sigma l_i \left(\frac{n_i}{l_i} - \frac{n}{L} \right)^2}{(R - 1)}$$

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 passes in the sample

The variance of D was calculated as follows:

$$Var(D) = D^2 \left[CV(n)^2 + CV(f(0))^2 + CV(G)^2 \right]$$

Where: CV(n), CV(f(0)), and CV(G) are the coefficients 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. $CV(n)=Var(n)^{1/2}/n$).

Averaged estimates

A single abundance estimate using different survey techniques was determined by calculating the mean which was weighted by the inverse of the variance. The formula for the mean of two estimates was as follows:

$$E(P) = \frac{\frac{E(P_1)}{V(P_1)} + \frac{E(P_2)}{V(P_2)}}{\frac{1}{V(P_1)} + \frac{1}{V(P_2)}}$$

Where: $E(P_1)$ and $V(P_1)$ are the abundance estimates and variance for the first set of data and $E(P_2)$ and $V(P_2)$ are the abundance estimate and variance for the second sample.

The weighted average variance for the above weighted mean was calculated as follows:

$$V(P) = \frac{1}{\frac{1}{V(P_1)} + \frac{1}{V(P_2)}}$$

Correction factors

1989 vessel surveys: A revised correction factor and associated variance was developed for the 1989 vessel surveys. Calambokidis (In press) had used a correction factor assuming 50% of animals along the transect line had been missed. This was based on the results of a model of the surfacing rate of harbor porpoise and a small sample based from a calibration experiment using a land observation team (Calambokidis *et al.* In press). No variance was originally estimated for this correction factor. Several improvements have been made to the procedure to calculate a correction factor for the vessel work and to determine an associated variance for this correction factor.

The correction factor used in the abundance estimate was based on the reanalysis of the land calibration experiment conducted in 1989. The vessel correction factor (1/g(0)) used in this report was obtained by determining the maximum likelihood estimator (MLE) for g(0) from the following likelihood:

$$\begin{aligned} L(g(0) \mid y_1,\ldots,y_N) &= \sum_{i=1}^{N} y_i \ln(g(0)p) + \sum_{i=1}^{N}(1-y_i)\ln(1-g(0)p) \quad , \\ &= n\ln(g(0)) + n\ln(p) + (N-n)\ln(1-g(0)\,p) \end{aligned}$$

Where: $y_i = 1$ if a calibration porpoise group was detected and 0 if not, n is the number of observed groups and N is the total number of calibration groups which could be observed in [0,W].

The value of p in the above likelihood is assumed to be known as determined from fitting a detection function g'(x) to the vessel survey data with:

$$p = \int_0^W g'(x)\frac{1}{W}dx \quad .$$

The MLE of g(0) is:

$$\hat{g}(0) = \frac{n}{N\ p} \quad ,7$$

and the variance is:

$$Var(g(0)) = \frac{Npg(0)(1 - pg(0))}{N^2 p^2} = \frac{g(0)(1 - pg(0))}{Np} \quad .$$

However, this assumes that *p* is known without error. A delta-method approximation to the variance (Seber 1982) including this uncertainty is:

$$Var(g(0)) = \frac{g(0)(1 - pg(0))}{Np} + g(0\ )^2\ \frac{Var(p)}{p^2} \quad ,$$

Where: $Var(p)=p^2\ CV^2(f(0))$ is obtained from the analysis of the survey data.

This above calculations yielded a point estimate for g(0) of 0.536 with variance of 0.076 (CV=0.514). The resulting correction factor (1/g(0)) was 1.87.

As a possible alternative to the above correction factor we also re-examined the breath rate model. The breath rate model simulated the surfacing behavior of harbor porpoise (including the observed variations) and the likelihood that a survey vessel would see a group directly on the transect line (Calambokidis In press). We modified the original model to use the detection function to predict the probability of a harbor porpoise group being seen ahead of the vessel on the transect line. This was assumed to vary from 0 (for harbor porpoise at the surface 500 m or more away from the vessel) to 1 (for harbor porpoise on the transect line and at the surface at the time the vessel passes). A crude variance for this estimate was calculated from the variance of the outcomes of a series of 100 trials with each trial consisting of the number of encounters that match the survey sample size (34 sightings based on 61 encounters). The proportion seen (g(0)) was estimated as 0.60 (Variance = 0.0055). This yields a correction factor (1/g(0)) of 1.7 (Variance = 0.044).

1989 - 1991 aerial surveys: The original abundance estimates from the aerial surveys conducted in 1989 (Turnock In press), 1990 (Calambokidis *et al.* 1991), and 1991 (Calambokidis *et al.* 1992), employed a correction factor (1/g(0)) of 3.2 based on the breath rate calculations made by Barlow *et al.* (1988). That correction factor had no variance associated with it. For the estimates reported here, we used a correction factor of 3.1 (g(0)=0.324, CV=0.171) recently calculated by determining the proportion of harbor porpoise groups on the transect line or g(0) seen by aerial observers (Calambokidis *et al.* 1993).

Variances for corrected estimates of abundance: The variance on the corrected abundances estimate was calculated as follows:

$$V(P_C) = E(P_c)^2 * [CV(P_{uc})^2 + CV(\frac{1}{g(0)})^2]$$

Where $V(P_c)$ and $E(P_c)$ are the variance and point estimate for the corrected abundance estimate, respectively, and CV(1/g(0)) and $CV(P_{uc})$ are the coefficients of variation for the correction factor and uncorrected abundance, respectively.

RESULTS AND DISCUSSION

Abundance estimates

1990-1991 aerial surveys

The pooled survey data from 1990 and 1991 provided the most complete abundance estimates of the different data sets (Table 3). Most of the pooled data were from 1991, when surveys were completed in all regions of coastal Oregon and Washington. Although abundance estimates from this pooled data were generally similar to those reported previously based on the 1991 survey results (Calambokidis *et al.* 1992), there were several minor differences. Abundance estimates for the inland waters of Washington using the pooled data were just over 5% higher than previously reported (Calambokidis *et al.* 1992) even though these areas were only surveyed in 1991. The higher revised estimate was the result of the higher f(0) calculation from the 1990-1991 data. Abundance estimates for Oregon changed from those previously reported because of the higher f(0) calculation and the separation of the Heceta Bank region from the rest of the Oregon survey region. These areas had been treated as a single region in the previous analysis (Calambokidis *et al.* 1992). Abundance estimates for the northern and southern Washington coasts were almost identical to those reported from the 1991 surveys because the higher f(0) which increased the estimates were offset by the lower sighting rates of harbor porpoise in 1990 compared to 1991.

Despite the larger sample size, variance estimates from the pooled 1990-1991 surveys were, in most cases, higher than reported for the 1991 data alone (Calambokidis *et al.* 1992). This was the result of three factors which affected the variance calculation: 1) the variance for f(0) was higher because of the use of a detection function with two parameters rather than one to better fit the observed sighting distribution, and 2) no variance was assigned to the correction factor used in the original analysis because this was not yet available. A relatively high variance was obtained for Heceta Bank (an area not defined in previous analyses) because of the limited sample size in this region. A lower variance was obtained for the northern Washington coast with the pooled 1990-1991 data because the limited number of sightings for this area in 1991 was almost doubled by pooling with 1990.

Though the variance for the abundance estimates was based on a variance for N from replicate lines, we also calculated a variance from replicate passes, when possible (Table 3). The variance from replicate passes was generally higher than that from replicate lines. Though the use of replicate passes may be more a accurate way to estimate variance, we did not use them because: 1) the low number of passes resulted in high variance estimates even when the sample size within each pass was large, and 2) a variance from replicate passes could not be calculated for all the different surveys (due to too few passes).

Table 3. Harbor porpoise abundance estimates for Oregon and Washington in 1990-91.

	Oregon w/o Heceta	S WA	N WA	Straits	S. Juans	Straits & S. Juans
ABUNDANCE ESTIMATE						
Effort - nm	760	408	374	456	377	833
Replicates (lines)	90	35	46	43	21	64
Replicates (passes)	7	6	7	5	4	6
Sightings	199	146	31	34	25	59
Number	322	220	43	49	37	86
f(0) - nm	9.14	9.14	9.14	9.14	9.14	9.14
Density (groups)	1.20	1.64	0.38	0.34	0.30	0.32
Group size	1.53	1.53	1.53	1.53	1.53	1.53
Density (animals)	1.83	2.50	0.58	0.52	0.46	0.50
Area (nm^2)	2,179	1,420	379	1,480	668	2,148
Uncorrected abundance	3,989	3,553	220	772	310	1,064
Correction factor	3.1	3.1	3.1	3.1	3.1	3.1
Corrected abundance	12,367	11,014	681	2,392	960	3,298
COEFFICIENT OF VARIATION CALCULATION						
cv f(0)	0.067	0.067	0.067	0.067	0.067	0.067
cv N (replicate lines)	0.111	0.154	0.220	0.259	0.242	0.186
cv N (replicates passes)	0.269	0.234	0.257	0.239	0.284	0.208
cv Group size	0.021	0.021	0.021	0.021	0.021	0.021
cv Density (replicate lines)	0.131	0.169	0.231	0.268	0.252	0.199
cv Correction factor	0.171	0.171	0.171	0.171	0.171	0.171
cv Abundance	0.216	0.241	0.287	0.318	0.305	0.262

Abundance for Oregon including Heceta Bank (pooled analysis) was 14,480 (CV=0.217).

The latter consideration would bias the variance-weighted averaging if some estimates of variance were based on replicate passes and other on replicate lines.

1989 aerial surveys

Revised abundance estimates of 9,234 and 8,543 were calculated from the 1989 aerial survey data for Oregon and southern Washington, respectively (Table 4). For northern Washington, only two transect lines with three harbor porpoise sightings were made under acceptable weather conditions. This was not adequate effort to compute a separate abundance estimate for this area.

These abundance estimates were higher than those reported by Turnock *et al.* (In press) who used the same data. Turnock *et al.* (In press) reported estimates of 5,215 and 7,961 for the Oregon and southern Washington coasts, respectively. The differences between those estimates and our revised estimates are attributable to a number of factors which differed between the analyses:

1) A primary reason for the higher abundance estimates we obtained was our use of a sighting function model that excluded sightings made in the 200 ft. (61 m) closest to the transect line. Because a higher proportion of sightings were missed near the transect line (due to the absence of a center observer) the original estimate was biased downward as was acknowledged by Turnock *et al.* (In press).

2) The weather criteria for selecting the effort and sightings used differed between the two analyses. We employed a more strict maximum cloud cover (25%) than was used originally (50%) but did not exclude any effort solely on the subjective visibility scores of the observers (as was previously done). Both studies used the same criteria for Beaufort sea state. The weather and visibility criteria we used were selected to be consistent with the criteria used in the 1990 and 1991 surveys.

3) There were some additional differences in how the regions were defined and how their areas were computed between the two analyses. Some of these were minor and reflected the exact location of boundaries between study areas. The boundary between the northern and southern Washington study areas was originally defined at La Push, while, for the revised estimate, we used a boundary 10 nm south that was consistent with that used in the 1989 vessel surveys and the 1990 and 1991 aerial surveys. Some minor differences in the area of the regions were likely the result of differences in how the area was calculated.

4) The method used to calculate density and abundance varied. Turnock *et al.* (In press) stratified by depth while our analyses did not. In theory this should not have altered the outcome because the systematic transect design should have sampled the different depths in proportion to their representation.

Table 4. Harbor porpoise abundance estimates for Oregon and Washington from 1989 aerial surveys.

	Oregon w/o Heceta	S WA
ABUNDANCE ESTIMATE		
Effort - nm	402	249
Replicates (lines)	27	15
Sightings	58	51
Number	70	77
f(0) - nm	13.25	13.25
Density (groups)	0.96	1.36
Group size	1.43	1.43
Density (animals)	1.37	1.94
Area (nm^2)	2,179	1,420
Uncorrected abundance	2,979	2,756
Correction factor	3.1	3.1
Corrected abundance	9,234	8,543
COEFFICIENT OF VARIATION CALCULATION		
cv f(0)	0.117	0.117
cv N (replicates lines)	0.197	0.246
cv Group size	0.041	0.041
cv Density (replicate lines)	0.233	0.275
cv Correction factor	0.158	0.158
cv Abundance	0.281	0.318

5) There was a slight difference in the correction factor employed for animals missed on the transect line. Turnock *et al.* (In press) used the correction factor determined by Barlow (1988) while we used the correction factor that was calculated recently from a calibration experiment (Calambokidis *et al.* 1993).

6) There was a difference in how group size was used in the analyses. Turnock *et al.* (In press) estimated abundance using total animals seen while we used total sightings and adjusted based on overall group size. Though this factor should cancel out among regions, it could alter the estimates for individual regions.

7) There were some minor unexplained differences in the distance of effort and number of sightings that could not be explained by the above factors. The causes or exact magnitude of this could not be identified because we could not reproduce all the aspects of the previous analyses. As far as we could tell these did not appear to have a major consequence on the results.

The difference between our estimates and those calculated previously was less for southern Washington than for Oregon. This appeared to be because some of the differences described above canceled each other out for southern Washington but influenced the Oregon estimates in the same direction, resulting in a larger cumulative difference between the results of the two analyses.

1989 Vessel surveys

An abundance estimate of 486 harbor porpoise was determined from the 1989 vessel surveys for the northern Washington region (Table 5). Calambokidis *et al.* (In press) previously reported an abundance estimate from the 1989 vessel surveys but this estimate was for the entire area surveyed which included portions of the Strait of Juan de Fuca and Swiftsure Bank.

The correction factor used to adjust the abundance estimate from the vessel surveys was based on the small sample available from the land calibration. Though a correction factor was also calculated using the breath rate model (Table 5), this probably did not include some animals missed at the surface and the variance for this factor was likely underestimated.

The estimate from the vessel surveys was based on effort in Beaufort sea states up to and including 2. There was some evidence, reported in Calambokidis *et al.* (In press), that sighting rates were biased downward at a Beaufort sea state of 2 compared to 0-1. Restricting the survey data used in our analysis to Beaufort 1 or better, however, only increased the abundance estimate slightly (<5%), while it decreased the usable survey effort by more than half and the number of harbor porpoise sightings to only 17. Because of the

Table 5. Harbor porpoise abundance estimates for northern coast of Washington from 1989 vessel surveys.

	N WA
ABUNDANCE ESTIMATE	
Effort - nm	379
Replicates (lines)	112
Replicates (passes)	6
Sightings	34
Number	55
f(0) - nm	8.78
Density (groups)	0.39
Group size	1.74
Density (animals)	0.69
Area (nm^2)	379
Uncorrected abundance	260
Correction factor (breath model)	1.67
Correction factor (experiment)	1.87
Corrected abundance (model)	434
Corrected abundance (experiment)	486
COEFFICIENT OF VARIATION CALCULATION	
cv f(0)	0.106
cv N (replicates lines)	0.099
cv N (replicates passes)	0.240
cv Group size	0.089
cv Density (replicate lines)	0.170
cv Correction factor (breath model, not used)	0.122
cv Correction factor (experiment, used)	0.514
cv Abundance	0.541

small sample size and the minimal difference in the point estimate, we used the less restrictive weather criteria (Beaufort sea state of 0-2) for the averaged estimate.

Abundance estimates using all data

Revised abundance estimates for harbor porpoise integrating all appropriate survey data were calculated for all regions (Table 6). All of the averaged estimates were in fairly close agreement. Uncorrected estimates and variances were used in averaging the 1989 and 1990-1991 aerial data because the same correction factor was used for both. Corrected abundances were used to average the aerial and vessel data because of the differences in correction factors. In averaging the estimates for the Oregon and southern Washington coasts, most of the weight was given to the 1990-91 surveys compared to the 1989 surveys. This was because of the greater effort in 1990-91 resulting in a lower variance compared to 1989.

Abundance estimates were highest for coastal Oregon and southern Washington, with estimates of 11,237 and 10,074 harbor porpoise, respectively. The Oregon estimate was 13,014 if the estimate for Heceta Bank is combined with the estimate for the coastal area. As indicated in all the separate surveys, relatively low numbers of harbor porpoise occurred along the northern Washington coast with an averaged estimate of only 613 harbor porpoise. Estimates for the Strait of Juan de Fuca and San Juan Islands area were 2,392 and 960, respectively. The combined estimate for all coastal regions of Oregon and Washington was 23,701 (CV=0.14) and 27,053 (CV=0.13) for all regions surveyed, respectively.

Final CVs for the regional estimates were generally below 0.26. The exceptions were the San Juan Islands area and Strait of Juan de Fuca, which only had a lower variance when pooled together, and Heceta Bank, which similarly only had a lower variance when combined with the rest of Oregon (Table 6).

Though the aerial surveys by Green *et al.* (1992) and vessel surveys by Barlow (1988) were not used in our abundance estimate, their results can be compared. Green *et al.* (1992) estimated an abundance (corrected for animals missed) of 15,046 harbor porpoise in waters out to the 100 m isobath off Washington and Oregon. This is just over half our estimate for these coastal areas. Barlow (1988) estimated a total of just over 30,000 harbor porpoise along the coast of Oregon and Washington (their regions 6-8, which excludes a small portion of the southern Oregon coast). That estimate is slightly higher than our totaled revised estimate for coastal waters (23,701), but in reasonably good agreement given the variances involved, the average 5 year separation between these surveys, and the different methods employed.

Table 6. Calculation of harbor porpoise abundance averaging seperate estimates.

	Oregon w/o Heceta	S WA	N WA	Straits	S. Juans	Straits & S. Juans
Puc – 1990–91 aerial	3,989	3,553	220	772	310	1,064
Vuc – 1990–91 aerial	0.13	0.17	0.23	0.27	0.25	0.20
Puc – 1989 aerial	2,979	2,756				
Vuc – 1989 aerial	0.23	0.28				
Puc – all aerial	3,625	3,250				
Vuc – all aerial	0.12	0.15				
Pc – all aerial	11,237	10,074	681	2,392	960	3,298
Vc – all aerial	0.21	0.22	0.29	0.32	0.30	0.26
Pc – 1989 vessel			486			
Vc – 1989 vessel			0.54			
Pc – all	11,237	10,074	613	2,392	960	3,298
CV – all	0.21	0.22	0.26	0.32	0.30	0.26

Abundance for all OR was 13,014 (CV=0.183)

Puc – Uncorrected abundance estimate

CVuc – Coefficient of variation for uncoorected abundance

Pc – Abundance estimate corrected for animals missed on the transect line

CVc – Coefficient of variation for coorected abundance

Locations of calves

The locations of calf sightings were examined in the different surveys. The aerial surveys by Ebasco Environmental provided the most complete geographic and seasonal coverage of offshore waters (Green *et al.* 1992). Seven sightings of harbor porpoise calves were made during those surveys with five of these during the systematic east-west transect flights. Calves were seen primarily during the summer and early fall with all but one made between 27 July and 2 October. Locations of these few sightings were distributed around the study area with six off the coast of Oregon and one off Washington (see Appendix Figure 6 for the locations of the five sightings made during the systematic surveys).

Locations of sightings of calves made during the dedicated harbor porpoise aerial surveys from 1989 to 1991 are shown in Figure 7. Sightings were distributed throughout the study area. Three sightings of calves were made at Heceta Bank off central Oregon during the 1991 surveys (Calambokidis *et al.* 1992), the farthest offshore area surveyed during these surveys.

Depth distribution and occurrence deeper than 50 fathoms

Harbor porpoise sightings from the systematic east-west transects reported by Green *et al.* (1992) covered waters much farther offshore than the dedicated harbor porpoise surveys used for the abundance estimates. These surveys provided a measure of the depth distribution of harbor porpoise both inside and outside of the more limited study area examined by the dedicated harbor porpoise surveys (Figure 8). A total of 54 of 197 (27%) harbor porpoise sightings made on the systematic surveys legs occurred in waters deeper than 50 fathoms. A slightly smaller portion of sightings (24%) fell outside the area surveyed by the dedicated harbor porpoise surveys (Turnock *et al.* In press, Calambokidis *et al.* 1990, 1991). Though the dedicated harbor porpoise surveys generally only surveyed waters out to 50 fathoms, in some areas near underwater canyons and banks, deeper waters were covered. Limiting this analysis to only the period from July to September when the dedicated surveys were conducted yielded similar results with 25% of the sightings outside the study area.

Green *et al.* (1992) summarized the sighting rates of harbor porpoise by broad depth classes (inner shelf: 0-100 m, outer shelf: 100-200 m, slope: 200-2,000 m, and offshore: >2,000 m). Harbor porpoise encounter rates (animals seen per 1,000 km) during the summer and overall were about three times higher in inner shelf waters than on the outer shelf. Sightings on the slope and offshore (>200 m water depth were negligible (more than 20 times lower than on the inner shelf).

The data from the surveys reported by Green *et al.* (1992) on the proportion of animals seen outside the area covered by the dedicated surveys could be used to adjust the

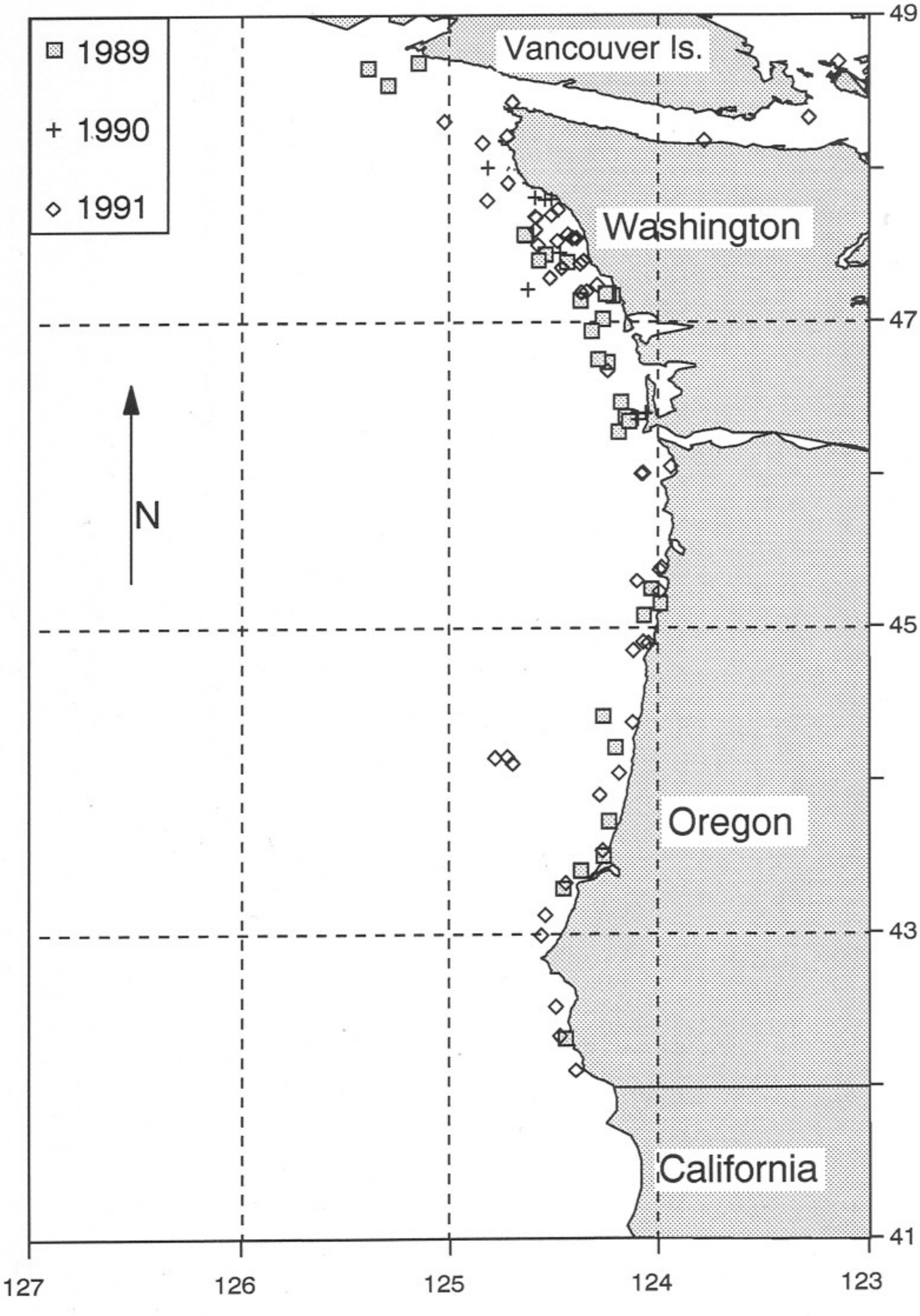

Figure 7. Locations of sightings of harbor porpoise calves during dedicated aerial surveys for harbor porpoise conducted 1989-1991.

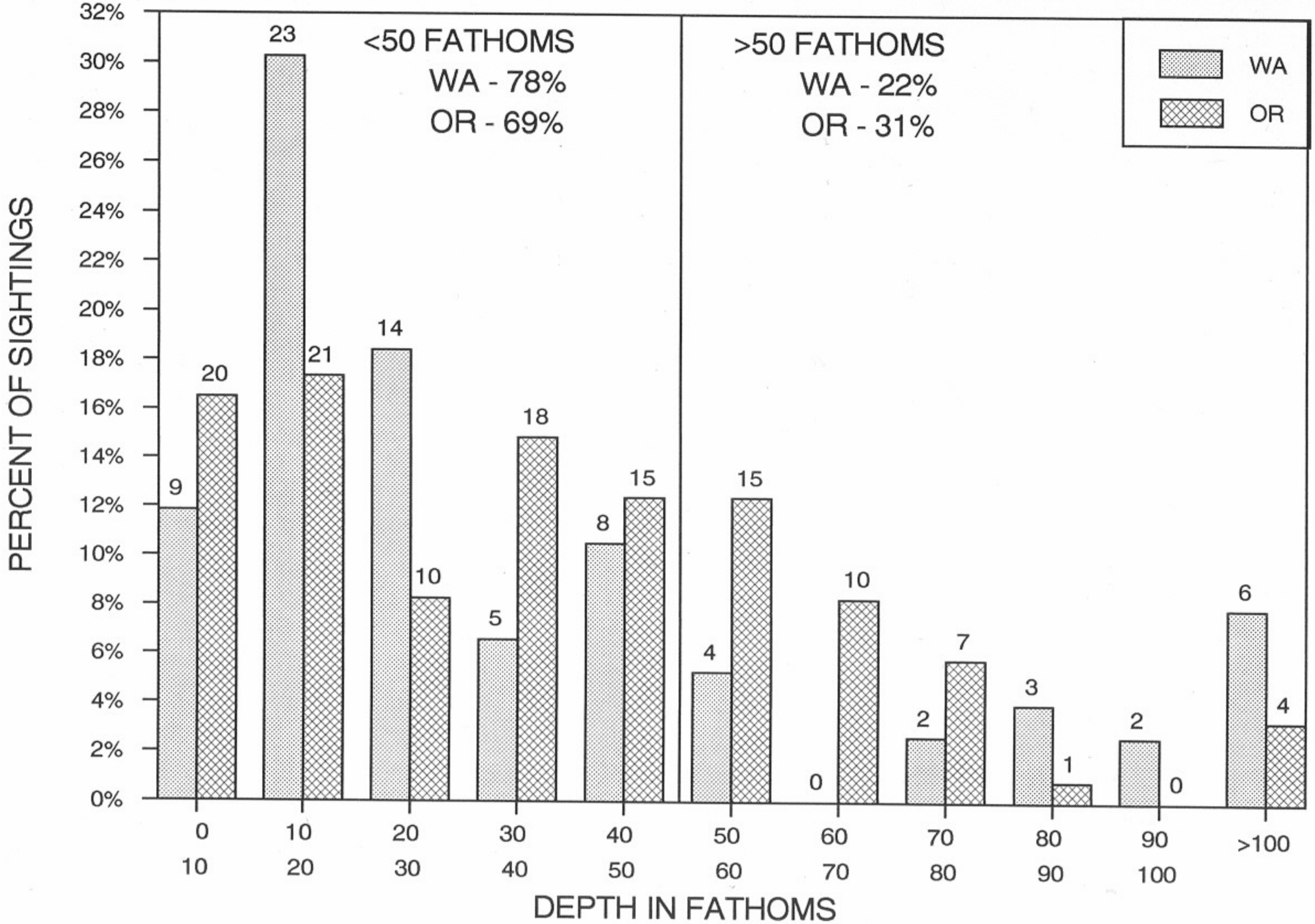

Figure 8. Number of harbor porpoise sightings made at different water depths during systematic east-west survey lines conducted by Ebasco Environmental (Green *et al.* 1992).

revised abundance estimates reported here. If the proportion of harbor porpoise seen outside the area covered by the dedicated surveys (24%) accurately reflects the proportion of the population outside the survey area, the revised abundance estimates calculated in this report would need to be adjusted by 1.31. For example, our abundance estimate of 23,701 for coastal waters of Oregon and Washington would be 31,048 if adjusted for animals outside the surveyed area. A variance for this correction factor was not calculated. Because the abundance estimates presented in previous sections of this report were not adjusted, these estimates are only for the population within the surveyed regions.

The dedicated harbor porpoise surveys conducted from 1989 to 1991 provided data on the depth distribution of harbor porpoise within more coastal regions (Calambokidis *et al.* 1991, 1992, Turnock *et al.* In press)). In waters off the coast of Oregon and Washington, harbor porpoise densities were highest in waters depths of 0 to 20 fathoms with low sighting frequencies near 50 fathoms. The sighting distribution by water depth was dramatically different in the Strait of Juan de Fuca and around the San Juan Islands. Harbor porpoise occurred commonly at a wide range of water depths out to greater than 100 fathoms with no clear pattern in the depth distribution. These differences in harbor porpoise depth distributions are probably related to differences in hydrographic patterns and prey distribution patterns between coastal waters off Oregon and Washington and those in of the inland waters of Washington.

ACKNOWLEDGMENTS

This study was only made possible by the help and contributions of the personnel who conducted the original surveys analyzed in this report. Southwest Fisheries Science Center made available their data from the aerial and vessel surveys along the coasts of Oregon and Washington in the early 1980s. Dr. Jay Barlow was especially helpful in providing this material and the programs that had been used to analyze that data. Ebasco Environmental and Minerals Management Service made available their data and documentation for the surveys conducted for the Minerals Management Services. Greg Green and Rich Grotefendt were especially helpful in providing well-formatted data. Funding or support for the surveys used in this report also came from the Southwest Fisheries Science Service, the National Marine Mammal Laboratory, the Washington Department of Wildlife, and the Oregon Department of Fish and Wildlife. Numerous personnel of the National Marine Mammal Laboratory and Cascadia Research assisted in the conducting of the aerial and vessel surveys for harbor porpoise from 1989 to 1991. Judy Zeh and Rodd Hobbs provided valuable advice on analysis methods. Gretchen Steiger, Jay Barlow, and Greg Green providing helpful comments on earlier drafts of this report.

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APPENDIX

Description and evaluation of data sets

SWFC vessel surveys, 1984-85

Background: Line transect surveys were conducted by Southwest Fisheries Center in using a 52 m ship (NOAA David Star Jordan) in 1984 and 1985 covering the coast of California, Oregon and Washington (Barlow 1988). These surveys were conducted along the 10 fathom line and relied on a model of harbor porpoise distribution by depth to extrapolate to all depth classes. A double observer experiment was used to determine the proportion of animals missed by the primary observation team.

Maps of effort and sightings: See Appendix Figure 1 for effort tracklines and Appendix Figure 2 for harbor porpoise sighting locations.

Usefulness for abundance estimate: These data were not used for the revised abundance estimate. They cannot be pooled with the more recent aerial survey data because they are a completely different survey type. It was not averaged with the more recent data because:

1) These surveys were conducted 5 years earlier than most of the other surveys.

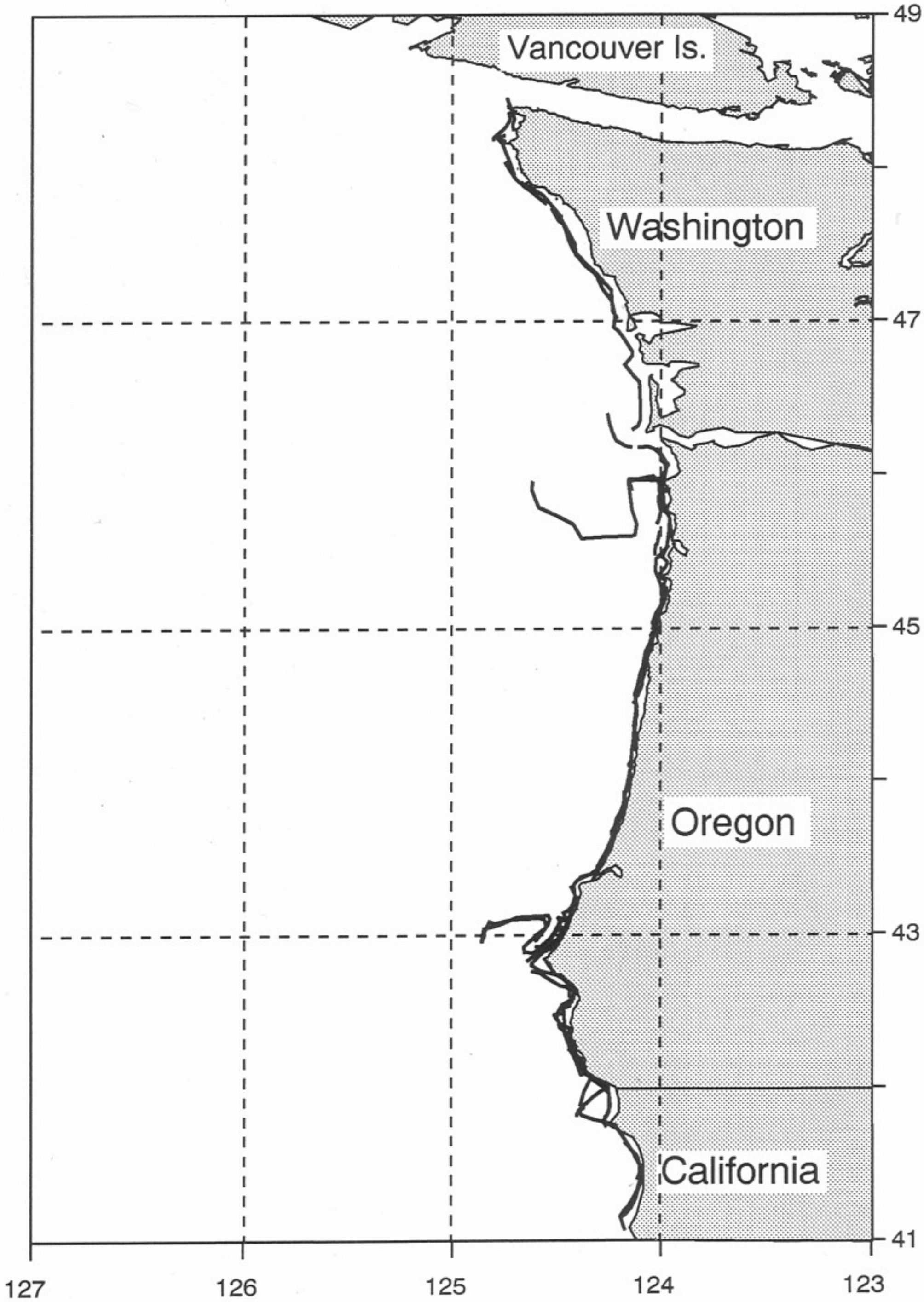
2) These estimates relied on a constant depth distribution model. More recent data have shown that the depth distribution can vary dramatically by region.

Usefulness for examining depth distribution and calf occurrence: These data were not useful to examine the secondary objectives of evaluating the depth distribution of harbor porpoise or the locations of calves. Because almost all the survey effort was conducted along a single depth contour, the depth distribution of sightings is meaningless.

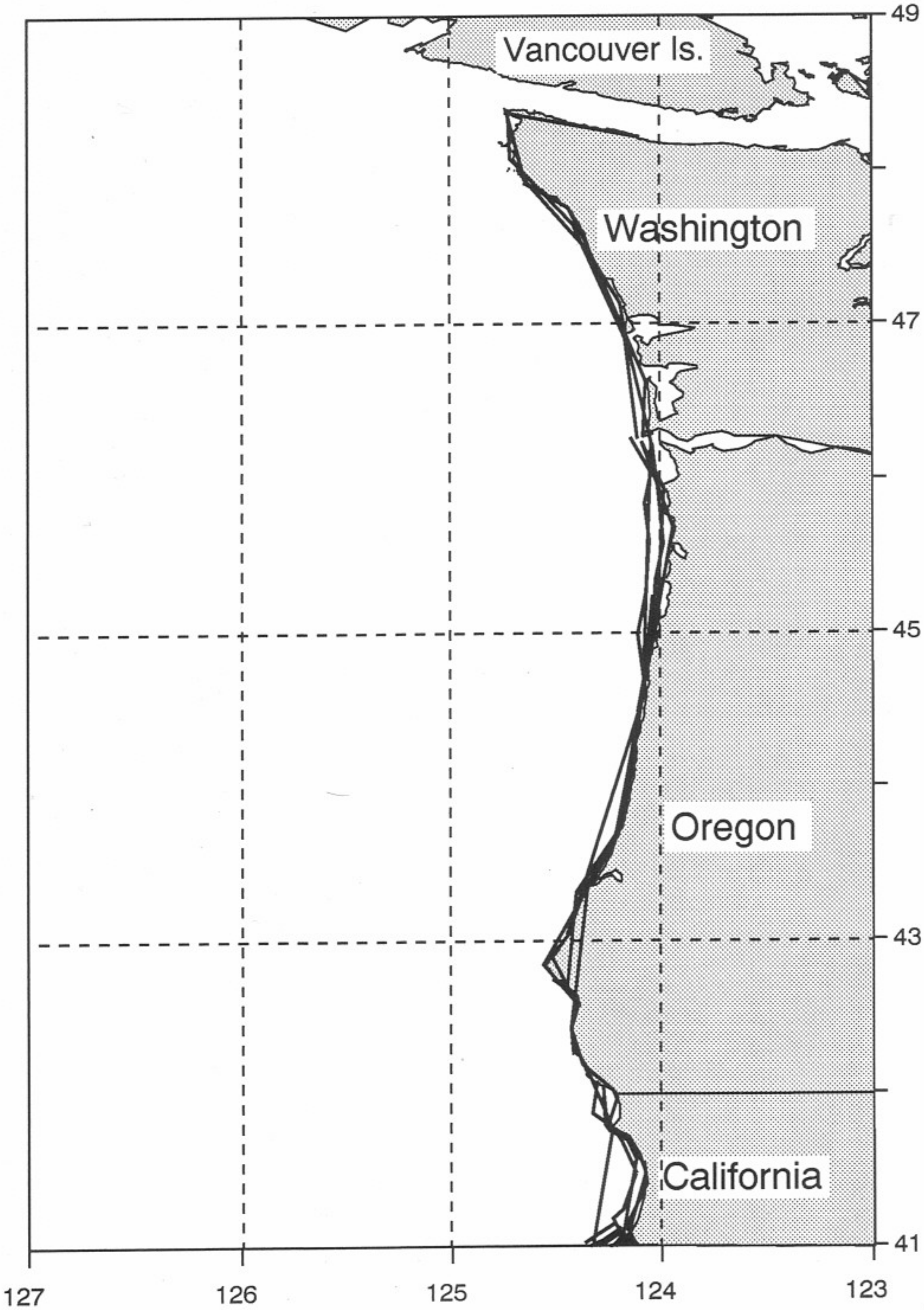
SWFC aerial surveys, 1984-85

Background: In conjunction with the vessel surveys described above, SWFC in conjunction with the Washington Department of Wildlife (WDW) and the Oregon Department of Fish and Wildlife (ODFW) also conducted aerial surveys of harbor porpoise along the coast of California, Oregon, and Washington in 1984 and 1985 (Barlow *et al.* 1988). Strip-transects were conducted from single and twin engine aircraft flown parallel to shore at a distance of 0.33 and 1 nm. These surveys were not used to develop an abundance estimate though the porpoise densities were compared to the ship surveys.

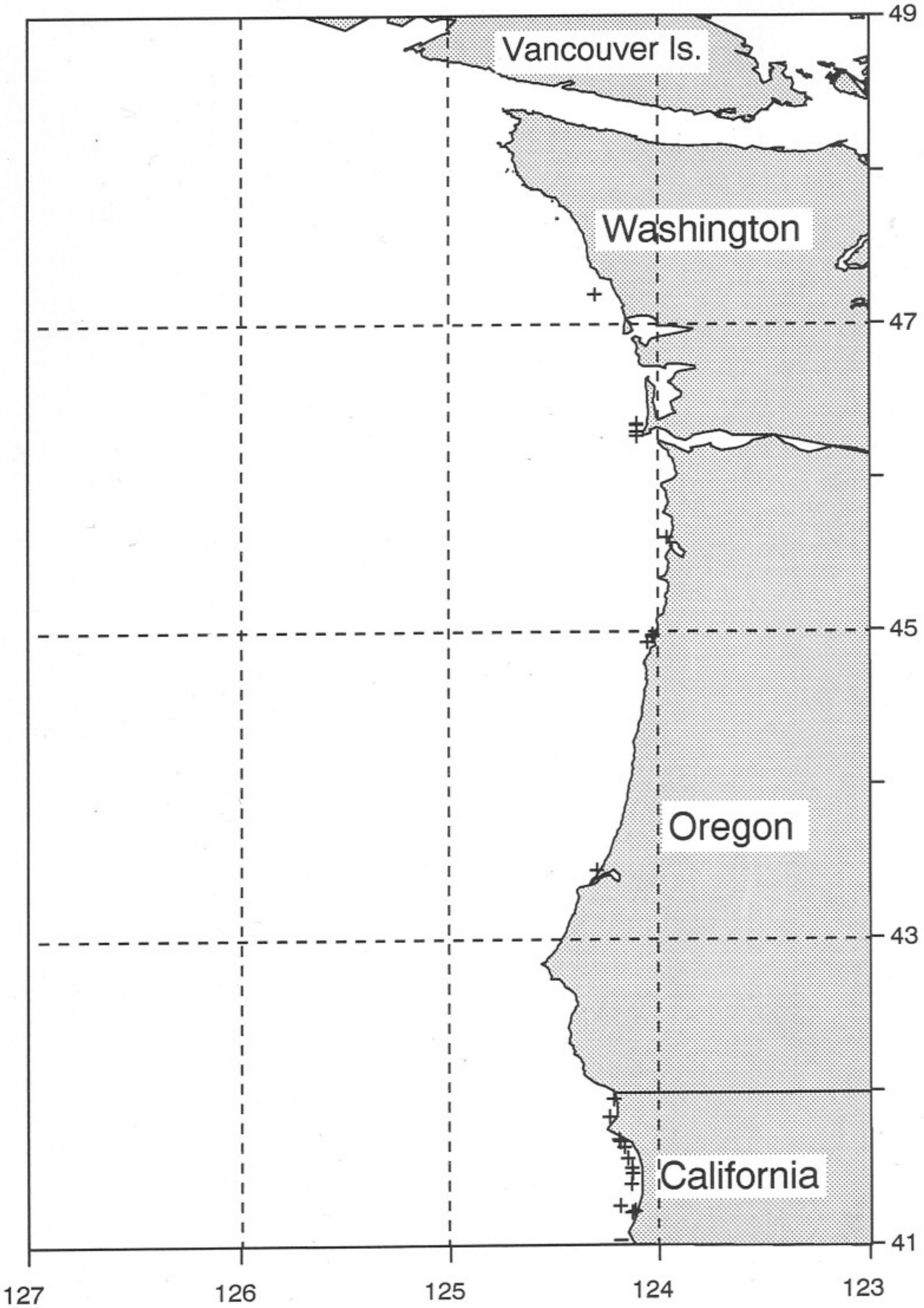
Maps of effort and sightings: See Appendix Figure 3 for effort tracklines and Appendix Figure 4 for harbor porpoise sighting locations.



Appendix Figure 1. Survey tracklines for SWFC vessel surveys, 1984-1985 (Barlow 1988).



Appendix Figure 3. Survey tracklines for SWFC aerial surveys, 1984-1985 (Barlow *et al.* 1988).



Appendix Figure 4. Locations of harbor porpoise sightings during SWFC aerial surveys, 1984-1985 (Barlow *et al.* 1988).

Usefulness for abundance estimate: These data were not used in the revised abundance estimate. They have the same limitations discussed above for the vessel surveys. Because the surveys were conducted parallel to shore, a model of the depth distribution of harbor porpoise would have to be used to develop an estimate. Barlow *et al.* (1988) did not feel these surveys were useful for abundance estimates and therefore did not calculate abundances.

Usefulness for examining depth distribution and calf occurrence: Like the ship surveys above, this data set was not useful for examining the depth distribution of sightings or the distribution of calves. The surveys were conducted parallel to shore making depths of sightings of little use.

Ebasco/MMS surveys - 1989-1990

Background: Ebasco Environmental conducted aerial surveys for marine mammals and marine birds for Minerals Management Service off the coast of Oregon and Washington (Green *et al.* 1992). For harbor porpoise abundance, a strip-transect analysis was conducted using the data from the bird observers surveying the non-glare side of the aircraft. Surveys were flown perpendicular to shore at an altitude of 200 ft (61 m). A single estimate was calculated for Washington and Oregon and was based on 34 sightings.

Maps of effort and sightings: See Appendix Figure 5 for effort tracklines and Appendix Figure 6 for harbor porpoise sighting locations (including calves).

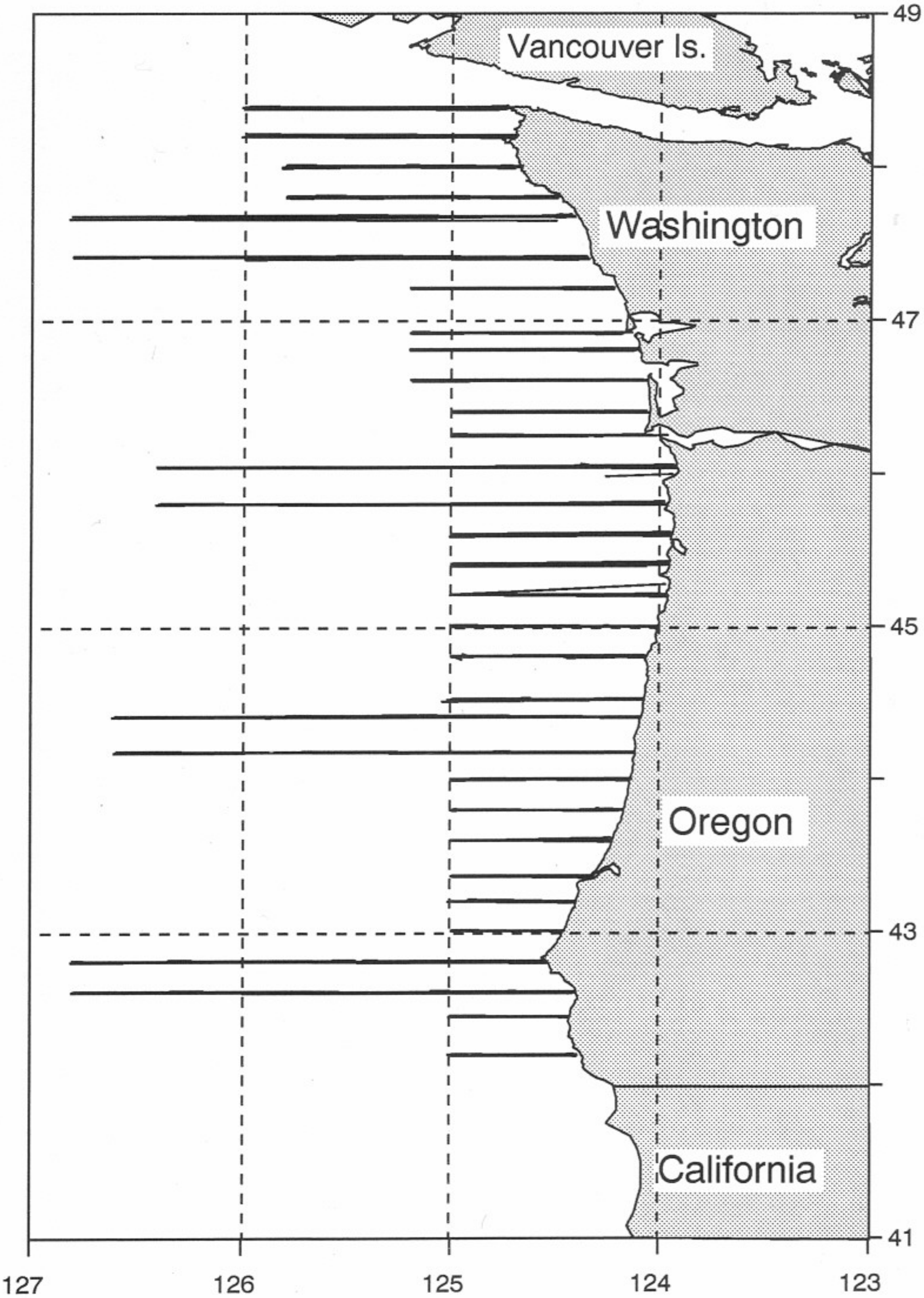
Usefulness for abundance estimate: The data set was not suitable for pooling because of the differences in methodology with the other aerial surveys. We did not include this estimate in the weighted average because:

1) sample size was very small, especially when divided into the three regions to be used in the current analysis.

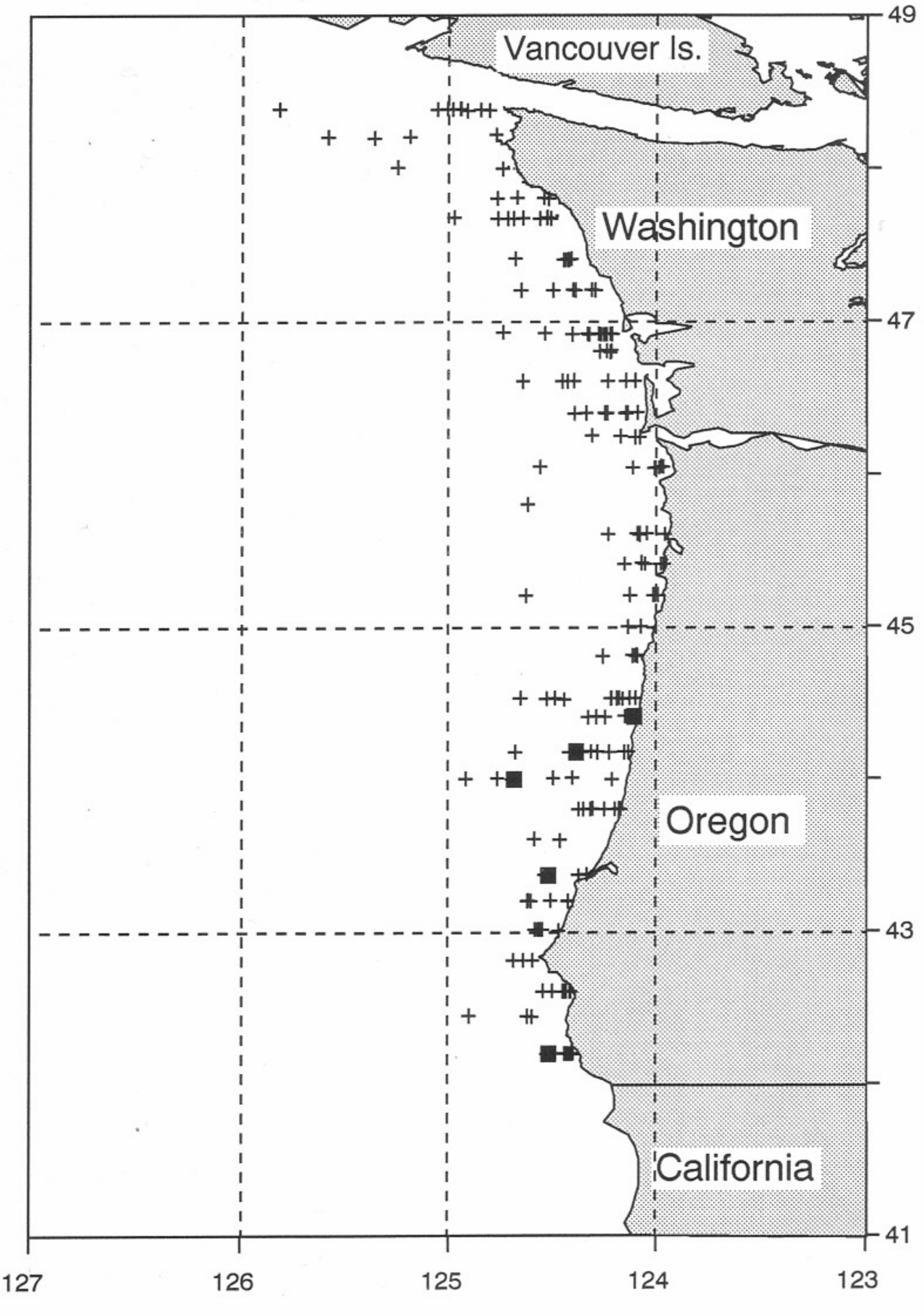
2) cloud cover, a critical factor that affects sighting rates of harbor porpoise in aerial surveys, was not recorded during surveys or used as a selection criteria for effort used in the abundance estimate.

3) the low altitude survey height (200 ft, 61 m) was much lower than other surveys (500-600 ft, 152-183 m) and had an unknown effect on sighting rate.

Usefulness for examining depth distribution and calf occurrence: The data were very useful for examining sighting distribution by depth, especially for depths >50 fathoms not covered in other aerial surveys.



Appendix Figure 5. Survey tracklines for systematic east-west lines during Ebasco Environmental aerial surveys (Green *et al.* 1992).



Appendix Figure 6. Locations of harbor porpoise sightings seen from east-west lines during Ebasco Environmental aerial surveys (Green *et al.* 1992). Boxes show locations of calves.

Dedicated vessel surveys for harbor porpoise - 1989

Background: Vessel surveys were conducted in 1989 by Cascadia Research, contract to NMML, along the northern Washington coast including Swiftsure Bank and the SW Strait of Juan de Fuca (Calambokidis *et al.* In press). These line-transect surveys yielded an abundance estimate with a relatively high variance. A correction factor was used based on a model of harbor porpoise breath rates and a small sample from a calibration experiment. Tracklines followed saw-tooth design out to 50 fathoms.

Maps of effort and sightings: See Appendix Figure 7 for effort tracklines and Appendix Figure 8 for harbor porpoise sighting locations.

Usefulness for abundance estimate: This data set was not appropriate for pooling with the aerial survey data because of the different survey type. It was used, however, for averaging with the aerial estimates for the northern Washington coast. One limitation of the past data analysis was that there was no variance for the correction factor for animals missed. This was addressed in our revised analysis.

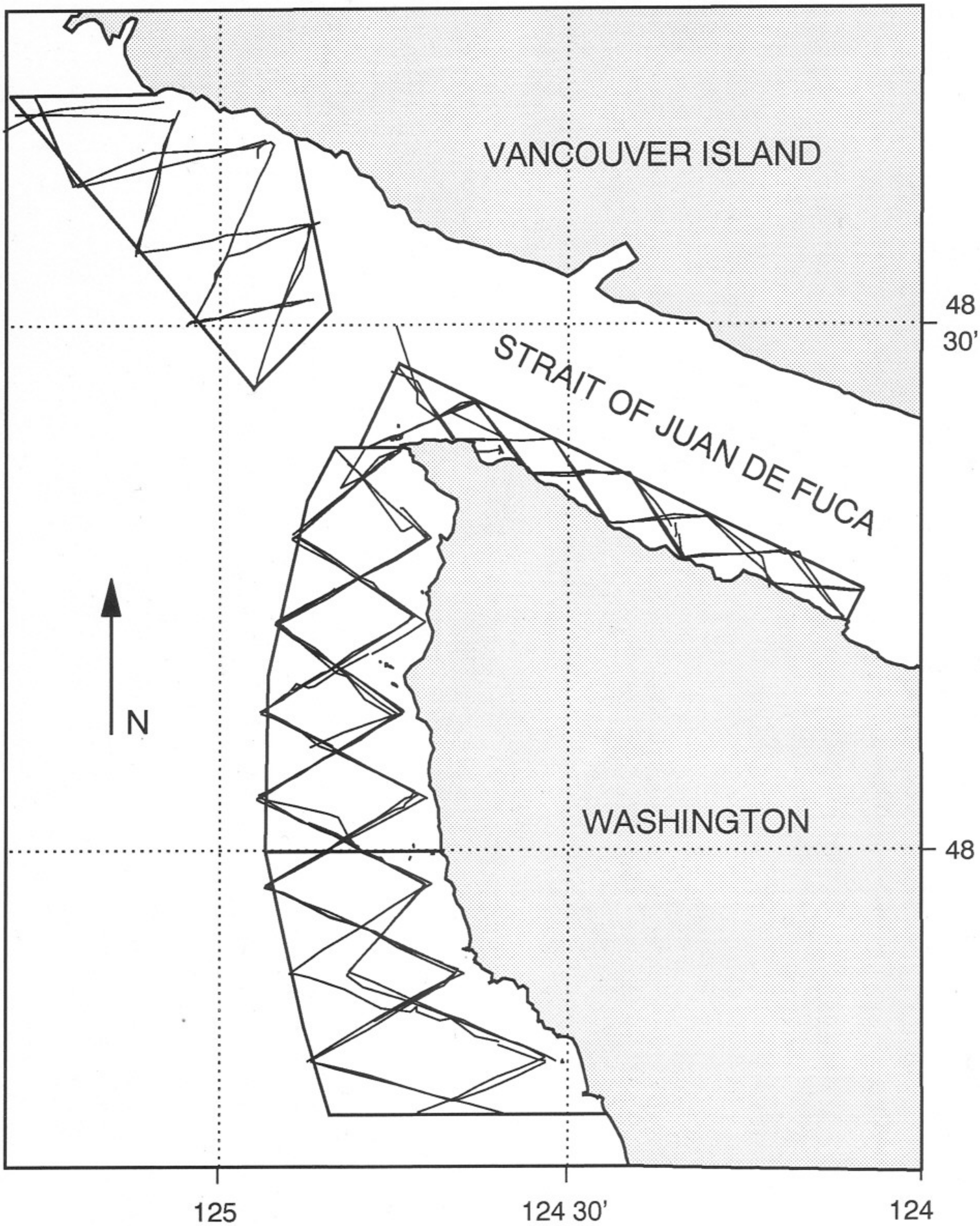
Usefulness for examining depth distribution and calf occurrence: Depths and sighting locations of calves were of limited usefulness from this data set because of the limited geographic coverage of these surveys.

Dedicated aerial surveys for harbor porpoise - 1989

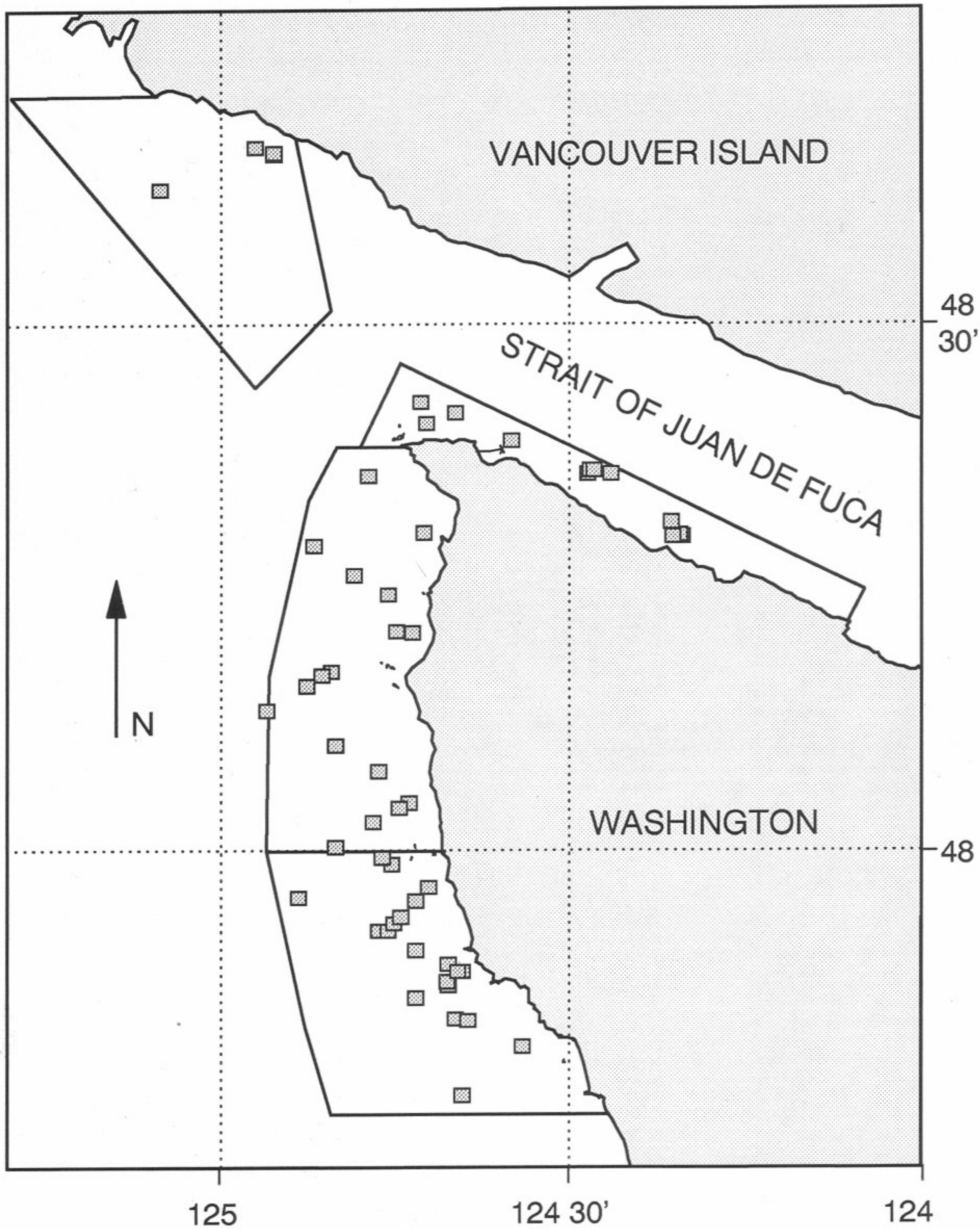
Background: Aerial surveys were conducted by NMML (in cooperation with WDW and ODFW) along the coast of Oregon and Washington in 1989 (Turnock *et al.* In press). These line-transect surveys were conducted from shore out to 50 fathoms and used two observed looking out both sides of twin-engine aircraft. Estimates were calculated for Oregon, the southern Washington coast, and Swiftsure Bank. Estimates for the N. Washington coast and the SW Strait of Juan de Fuca were not possible because no sightings were made in acceptable conditions.

Maps of effort and sightings: See Appendix Figure 9 for effort tracklines and Appendix Figure 10 for harbor porpoise sighting locations.

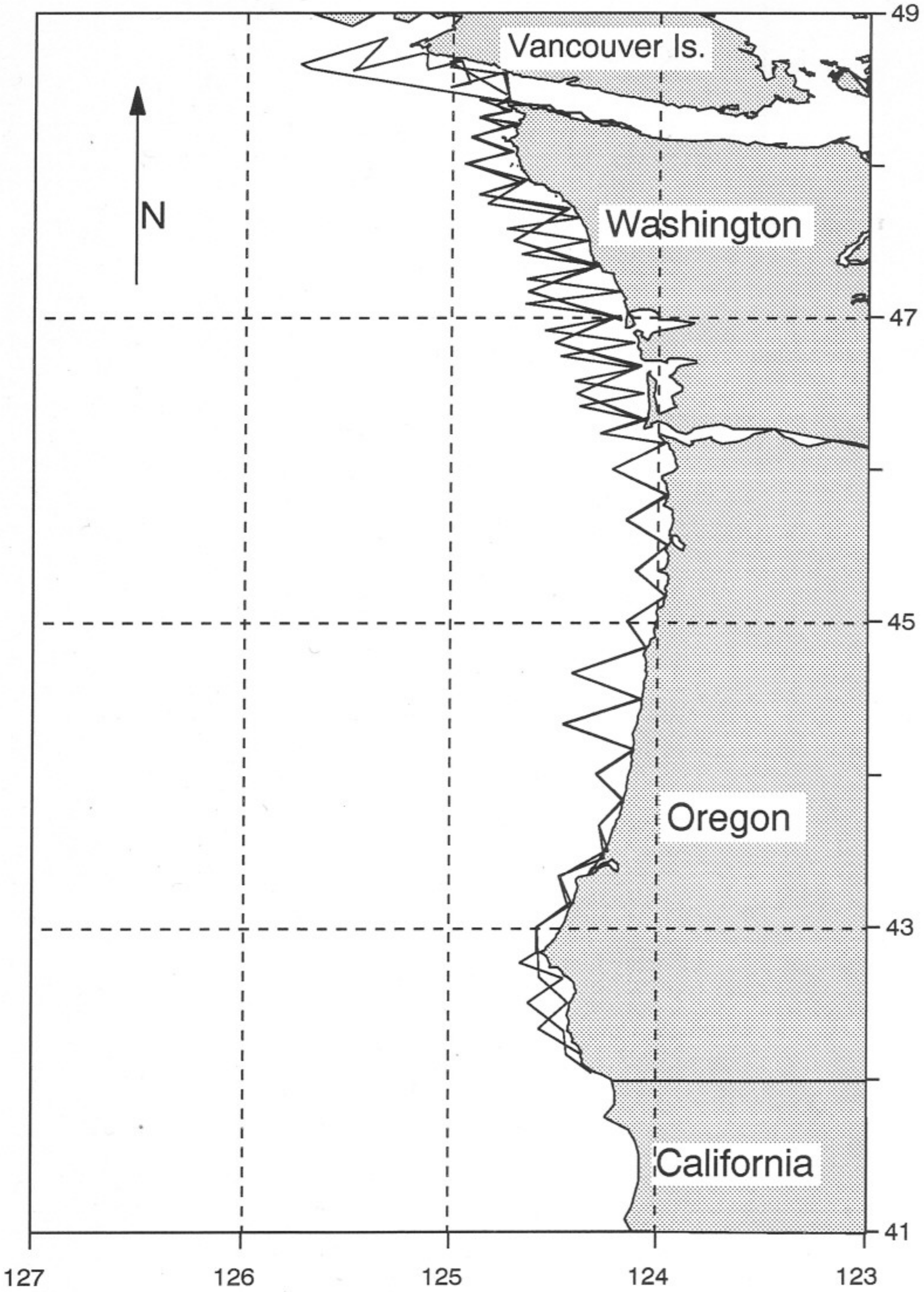
Usefulness for abundance estimate: This data set was analyzed separately and then the uncorrected abundance averaged with the survey results from 1990 and 1991. The primary problem with this data was that they were conducted without a center observer. The lack of a center observer and the resulting lower sighting rate near the transect line was clearly apparent in the perpendicular sighting distances (Figure 1). The sighting function was clearly different from the 1990 and 1991 surveys making pooling of this data set with the later surveys not advisable. The weather cut-off from the 1989 surveys was also slightly different from those in the later surveys.



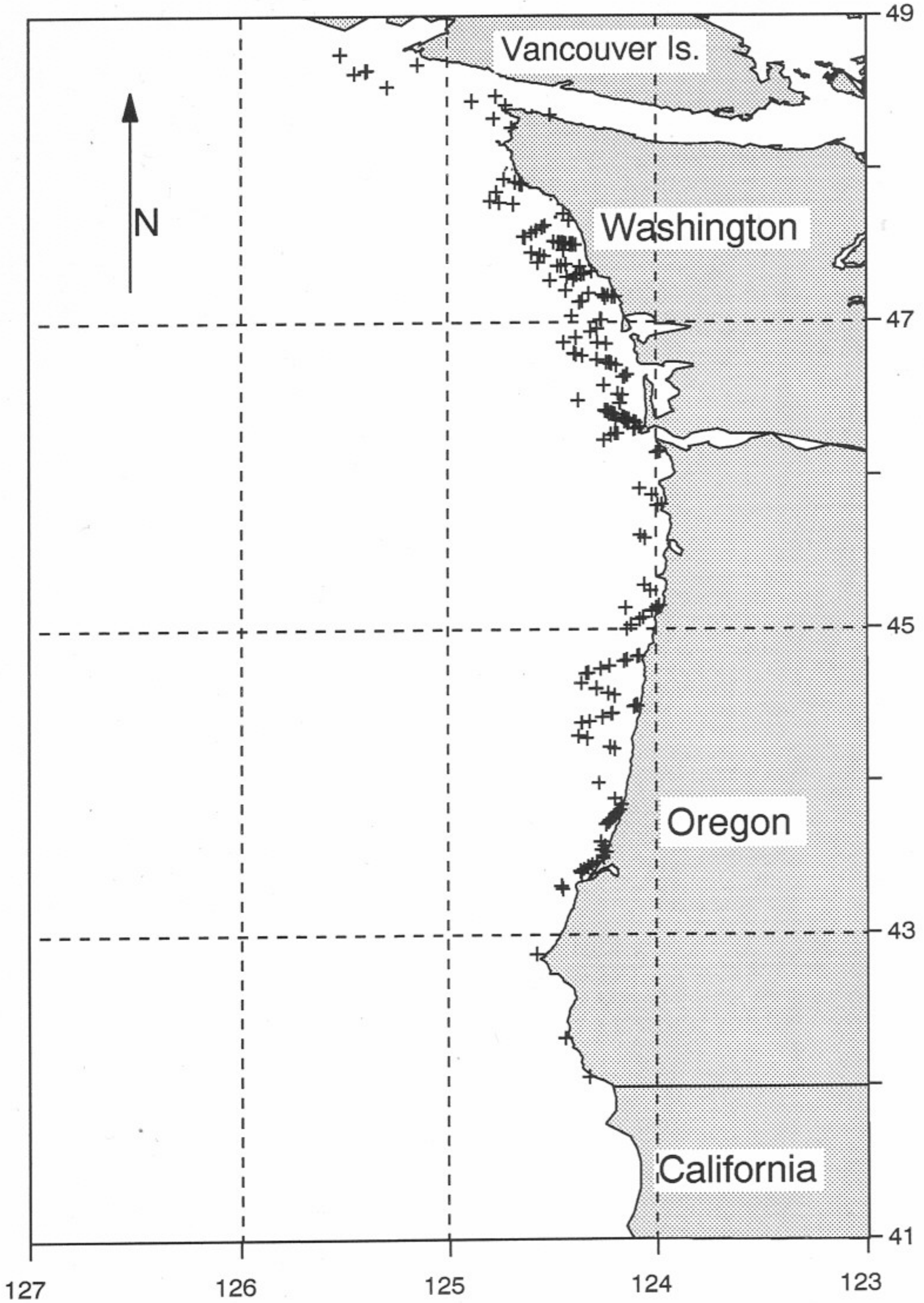
Appendix Figure 7. Survey tracklines for 1989 vessel surveys (Calambokidis In press).



Appendix Figure 8. Locations of harbor porpoise sightings during 1989 vessel surveys (Calambokidis In press).



Appendix Figure 9. Survey tracklines for 1989 aerial surveys (Turnock *et al.* In press).



Appendix Figure 10. Locations of harbor porpoise sightings during 1989 aerial surveys (Turnock *et al.* In press).

Usefulness for examining depth distribution and calf occurrence: These survey data were of use in examining depth distribution and calf distribution. One limitation, however, was that the locations of sightings were extrapolated based on time of flight along the survey line. Given the likely changes in wind speed and pilot course corrections, these positions may not be very accurate.

Dedicated aerial surveys for harbor porpoise - 1990

Background: Aerial line-transect surveys were conducted by Cascadia Research and NMML (in cooperation with WDW and ODFW) along the Washington coast in 1990 (Calambokidis *et al.* 1991). Surveys were conducted with two side and one center observer. Tracklines followed saw-tooth design out to 50 fathoms.

Maps of effort and sightings: See Appendix Figure 11 for effort tracklines and Appendix Figure 12 for harbor porpoise sighting locations.

Usefulness for abundance estimate: These surveys were compatible with the 1991 surveys and were pooled with 1992.

Usefulness for examining depth distribution and calf occurrence: Useful for this purpose and data was available.

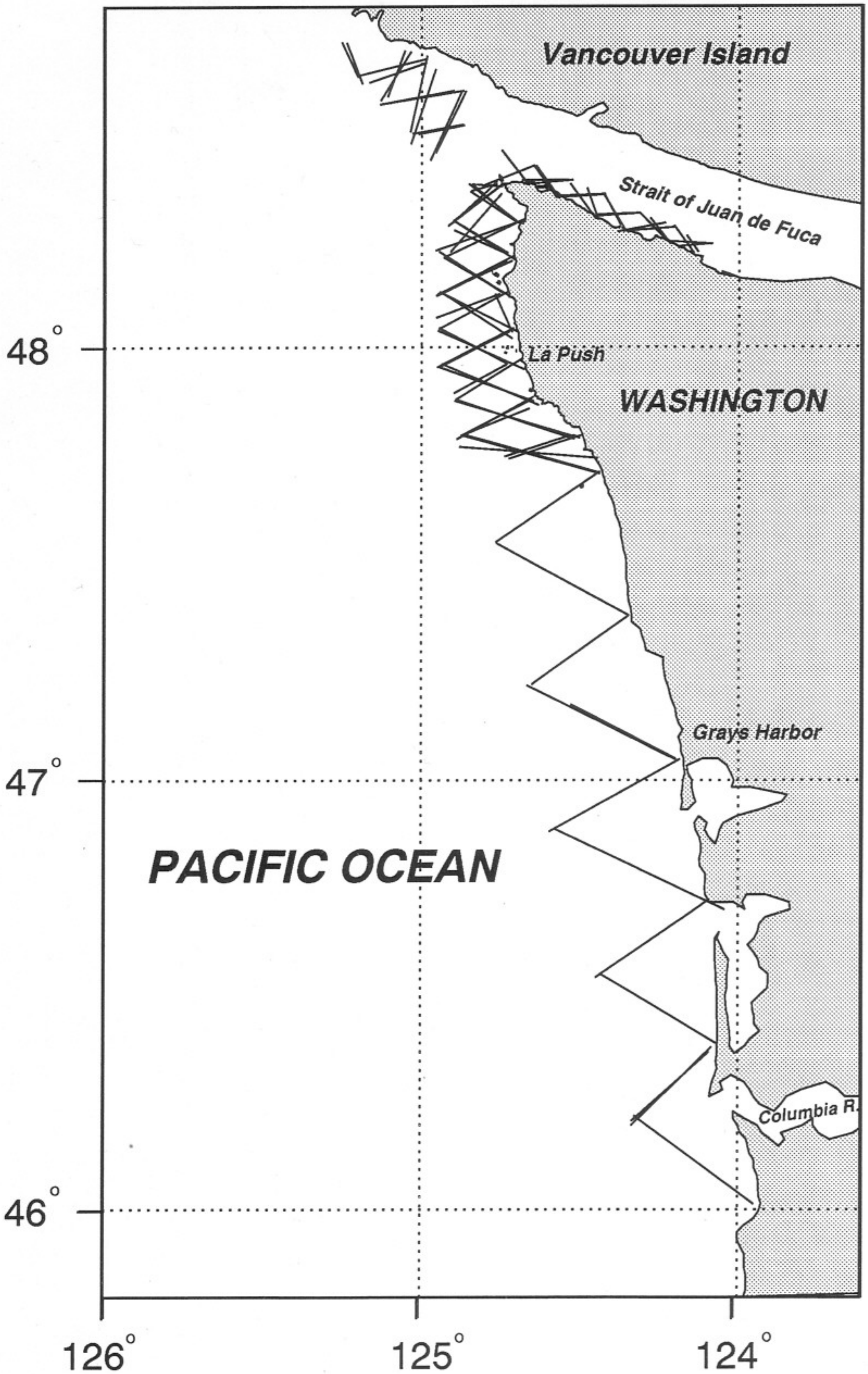
Dedicated aerial surveys for harbor porpoise - 1991

Background: Aerial line-transect surveys were conducted by Cascadia Research and NMML personnel along the Oregon and Washington coast in 1991 (Calambokidis *et al.* 1992). Survey effort was substantially higher than the 1989 and 1990 surveys. These surveys also covered all the Strait of Juan de Fuca and San Juan Islands. Surveys were conducted with two side and one downward observer. Tracklines followed saw-tooth design out to 50 fathoms except in inland waters were all depths were surveyed. Additional surveys were also conducted with a single-engine plane and two observers in Puget Sound and three coastal embayments to verify that harbor porpoise were either absent or present in very low numbers in these areas.

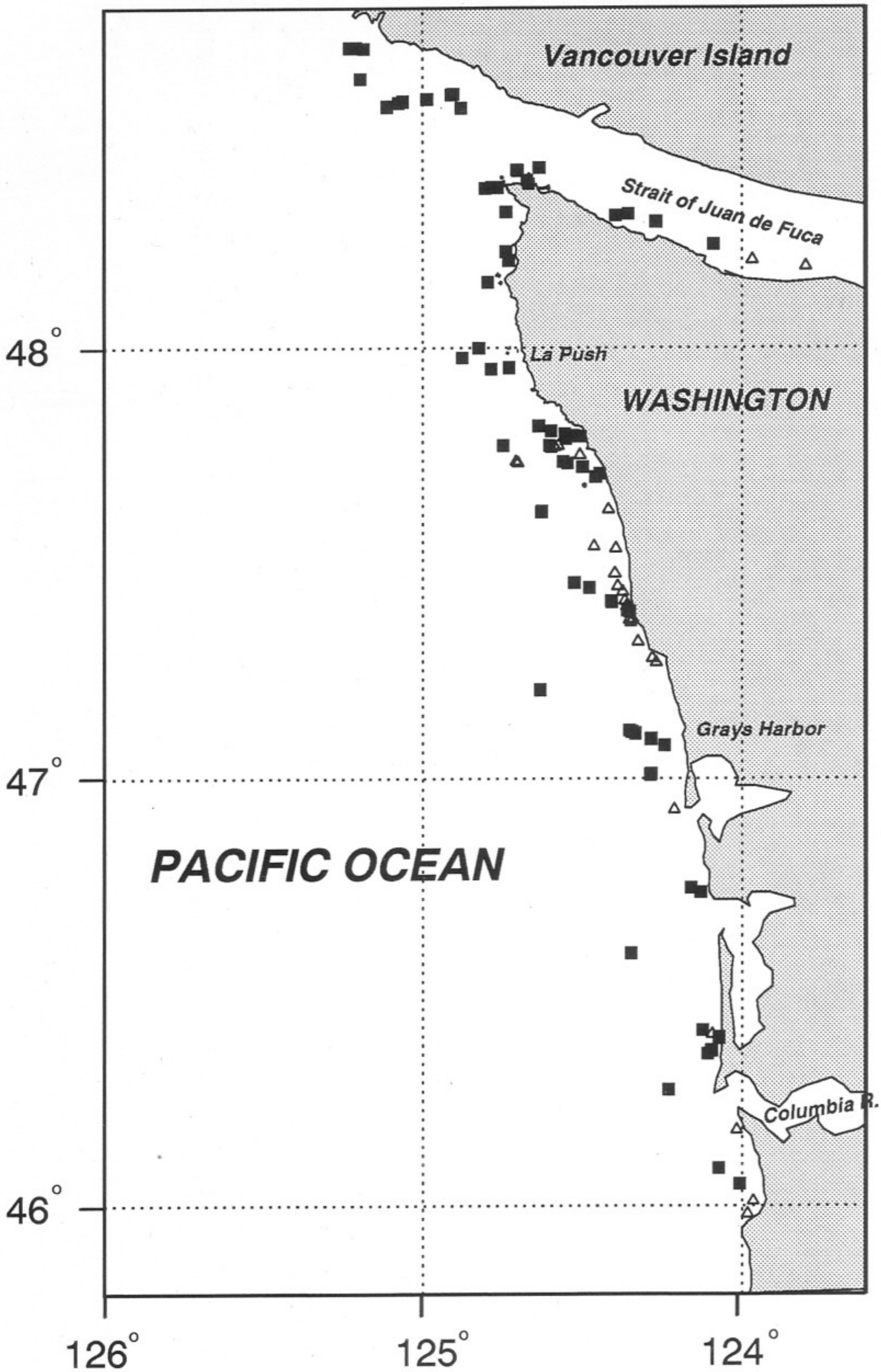
Maps of effort and sightings: See Appendix Figures 13 and 14 for effort tracklines and Appendix Figure 15 and 16 for harbor porpoise sighting locations.

Usefulness for abundance estimate: These surveys provided the best estimates of harbor porpoise to date. CVs for most areas were below 0.30. These surveys were pooled with the 1990 aerial surveys and formed the primary basis for the pooled estimate.

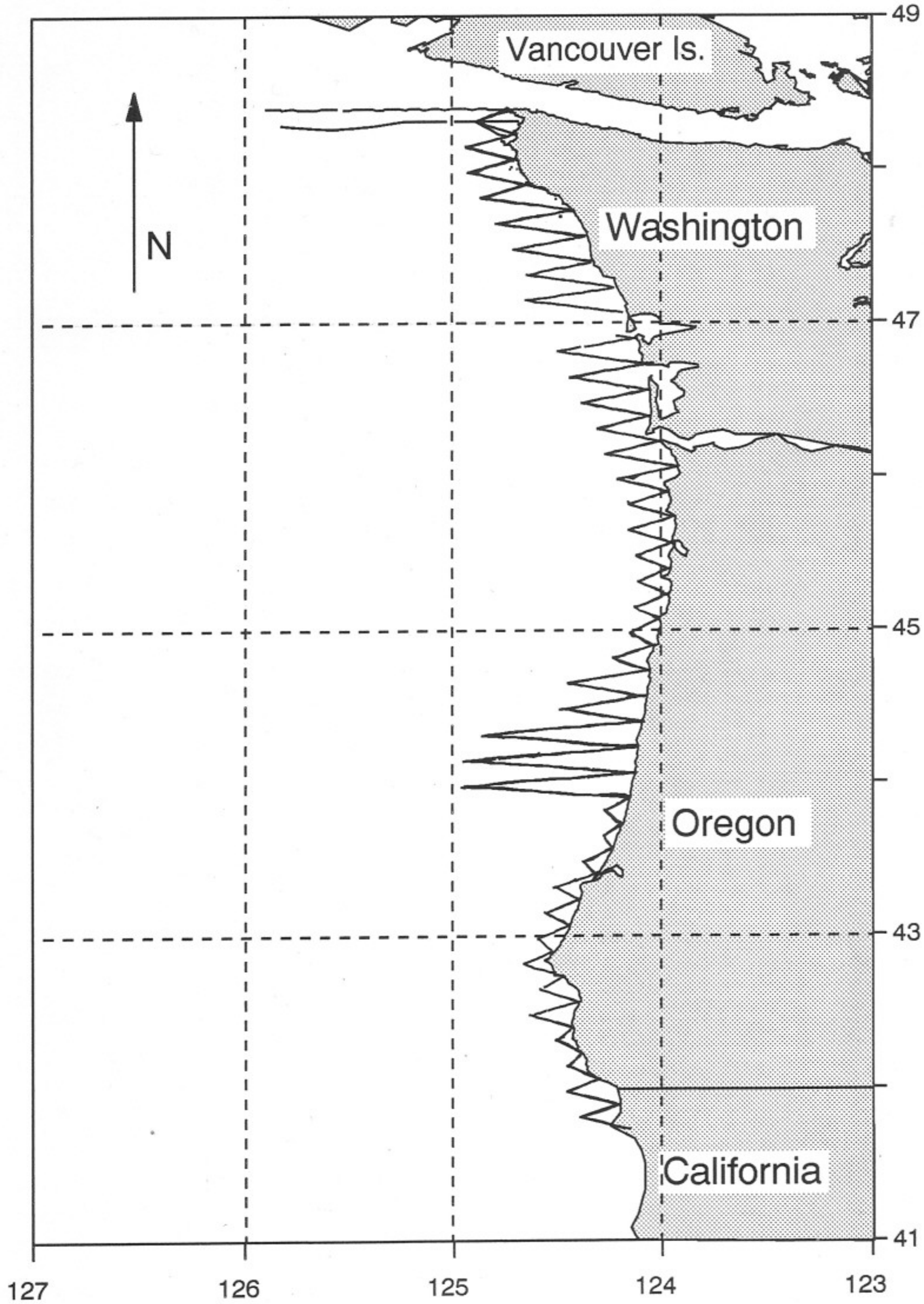
Usefulness for examining depth distribution and calf occurrence: Useful for this purpose.



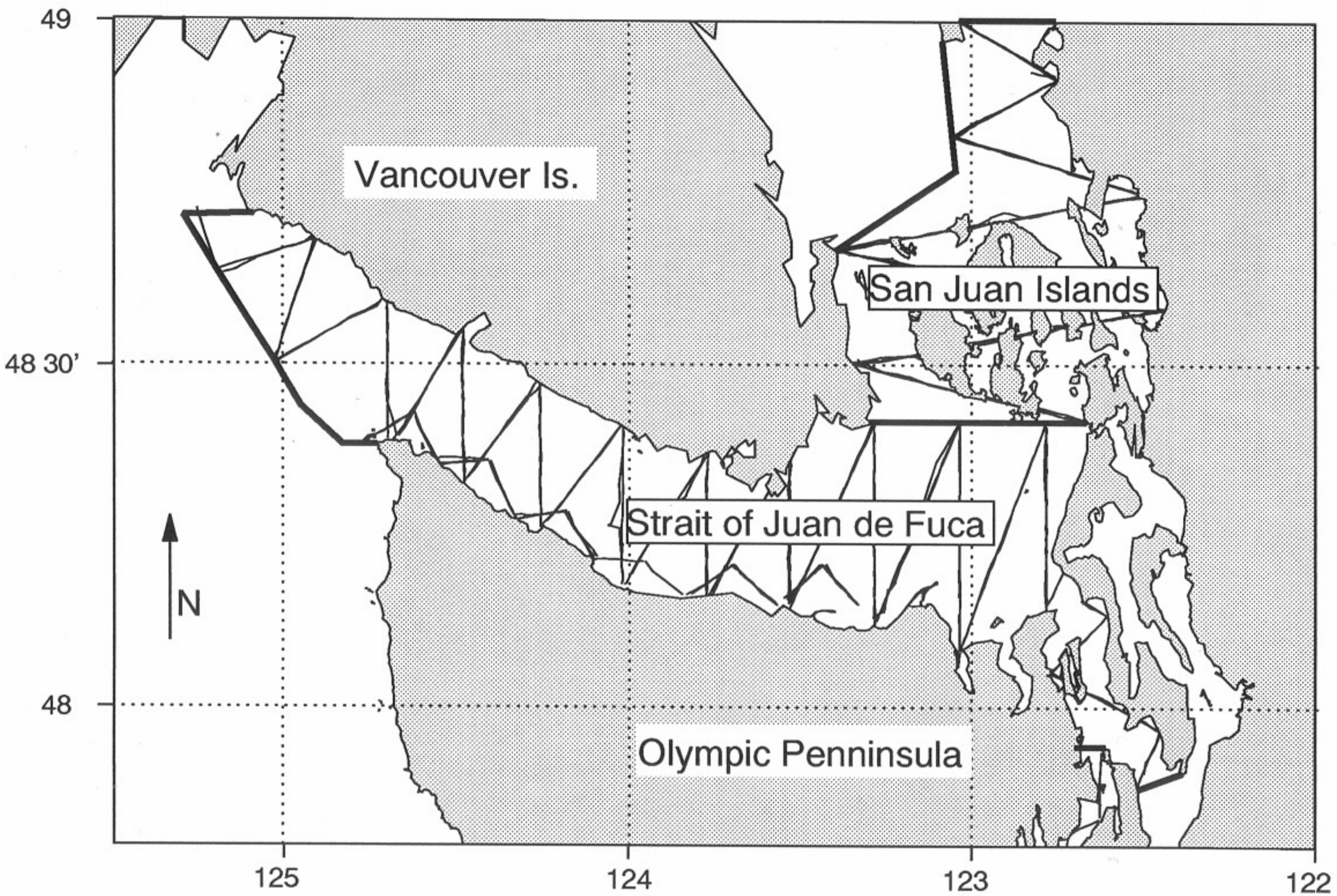
Appendix Figure 11. Survey tracklines for 1990 aerial surveys (Calambokidis *et al.* 1991).



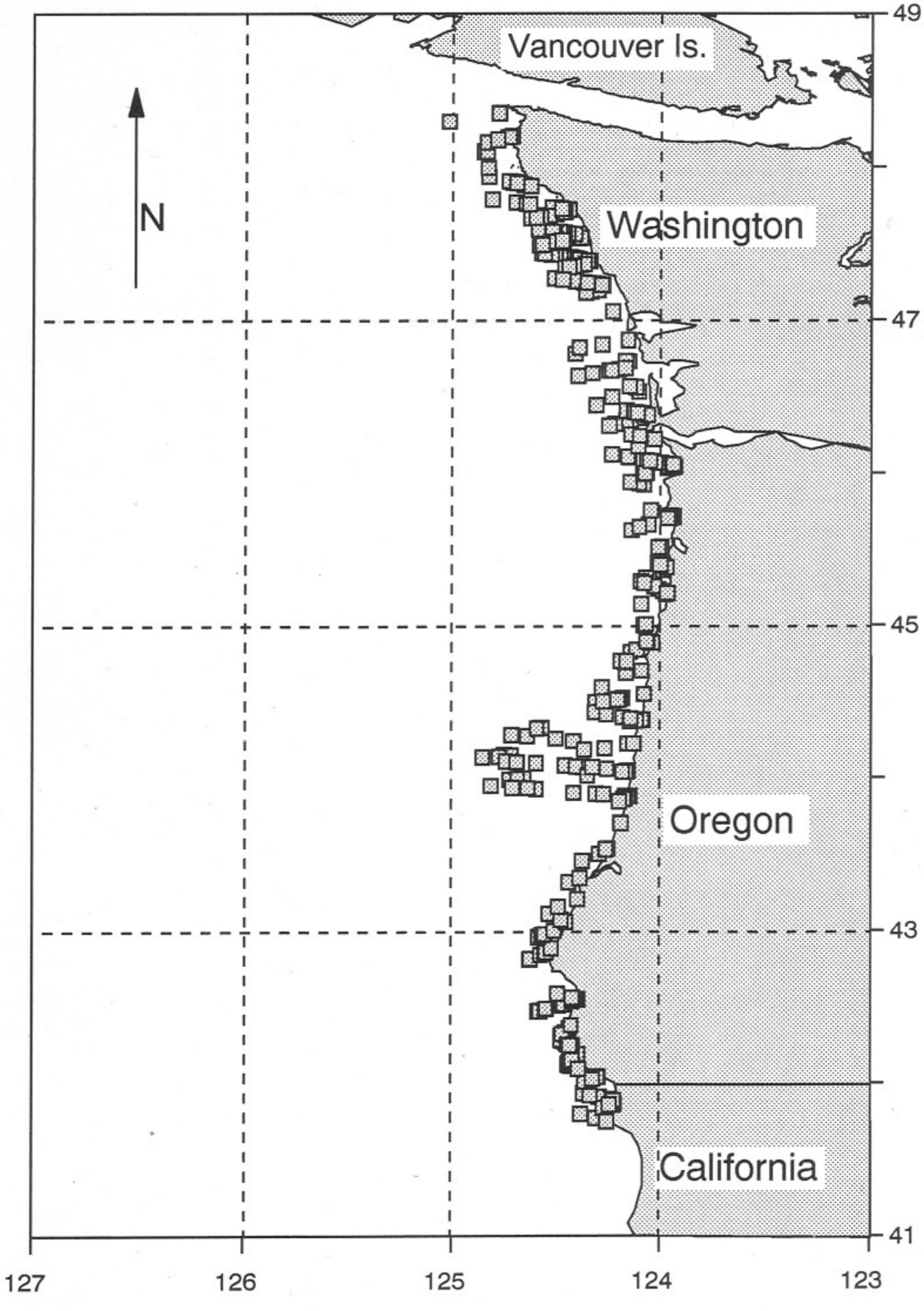
Appendix Figure 12. Locations of harbor porpoise during 1990 aerial surveys (Calambokidis *et al.* 1991). Triangles are off-effort sightings.



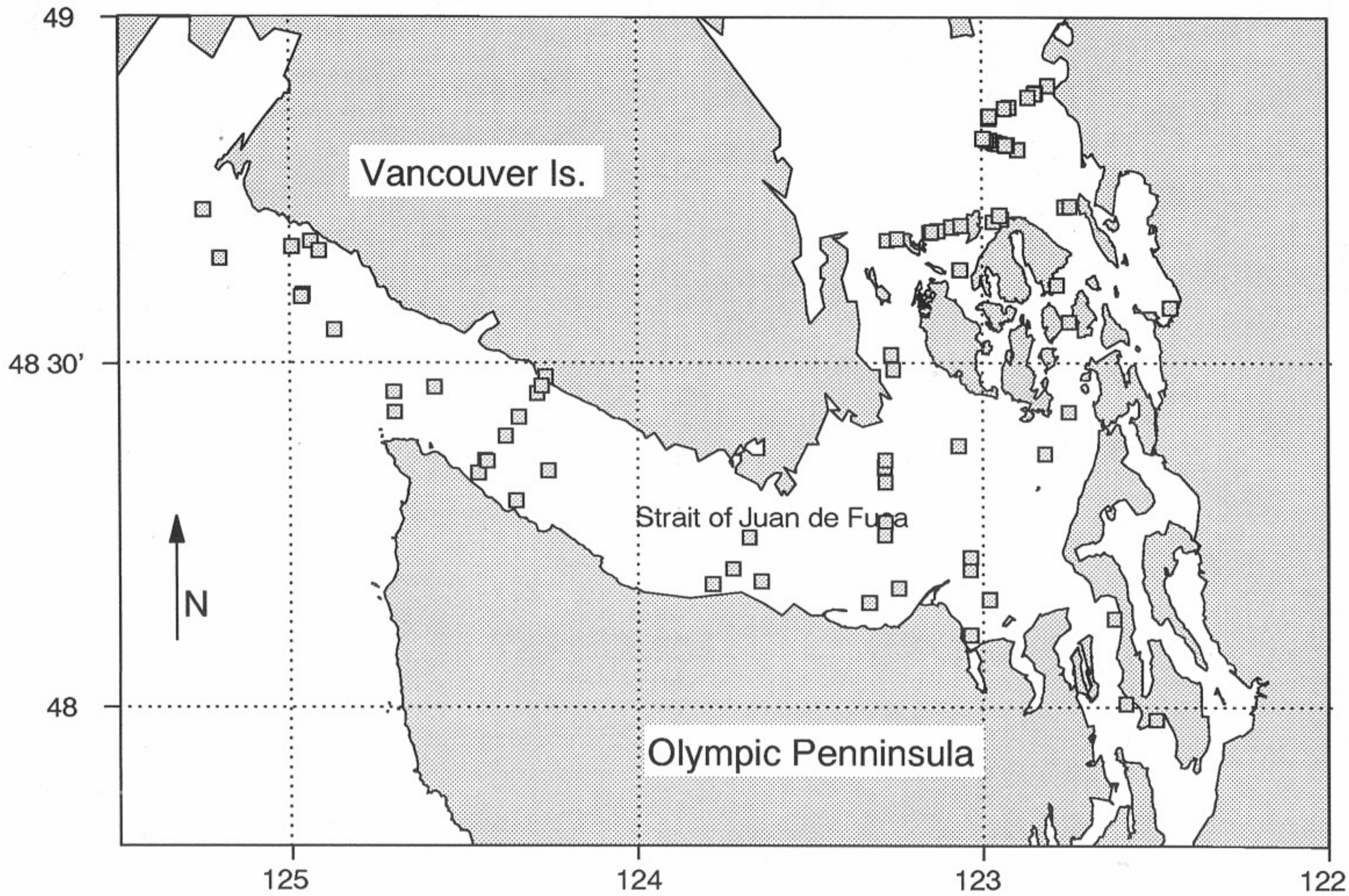
Appendix Figure 13. Survey tracklines off the coast of Oregon and Washington for 1991 aerial surveys (Calambokidis *et al.* 1992).



Appendix Figure 14. Survey tracklines in the Strait of Juan de Fuca and the San Juan Islands area for 1991 aerial surveys (Calambokidis *et al.* 1992).



Appendix Figure 15. Locations of harbor porpoise sightings off the coast of Oregon and Washington during 1991 aerial surveys (Calambokidis *et al.* 1992).



Appendix Figure 16. Locations of harbor porpoise sightings in the Strait of Juan de Fuca and the San Juan Island area during 1991 aerial surveys (Calambokidis *et al.* 1992).