Analysis of Experiments to Assess Movement of Dall's Porpoise in Relation to Survey Vessels and Population Estimates Corrected for Movement and Visibility Bias for the North Pacific Ocean

by

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THIS REPORT MAY BE CITED IN THE FOLLOWING MANNER:

SUMMARY

Population estimates using line transect methods will be biased if undetected movement in response to the observer occurs. Bias may also occur from violation of other assumptions of line transect methods when using data collected on Dall's porpoise sighting surveys.

Surveys were conducted by the National Marine Mammal Laboratory, Seattle, Washington, in 1982, 1983 and 1984 to assess the movement of Dall's porpoise in response to a vessel. During all three years the survey was conducted in and around Prince William Sound in the Gulf of Alaska (near shore). In 1984 the area from Seattle to Prince William Sound was also surveyed (off shore).

Data collected in 1983 only is used for estimating distances moved by animals, because animals could not be followed in 1984 due to a noisy helicopter. The 1982 data cannot be used as linked sightings were not determined.

Twenty eight groups of animals were followed by the helicopter or were linked with the vessel and were used to estimate correction factors for movement. Net perpendicular distance moved by groups of animals before they were sighted by the ship indicates that attraction from large distances can occur. The correction factor for density estimates due to attraction using the 1983 data is 0.41 (c.v. 0.26).

In addition, mark recapture methods were used to obtain estimates of correction factors for movement for the 1983 and 1984 data. The correction factor for the 1983 survey is 0.47 (c.v. 0.20). For the 1984 near shore survey the correction factor is 0.10 (c.v. 0.26), and for the off shore survey, 0.15 (c.v. 0.25). The correction factors for 1984 are not significantly different so the data were pooled to estimate a correction factor of 0.12 (c.v. 0.19) for 1984. A simple linear interpolation between the 1984 and 1983 correction factors based on the mean perpendicular distances of observed groups was used to estimate a correction factor for standard shipboard surveys of 0.22 (c.v. 0.19).

Correction factors for missing animals on the transect line due to poor weather were estimated by comparing the number of sightings per line length at the best visibility conditions to the number sightings at poorer visibility in the fishzone area (as defined in Bouchet et al. 1986). The correction factor for visibility code 2 is 2.74 (c.v. 0.19) and code 3 is 3.5 (c.v. 0.18).
The Fourier series was used to estimate $f(0)$ because of its shape, model and pooling robustness, and its statistical efficiency (Burnham et al. 1980). Data were pooled for years 1980 to 1984 for the Western Central North Pacific area (as defined in Bouchet et al. 1986) for estimation of $f(0)$ and mean group size.

The density estimate for the fishzone at visibility 1 is 0.3793 animals/nm$^2$ (c.v. 0.20). This gives a population estimate of 34,797 animals (c.v. 0.20). The corrected density in the Western-Central North Pacific excluding the fishzone area is 0.6815, which gives a population estimate of 706,275 (c.v. = 0.25). The population estimate for the North Pacific area as a whole is 741,072 animals (c.v. 0.24). Using the log transform to estimate the 95% confidence interval gives 457,000 to 1,200,000 animals.

The population estimate for the Bering Sea limited area is 212,000 (c.v. 0.27). Using the log transform to estimate the 95% confidence interval gives 126,000 to 357,000 animals.
INTRODUCTION

Population estimates using line transect methods will be biased if undetected movement in response to the observer occurs. Bias may also occur from violation of other assumptions of line transect methods. Data from experiments on movement of Dall's porpoise conducted by the National Marine Mammal Laboratory will be used to estimate correction factors for population abundance from line transect methods. Correction factors will also be estimated for bias caused by pooling data over poor weather conditions. Finally, population estimates will be made for Dall's porpoise in the Western North Pacific Ocean and Bering Sea areas corrected for movement and visibility bias.

REVIEW OF LINE TRANSECT THEORY

The basic assumptions of line transect methodology are,

1) animals are uniformly distributed in the local vicinity of the transect line,
2) animals are stationary or movements are slow and independent with respect to the observers movement,
3) animals directly on the transect line are seen with probability equal to one,
4) distances and angles are measured exactly (no measurement errors),
5) no animal is counted more than once for a given leg of effort, and
6) sightings are independent events.

Movement of animals may violate assumptions 1 and 2, depending on the type and extent of movement involved. Animals may move slowly and randomly with respect to the observer and cause low levels of bias (Hiby 1982, Basson, 1982). However if speed of the animal is significant with respect to the observer speed, then larger bias may occur. If animals move randomly with respect to the observer then overestimates in density may occur due to increased rate of encounter. If animals move in response to the observer, then density will be biased upward for movement toward the line and downward for movement away from the line. The effect of movement in response to the observer is to alter the distribution of animals with respect to the transect line so that it is no longer locally uniform.

The probability density function (pdf) for the observed perpendicular distances of animals \( f(x) \) can be written as a combination of the detection function \( g(x) \) and the distribution of animals with respect to the transect line \( h(x|W^*) \). \( W^* \) is the truncation point for \( h(x|W^*) \).
\[ f(x) = \frac{g(x) \ h(x|W^*)}{\int_0^W g(x) \ h(x|W^*) \ dx} \]

w is the truncation point for g(x). In the usual theory, h(x|W*) is assumed to be a uniform distribution (h(x|W*) = 1/W*) then, the value needed for density estimation is,

\[ f(0) = \frac{1}{\int_0^W g(x) \ dx} \]

Where f(0) is the value of f(x) at x=0. The formula for estimation of density is,

\[ n \ f(0) \]

\[ D = \frac{\text{-----------}}{2 \ L} \]

where n is the number of observations, and L the transect line length.

When animals move in response to the survey vessel, population estimates using line transect methods will be biased. The effect of movement by attraction or repulsion from the observer can be thought of as creating a local density gradient near the transect line. When attraction occurs, density is high, close to the line, then declines with distance. Where responsive movement no longer occurs, the distribution of animals returns to a uniform distribution. If repulsion occurs, then density will be low close to the line, increase with perpendicular distance, and then decline to a uniform distribution. Burnham, et al. (1980) derive the f(0) value appropriate for the case where movement occurs:

\[ f_m(0) = \frac{1}{W^* \ \int_0^W g(x) \ h(x|W^*) \ dx} \]  \[ [1] \]

Density is estimated by the usual equation, substituting \( f_m(0) \) for \( f(0) \).

Two methods for correcting population estimates when responsive movement occurs have been investigated for estimation of \( f_m(0) \) by Turnock (Draft M.S. Thesis). One method is to estimate a correction factor for \( f(0) \), and the other method is to estimate \( f_m(0) \) from equation 1 above. The observed perpendicular distances after movement near the observer (h(x|W*), and/or the true sighting function (g(x)) must be estimated. These have to be estimated from designed experiments, they cannot be determined from the observed perpendicular distances of animals from sighting surveys. A
formula for estimation of a correction factor for $f(0)$ can be derived by combining two equations as follows. When $h(x|W^*)$ is not uniform,

$$f(0) = \frac{h(0|W^*)}{\int_0^W g(x) h(x|W^*) \, dx} \quad [2]$$

Combining equations [1] and [2],

$$f_m(0) = \frac{f(0)}{h(0|W^*) W^*}$$

The value $1/(h(0|W^*) W^*)$ can be regarded as a correction factor for estimates of $f(0)$, or the density estimate based on $f(0)$. The correction factor method and a correction method based on mark recapture will be used here as the method using equation one was not found to improve estimation of $f_m(0)$.

ANALYSIS OF MOVEMENT SURVEYS

Surveys were conducted by the National Marine Mammal Laboratory, Seattle, Washington, in 1982, 1983 and 1984 to assess the movement of Dall's porpoise in response to a vessel. During all three years the survey was conducted in and around Prince William Sound in the Gulf of Alaska (near shore). In 1984 the area from Seattle to Prince William Sound was also surveyed (off shore). A helicopter was flown 1 to 2 nm in front of a moving ship to track movements of Dall's porpoise groups. Groups that were seen by both the ship and the helicopter were termed "links". Details of the experiments can be found in Bouchet et al. (1983, 1984) and Withrow et al. (1985).

The perpendicular distance of a group of animals before movement is defined as the perpendicular distance, relative to the ship transect, of the initial sighting by the helicopter. The perpendicular distance after movement is defined as the perpendicular distance, relative to the ship transect, of the last sighting of a group followed by the helicopter, or of a linked sighting by the ship. The perpendicular distances after movement will be used to estimate $h(x|W^*)$. Data collected in 1983 only will be used for estimating $h(x|W^*)$ (the distribution of animals after movement) because animals could not be followed in 1984 due to a noisy helicopter. In addition, mark recapture methods will be used to obtain estimates of density unbiased by animal movement for the 1983 and 1984 data. The 1982 data cannot be used as linked sightings were not determined.
An animal may react to a vessel in a variety of ways. It may move at random (no reaction), or be attracted to or repelled by the vessel. Animals near the transect line may react differently from animals farther away. The reaction of the animal may depend on the animal's distance from the observer, some characteristic of the observer, or some attribute of the animal.

The important values to measure in the case of movement are the net change in perpendicular distance of animals before they are seen by the observer and net change of animals not seen by the observer. Net change in perpendicular distance (Y), is the absolute value of the perpendicular distance after movement (Z) minus the absolute value of the perpendicular distance before movement (X) (Figure 1). A negative net change is then movement toward the line and a positive net change is movement away. Using this definition, a net movement toward the line (a negative y value) can be no smaller the -x. Animals at zero distance can only have a net movement of zero or greater.

Fifty-eight groups were seen by the helicopter in 1983, of which 14 were followed by the helicopter and 14 were links, resulting in 28 groups for which movements can be evaluated (Figure 2). The other 30 animals were lost in glare or chop, or went into a deep dive after the initial sighting. The lost groups were assumed to react in the same way as the 28 that were followed or linked. Since the distribution of animals near the ship is ultimately what has to be estimated, the linked animals as well as the animals followed by the helicopter but not seen by the ship must be taken into account.

Due to the definitions of Y and X, the mean value of y with random movement will not be zero, but rather some positive value that will depend on the variance of y given x as well as the relationship between y and x. First a test for random movement should be applied, however, since the variance of y appears to depend on x, and y depends on x, a test of the hypothesis E(Y) = 0, is not appropriate (Figure 2).

Attempts to fit a probability density function (pdf) to the y vs x data are investigated in Turnock (draft, M.S. Thesis) for purposes of simulation of animal movement and estimation of the resulting bias in animal density. The pdf for h(x|W*) can be derived from the pdf for y given x, and the pdf of x. However, the variance of the data is quite large and the sample size small, so that problems were encountered in fitting the equations. Due to these problems, a probability density function was fit directly to the perpendicular distances after movement to estimate h(x|W*).
Distribution of Animals Seen by the Helicopter

The use of the perpendicular distance after movement to estimate \( h(x|W^*) \) will be valid if the observations can be regarded as a random sample of the perpendicular distances of all animals in the vicinity of the vessel. If animals have not reacted to the presence of the ship, and if sighting effort is uniform, then the distribution of initial perpendicular distances seen by the helicopter should be uniform (Figure 4). The Kolmogorov-Smirnov Goodness of Fit test for continuous grouped data was used to test the hypothesis that the data come from a uniform distribution (Zar 1984, pg. 57). The hypothesis cannot be rejected at the 0.05 level (.10<P<.20).

Correction Factor Estimation

The perpendicular distances after movement used to estimate \( h(x|W^*) \) were truncated at 2,167 meters which is the largest perpendicular distance for animals before movement. This was chosen because animals still seem to react to the ship at this distance (Figure 2). However, the point at which the distribution of animals returns to a uniform distribution is not evident for these data. More extensive surveys would have to be conducted to determine this. The distribution of animals after movement should be estimated out to a perpendicular distance at which the distribution returns to a uniform density (Burnham et al. 1980). This is due to the method of deriving the formula for \( f_m(0) \) which considers the average density from 0 to the point at which there is a uniform distribution again (i.e. animals no longer react to the observer). This point cannot be determined from the data. Therefore, the largest perpendicular distance before movement will be used as the truncation point. If animals continue to be attracted at larger perpendicular distances, then \( f_m(0) \) will be overestimated. The data were grouped into 5 intervals due to the small sample size (n=26 after truncation), and the errors that may occur in measurement of angle and distances. This resulted in an interval width of 450 meters.

The form of the curve will not necessarily be similar to that of a detection function, with a shoulder near zero. The exponential power series, Fourier series and negative exponential models were fit to the data. However the exponential power series failed to converge, and the Fourier series did not fit the peak at small perpendicular distance. While theoretically the Fourier series will fit peaked data, the small sample size, and the use of the log likelihood ratio test to select the number of parameters resulted in a poor fit. So the negative exponential is used (Figure 3).
There may be bias in using this method, if animals reacted to the ship at perpendicular distances greater than the maximum perpendicular distance used (2,167 m). Also, $f_m(0)$ will be biased, if some animals had already reacted to the ship and moved away before being seen by the helicopter.

The estimate of $h(x|W^*)$ is $0.00111 \exp(-0.0009789 x)$ for $0 < x < 2167$ meters. The estimate of $h(0|W^*)$ has a high coefficient of variation of 0.26, which is not surprising given the small sample size and peak in the data near 0 perpendicular distance.

If animals were distributed uniformly then $h(x|W^*) = 1/W^* = 1/2167 = 0.00046$. A correction factor for $f(0)$ can be estimated by the ratio of $1/W^*$ to $h(0|W^*)$ as previously described. Using this method the correction factor for the effect of attraction is 0.41 (s.e. 0.1081).

Mark-Recapture Methods

Another method of estimating a correction for movement is to compare the density of groups from mark recapture methods to the density from shipboard sightings using line transect methods. Animals seen by the helicopter can be thought of as 'marked', those seen by the ship as the second sample, and those animals seen by both the helicopter and the ship as recaptures.

The assumptions of the mark recapture method are (Seber 1982),

1. The population is closed.
2. All animals have the same probability of being caught in the first sample.
3. Marked and unmarked animals have the same probability of capture in the second sample.
4. The second sample is a simple random sample.
5. All marked animals are correctly identified and reported.

Assumption four need not hold if there is uniform mixing of marked and unmarked, and if marked and unmarked have an equal probability of capture. This is the same as assuming the first sample is a simple random sample. The shipboard sample in this case is not a simple random sample, since the ship samples a small part of the area sampled by the helicopter. However, since the helicopter appears to take a random sample (i.e., the distribution is uniform) assumption four is met. If animals do not move from outside the area surveyed by the helicopter into the area where they
are likely to be seen by the ship, then the population can be regarded as being closed. If animals move out of the area where they may be seen by the ship, after the helicopter passes, the data will estimate the density seen by the helicopter, provided that marked and unmarked animals exhibit the same behavior.

The population estimate is then,

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_{12}+1)} - 1$$

Where, $N$ is the population size

- $n_1$ is the number of animals in the first sample
- $n_2$ is the number of animals in the second sample
- $m_{12}$ is the number of animals seen in the second sample that were also seen in the first.

$$\text{Var } \hat{N} = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_{12})(n_2 - m_{12})}{(m_{12} + 1)^2(m_{12} + 2)}$$

Where $D_{mr}$ is the density of groups

- $W$ is the width of the area surveyed
- $L$ is the line length

$$\text{Var } D_{mr} = \text{Var}(\hat{N})(1/2WL)^2$$

The correction factor for movement is then,

$$\hat{c}_{mr} = \frac{D_{mr}}{\hat{D}_g}$$

The variance is,

$$\text{Var } \hat{c}_{mr} = \hat{c}_{mr}^2 [\text{c.v. } D_{mr}]^2 + \text{c.v. } \hat{G}(0)^2$$

$\hat{D}_g$ is the line transect estimate of the density of groups from ship sightings during the movement surveys. The ratio of $D_{mr}$ to the density from line transect methods using the ship sightings should give a correction for attraction as well as correcting for a probability of less than one of sighting an animal on the transect line.

The estimation of density requires the selection of a width for calculation of the area over which to apply the density estimate. The width was chosen at a point where the number of sightings started to decline, indicating a reduction in effort or a change in density of animals. In general the helicopter flew 1 to 1.5 nm either side of the track line. Width for 1983 was .864 nm, and for 1984 near
shore width was 1.19 nm and offshore width was 1.07 nm (Figure 5, 6a and 6b). However the density estimate will depend on the width selected, due to the movement of the animals. The width should include the maximum perpendicular distance at which animals react to the ship, as long as the helicopter has taken a random sample of animals in the total area. A graphical method of determining the area covered by the helicopter would be less arbitrary and possibly more accurate. Work is in progress on this approach.

Results

A total of 40 groups were sighted by the helicopter in 1983 within the selected width, 85 by the ship, and 14 by both (Table 1). The density estimate is .5375 groups/nm² (c.v. .1684). The density using the ship sightings will be presented in the next section.

Information on the linked sightings only is available for 1984. This information is not sufficient to estimate \( h(x|W^*) \) due to the omission of movement of animals seen by the helicopter and not seen by the ship. Since animals may react at and move distances larger than the average sighting distance from the ship, most animals seen by both the helicopter and the ship will have moved toward the vessel. Animals moving away from the vessel will usually not be seen because they will have moved too far away from the ship. However, a mark recapture estimate can be made. Weather during the 1984 surveys was not as good as during 1983 with most effort in the visibility 2 and 3 range (on a scale of 1 to 4, 1 is the best and 4 the poorest acceptable), and none or very few sightings and effort at visibility code 1. Weather during the 1983 survey was good with most effort at visibility 1 and 2. The data for 1984 have been analyzed for two areas, near shore (in and around Prince William Sound) and off shore (in transit from Seattle to Prince William Sound), as well as pooled over areas.

A total of 25 groups were seen by the helicopter within 1.19 nm perpendicular distance in the 1984 near shore survey, of which 11 were links. The ship saw a total of 27 groups. The mark recapture density estimate is .1939 groups/nm² (c.v. .1558)(Table 1). In the offshore area 33 groups were seen by the helicopter of which 11 were links. Fifty-one groups were seen by the ship. The density estimate for the 1984 off shore survey is .1663 groups/nm² (c.v. .1960). The density estimate for the pooled data is .1563 (c.v. .1350). The density estimate from shipboard sightings is needed to compare with these density estimates for determination of a correction factor. The next section discusses the estimation of density from ship sightings.
ESTIMATION OF DENSITY FOR SHIP SIGHTINGS

Methods

There are several problems with the estimation of Dall's porpoise density from ship sightings using line transect methods,

1. responsive movements of animals;
2. effects of pooling data from all levels of visibility and observers when \( g(0) \) differs;
3. unknown \( g(0) \) (the probability of seeing an animal on the track line);
4. inaccuracies of measurement of the angle, distance and group size.

A correction for movement for the standard shipboard survey data will be applied as described earlier. No correction will be made for the experimental survey data because a correction factor will be estimated by the ratio of the mark recapture density to the density from shipboard sightings. A correction for visibility bias will be estimated from the standard survey data. Sample size for the experimental survey data was too small for stratification by visibility. The value of \( g(0) \) may not be 1 even for the best observers in the best visibility conditions. A pilot survey has been recently conducted to estimate \( g(0) \), however the sample size was too small for analysis. Inaccuracies in measurement of angle and distance can result in overestimation of density due to the over recording of 0 angle, resulting in more 0 perpendicular distances than should appear. Also bias will result if systematic errors in measurements occur near \( x=0 \). If data are grouped into intervals that might include the true perpendicular distance values, then the effect will be reduced. At this time no surveys have been conducted to estimate the errors in angle and distance measurements for Dall's porpoise data. However use of smearing techniques (Butterworth 1982) could be used to estimate possible effects of the inaccuracies.

The selection of the model to use for estimation of \( f(0) \) can be critical depending on the shape of the histogram of perpendicular distances. Burnham et al. (1980) recommend basing the decision on shape criterion, robustness, and efficiency of the model. The model should have a "shoulder" at small perpendicular distances. One parameter models such as the negative exponential and half normal are not robust and in general are not useful. Two parameter models such as the exponential power series and the exponential polynomial, while more flexible, can have high variances if the data are peaked at small perpendicular distances, and will not meet shape criterion. The Fourier series is a multiple parameter model recommended for use by Burnham et al. (1980) as it...
meets the shape criterion, is robust, and efficient. More recently developed models may improve on the Fourier series (Buckland 1985). The truncation point must be carefully selected to avoid unreasonable shapes in the tail of the distribution and to improve precision of f(0). Truncation in general will improve the estimation of f(0) (Burnham et al. 1980). The Fourier series will be used here.

Movement Surveys: Ship Density Estimates

The ratio of the mark recapture density estimate to that from the ship sightings should estimate a correction factor for movement and visibility effects. Due to the small sample sizes no stratification by visibility can be made for the ship sightings. The data for 1983 were truncated at .27 nm and grouped into five intervals (Figure 7). The 1984 near shore and offshore sightings were at much smaller perpendicular distances than the 1983 data (Figures 8). The 1984 near shore data was truncated at .102 nm and grouped into 5 intervals. The 1984 offshore data was truncated at .108 nm and grouped into 5 intervals. The 1984 pooled data were truncated at .102 nm and grouped into 5 intervals.

The density for 1983 was 1.1432 groups/nm$^2$ (Table 2). The correction factor is 0.47 (c.v. 0.20). This is close to the correction factor previously estimated (0.41). The density estimate for 1984 near shore, which is in the same area as the 1983 survey is 1.91 groups/nm$^2$ (c.v. .39). The correction factor is 0.10 (c.v. .26). The 1984 offshore density was lower than the near shore (1.14, c.v..26), however, the correction factor was similar (0.15, c,v..25). For the pooled data the density is 1.3047 groups/nm$^2$ (c.v. 0.22). The correction factor is 0.12 (c.v. 0.19).

DISCUSSION OF CORRECTION FACTORS FOR MOVEMENT

The correction factor for 1984 is lower than for 1983 possibly due to differences between observers and the better visibility conditions in 1983. If some observers see animals at larger distances than other observers, then the effect from attraction will be greater. Observers during the 1983 survey were more experienced at observing animals at larger distances than were observers in 1984. Animals may be seen at larger distances during better visibility conditions and so will have moved smaller distances toward the ship than would be expected at poorer visibility conditions where animals are seen at smaller distances. If animals are seen at shorter sighting distances, then attracted animals will have moved farther before being seen, and the effect of attraction will be greater. If there is an effect from visibility on g(0), then the density from
ship sightings would be lower, and the correction factor would be higher. However, the $f(0)$ values for 1984 are high (about 20 nm$^{-1}$) compared to the $f(0)$ from 1983 (about 9 nm$^{-1}$) and the $f(0)$ values for survey data from Dall's porpoise observers in the North Pacific (about 12 nm$^{-1}$). This indicates that the effect on $g(0)$ due to visibility during the movement surveys was small. The lack of any effect due to visibility during the experiment could be due to an "experiment effect". Observers may have been more intensely searching and so were less apt to miss animals than during standard surveys. Also, in 1984, one person on the ship, independent of the observer doing sightings, kept track of the groups seen by the helicopter for identification of links. This may have resulted in more accurate determination of linked animals. If links were underestimated in 1983, then the density estimate from the mark recapture method is higher than it should be, and the correction factor is higher than it should be.

The dive times of Dall's porpoise are not known. The effect on density estimates will depend on the length of dives, and the percentage of animals that may be underwater at any one time. It is not known if animals recorded by the helicopter as deep diving were exhibiting normal behavior, reacting to the helicopter, or showing ship avoidance behavior. However, for the 1983 data a number of groups were recorded as deep diving by the helicopter and recorded as links. This would indicate that either deep diving was not an avoidance behavior, or that the identification of links was inaccurate. The helicopter in 1984 was bigger and noisier than in 1983, so that animals could not be followed. This may have resulted in animals avoiding the helicopter or being scared by the helicopter. If animals' behavior was changed by the helicopter, then their reaction to the ship may have been altered.

The similarity of the correction factor for near and offshore surveys indicates that reaction of animals may be similar in the two areas. However, the differences between the 1983 and 1984 sighting curves and resulting correction factors for movement show that the applicability of the correction for movement depends on the similarities of the sighting curve, which can depend on sighting conditions and observers.

The average perpendicular distance of sightings in standard surveys is between that for the 1983 and 1984 sighting data. This indicates that neither correction factor directly applies to the standard surveys. A simple linear interpolation between the correction factors based on the average perpendicular distances was used to estimate a correction factor for the standard survey data. The correction factor is 0.22 (c.v. .20).
Visibility Correction

Methods

If the assumption that all animals on the line is met, then there will be no effect of changes in visibility on density estimates. Animals would be seen at closer perpendicular distances, so that \( f(0) \) would be greater, compensating for a reduction in the number of animals sighted per unit of transect. The area of the fishing grounds (fishzone area defined by Bouchet et al. 1986) provides an opportunity to test this assumption. A large amount of effort is concentrated in a relatively small area (Figure 9). If sightings are stratified by visibility code then the density estimate for each visibility code should estimate the same density. If the density at visibility code 1 is taken as the best estimate of the true density, then the ratio of the density for visibility code 1 to that of visibility code \( j \) \((j=2,4)\) would be a correction factor for density estimated from data at visibility code \( j \).

Preliminary analysis has shown that the detection functions and mean group sizes for visibility codes 1 through 3 are not different, therefore, correction factors for visibility can be estimated simply by the ratio of the number of observations per line length at visibility code 1 to that at visibility code 2 and 3 respectively.

\[
\hat{C}_{vj} = \frac{(n_1/L_1)}{(n_j/L_j)}
\]

Where, \( n_1 \) is the number of observations for code 1
\( n_j \) is the number of observations for code \( j \)
\( L_1 \) is the line length in nautical miles for code 1
\( L_j \) is the line length in nautical miles for code \( j \)
\( C_j \) is the correction for visibility code \( j \).

The variance is,

\[
\text{Var} \hat{C}_{vj} = \hat{C}_{vj}^2 \left[ (c.v.(n_1))^2 + (c.v.(n_j))^2 \right]
\]

The variance of \( n_j \) is estimated by empirically by a formula from Burnham et al. 1980,

\[
\text{Var} (n) = \frac{\sum_{i=1}^{R} l_i [(n_i/l_i) - (n/L)]^2}{L (R-1)}
\]

where,

\( n \) is the total number of observed groups,
\( n_i \) is the number of observed groups in transect \( i \),
\( l_i \) is the length of transect \( i \),
R is the number of transects.

Results

The correction factor for code 2 is 2.74 (c.v. 0.19) (Table 3), for code 3, 3.50 (c.v. 0.18). These correction factors will be applied to density estimates for each visibility code from the western North Pacific area.

Population Estimation for Surveys in the North Pacific Ocean

Methods

A great amount of sighting effort is concentrated in the salmon mothership fishing area of the North Pacific Ocean (fishzone area as defined in Bouchet 1986) (Figures 10 and 11). These sighting data are from U.S. observers on board Japanese salmon fishing vessels. Due to the high concentration of effort in the fishzone, this area will be analyzed separately from the rest of the North Pacific area, where sighting data are from U.S. observers on board Japanese salmon and U.S. research vessels. The sightings were pooled for years 1980 to 1984 because there were not enough sightings to stratify by visibility for each year. The sightings data were stratified by visibility codes 1 through 3, for estimation of the number of observations and the line length for each visibility code. Visibility code 4 has previously been used in sighting surveys, however, the detection function at visibility code 4 is different than at codes 1 through 3 so the data at visibility code 4 will not be used. For estimation of f(0) and the mean group size, data will be pooled over visibility codes 1 through 3 and for the whole western North Pacific area. This results in one estimate of f(0) and one estimate of the mean group size. The sightings were analyzed grouped by 80 meter intervals, and truncated at 400 meters. This results in five intervals, which are regarded as the least number of intervals desirable for grouped analysis, while maintaining as large an interval width as possible. The Fourier series model was fit to the data for estimation of f(0). The equation for density at each visibility code corrected for visibility bias is,

\[ D_C = \frac{f(0) \sum_{j=1}^{3} n_j c_{vj}}{2 \sum_{j=1}^{3} l_j} \]

The variance of the density of individuals by visibility was estimated by,
\[ \text{var } D_c = D_c^2 \left[ (CV(G))^2 + (CV(f(0)))^2 + (CV(\Sigma_{j=1}^3 n_j C_{vj}))^2 \right] \]

where,

\[ \text{var}(\Sigma_{j=1}^3 n_j C_{vj}) = \text{var}(n_1) + (n_2 C_{v2})^2 \left[ (CV(n_2))^2 + (CV(C_{v2}))^2 \right] + (n_3 C_{v3})^2 \left[ (CV(n_3))^2 + (CV(C_{v3}))^2 \right] \]

Where, \( D_c \) is density weighted by line length and corrected for visibility.

\( G \) is mean group size.

\( n_j \) is the number of groups sighted for visibility code \( j \).

\( f(0) \) is the value at 0 of the probability density function for observed perpendicular distances.

\( C_{vj} \) is the correction factor for visibility code \( j \).

\( CV \) means coefficient of variation.

\( L_j \) is the line length for visibility code \( j \).

The density estimate at visibility 1 only will be used to estimate population size in the fishzone area. The density estimate for the total North Pacific area is the weighted average of the density estimates for the fishzone and the North Pacific minus the fishzone areas, the weights being the respective areas in nm²,

\[ N_c = A_f D_f + A_n D_c. \]

The correct factor for movement is then applied,

\[ N_{cm} = N_c C_{mr}. \]

Where, \( A_f \) is the area of the fishzone within the western North Pacific (91,740 nm²)

\( A_n \) is the area of the western North Pacific excluding the fishzone (1,036,354 nm²)

\( D_f \) is the density in the fishzone area corrected for visibility bias

\( N_c \) is the population estimate for the western North Pacific area corrected for visibility bias

\( N_{cm} \) is the population estimate for the western North Pacific area corrected for visibility and movement bias.

The population number is bounded below by the number of distinct animals sighted. If the variance is large compared to the estimate, a 0 or negative lower confidence level can be estimated assuming a normally distributed random variable. Assuming a log normal random variable is more appropriate in this case, the confidence interval can then be estimated by,
95% C.I. = \( \left( \hat{N}_{cm}/C, \hat{N}_{cm} C \right) \),

Where, \( C = \exp(Z_{a/2} / \text{Var}(\ln(\hat{N}_{cm})) \)

and,

\( \text{Var}(\ln(\hat{N}_{cm})) = \ln(1 + (c.v. N_c)^2) + \ln(1 + (c.v. C_{mr})^2) \)

Results

The density estimate for the fishzone at visibility 1 is \( .3793 \) animals/nm\(^2\) (c.v. = 20) (Table 4). This gives a population estimate of 34,797 animals (s.e. = 12,045).

The corrected density is \( 0.6815 \) (c.v. = 0.25), which gives a population estimate of 706,275 (c.v. = 0.25) in the western North Pacific excluding the fishzone area. The population estimate for the North Pacific area as a whole is 741,072 animals (s.e. = 179,464). Using the log transform to estimate the 95% confidence interval gives 457,000 to 1,200,000 animals. The population estimate for the Bering Sea limited area is 212,000 (c.v. = 0.27). Using the log transform to estimate the 95% confidence interval gives 126,000 to 357,000 animals.

Discussion

Previous estimates of population size have been made using the 1980 to 1984 pooled data unstratified by area or visibility, and not corrected for movement or visibility (Bouchet et al. 1986). Line transect methods were used on ungrouped data using the negative exponential and half normal estimators. These two models were used to obtain a range for the population size due to the inability at the time of correcting estimates for movement. The estimates for the North Pacific area was 955,000, for the negative exponential, and 483,000 for the half normal. The large amount of effort and lower density in the fishzone resulted in a lower density for the North Pacific area when data were pooled over areas. The correction for visibility is opposite and of smaller magnitude than the effect of movement. The population estimates presented here may still be biased by inaccuracies in measurement of angle and distance. These biases most likely would cause an overestimate of density. The value of \( g(0) \) in good visibility conditions is not known to be 1. If it is less than 1 then density will be underestimated. The effect of observers with different abilities may also cause underestimation of density. The correction for movement may not be applicable to data for standard surveys due to differences in sighting probabilities, or reaction of the
porpoise due to composition of the population or "sound signatures" of the vessels. Different vessels produce different sounds underwater to which the porpoises react. In order to reduce "experiment effects", and assure applicability of results to standard cruises, experiments to determine movements need to be conducted during standard surveys. This will be true of experiments for determination of other possible biases as well. The coefficient of variation for the population estimate is large (0.31). Experiments to estimate correction factors with larger sample sizes, as well as increased coverage will improve standard errors.

The correction factor estimated from mark recapture methods resulted in the lowest variance, compared to the correction factor method using the estimated \( h(z|w^*) \). If a larger sample size could be obtained for estimation of \( h(z|w^*) \) the correction methods would improve. However, a larger sample size can be obtained with the same amount of effort for use with the mark recapture method. This is due to the difficulty of following animals to obtain movement information. However, preliminary movement data is needed to determine the distances that animals may move, even if mark recapture methods are used to estimate a correction factor. Possibly stratification of the data by observer experience, sighting cue or other factor would reduce the peak near 0 perpendicular distance and improve estimation of \( f(0) \). A survey with multiple observers is needed to estimate a correction for missed track line animals. Mark recapture methods used by Buckland (1986) could be used to estimate \( g(0) \). Also, experiments to determine errors in and to identify improved methods of estimating sighting distances and angles are needed. Smearing of the sighting distances and angles may also improve estimation of \( f(0) \), if errors in sighting distances and angles can be estimated.
REFERENCES CITED


Table 1. Estimates of density from mark recapture methods for the 1983 and 1984 movement surveys.

<table>
<thead>
<tr>
<th>Year</th>
<th>( n_1 )</th>
<th>( n_2 )</th>
<th>( m_{12} )</th>
<th>( N )</th>
<th>( W ) (nm)</th>
<th>( D_{mr} )</th>
<th>c.v. ( D_{mr} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>40</td>
<td>85</td>
<td>14</td>
<td>234</td>
<td>.864</td>
<td>.5375</td>
<td>.1684</td>
</tr>
<tr>
<td>1984 Near shore</td>
<td>25</td>
<td>27</td>
<td>11</td>
<td>60</td>
<td>1.19</td>
<td>.1939</td>
<td>.1558</td>
</tr>
<tr>
<td>Off shore</td>
<td>33</td>
<td>51</td>
<td>11</td>
<td>147</td>
<td>1.07</td>
<td>.1663</td>
<td>.1960</td>
</tr>
<tr>
<td>Pooled</td>
<td>58</td>
<td>78</td>
<td>22</td>
<td>202</td>
<td>1.19</td>
<td>.1563</td>
<td>.1350</td>
</tr>
</tbody>
</table>

\( n_1 \) is the number of groups sighted by the helicopter.
\( n_2 \) is the number of groups sighted by the ship.
\( m_{12} \) is the number of groups sighted by both the helicopter and the ship.

\( N \) is the population estimate using mark recapture methods.
\( W \) is the width selected for density estimation.
\( D_{mr} \) is the density of groups for mark recapture methods.
c.v. \( D_{mr} \) is the standard error of density of groups.
Table 2. Density estimates for shipboard sightings from movements surveys using line transect methods.

<table>
<thead>
<tr>
<th>Year</th>
<th>L</th>
<th>n</th>
<th>cvn</th>
<th>PD</th>
<th>f(0)</th>
<th>cvf(0)</th>
<th>Dg</th>
<th>cmr</th>
<th>cvCmr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>252</td>
<td>63</td>
<td>.20</td>
<td>.19</td>
<td>9.15</td>
<td>.10</td>
<td>1.14</td>
<td>.47</td>
<td>.20</td>
</tr>
<tr>
<td>近岸</td>
<td>130</td>
<td>25</td>
<td>.32</td>
<td>.06</td>
<td>19.89</td>
<td>.21</td>
<td>1.91</td>
<td>.10</td>
<td>.26</td>
</tr>
<tr>
<td>远岸</td>
<td>413</td>
<td>49</td>
<td>.22</td>
<td>.05</td>
<td>19.23</td>
<td>.15</td>
<td>1.14</td>
<td>.15</td>
<td>.25</td>
</tr>
<tr>
<td>合計</td>
<td>543</td>
<td>71</td>
<td>.18</td>
<td>.05</td>
<td>19.96</td>
<td>.13</td>
<td>1.30</td>
<td>.12</td>
<td>.19</td>
</tr>
</tbody>
</table>

L  is the line length in nautical miles.
n  is the number of groups observed from the ship.
PD  is the average perpendicular distance of all animals sighted by the ship in nautical miles.
f(0)  the value of the detection function (f(x)) at x=0.
Dg  is the density of groups from ship sighting data.
C_{mr}  is the correction factor for movement
cv  is coefficient of variation.
Table 3. Correction factors for visibility bias estimated from data in the fishzone area with pooled data 1980 to 1984.

<table>
<thead>
<tr>
<th>Visibility Code</th>
<th>n</th>
<th>L</th>
<th>$cv_n$</th>
<th>$C_{vj}$</th>
<th>$cv_{C_{vj}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95</td>
<td>1039</td>
<td>.16</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>223</td>
<td>6686</td>
<td>.11</td>
<td>2.74</td>
<td>.19</td>
</tr>
<tr>
<td>3</td>
<td>282</td>
<td>10795</td>
<td>.08</td>
<td>3.50</td>
<td>.18</td>
</tr>
</tbody>
</table>

$C_{vj}$ is the correction factor for visibility code j.
Table 4. Density estimates corrected for visibility bias for the western North Pacific area, and for visibility code 1 for the fishzone area inside the western North Pacific area.

<table>
<thead>
<tr>
<th>Area</th>
<th>Visibility Code</th>
<th>n</th>
<th>L</th>
<th>cv n</th>
<th>Dc</th>
<th>cv Dc</th>
</tr>
</thead>
<tbody>
<tr>
<td>WNPAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>88</td>
<td>653</td>
<td>.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>218</td>
<td>3586</td>
<td>.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>198</td>
<td>5662</td>
<td>.13</td>
<td>3.0959</td>
<td>.15</td>
</tr>
<tr>
<td>Fishzone within the WNPAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>66</td>
<td>852</td>
<td>.20</td>
<td>1.7241</td>
<td>.20</td>
</tr>
<tr>
<td>Bering sea area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>61</td>
<td>870</td>
<td>.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>82</td>
<td>2380</td>
<td>.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>100</td>
<td>3282</td>
<td>.14</td>
<td>2.6321</td>
<td>.24</td>
</tr>
</tbody>
</table>

Dc is the density of animals corrected for weather bias but not for movement.

WNPAC is the western North Pacific area excluding the fishzone area.

Estimates used in common for estimation of density are,

Mean group size (G) = 3.649

\[ \text{cv G} = 0.0194 \]

\[ f(0) = 12.19 \]

\[ \text{cv f}(0) = 0.0353 \]

Mean perpendicular distance in WNPAC, of observed animals = 0.091 nm

Mean perpendicular distance in the Bering sea, of observed animals = 0.112 nm
Figure 1. Definitions of movement variables.
Figure 2. Movement of Dall's porpoise relative to ship survey for 1983 in Prince William Sound. Movement away from the line is positive and movement toward the line is negative. Animals can move no more than -x toward the line.
Illustration of the estimated PDF of perpendicular distances (F) fit to the shape of the histogram of the data. (CUT POINT SET 1)

Negative exponential fit

Uniform density

Figure 3. Negative exponential fit to distances after movement of Dall's porpoise for the 1983 survey data.
Figure 4. Histogram of the perpendicular distances before movement (distances at which groups were first seen by the helicopter) from the 1983 survey.
Figure 5. Histogram of perpendicular distances of all Dall's porpoise seen by the helicopter in 1983.
### a. Offshore

<table>
<thead>
<tr>
<th>MIDDLE OF INTERVAL (nm)</th>
<th>NUMBER OF OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.108</td>
<td>4</td>
</tr>
<tr>
<td>0.324</td>
<td>5</td>
</tr>
<tr>
<td>0.540</td>
<td>6</td>
</tr>
<tr>
<td>0.756</td>
<td>7</td>
</tr>
<tr>
<td>0.972</td>
<td>4</td>
</tr>
<tr>
<td>1.188</td>
<td>2</td>
</tr>
<tr>
<td>1.404</td>
<td>1</td>
</tr>
<tr>
<td>1.620</td>
<td>3</td>
</tr>
<tr>
<td>1.836</td>
<td>3</td>
</tr>
<tr>
<td>2.052</td>
<td>1</td>
</tr>
</tbody>
</table>

### b. Nearshore

<table>
<thead>
<tr>
<th>MIDDLE OF INTERVAL (nm)</th>
<th>NUMBER OF OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.108</td>
<td>3</td>
</tr>
<tr>
<td>0.324</td>
<td>2</td>
</tr>
<tr>
<td>0.540</td>
<td>6</td>
</tr>
<tr>
<td>0.756</td>
<td>4</td>
</tr>
<tr>
<td>0.972</td>
<td>5</td>
</tr>
<tr>
<td>1.188</td>
<td>4</td>
</tr>
<tr>
<td>1.404</td>
<td>0</td>
</tr>
<tr>
<td>1.620</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 6.** Histograms of perpendicular distances of all animals seen by the helicopter 1984 for offshore (a) and nearshore (b).
Figure 7. Fit of the Fourier series to the 1983 movement survey shipboard sighting data.
Figure 8. Fit of the Fourier series to the shipboard sighting data for the 1984 movement survey for pooled data (nearshore and offshore).
Figure 9. Sighting effort for Dall's porpoise, 1978-1984. From the National Marine Mammal Laboratory's NOAA's Platform of Opportunity Program data files.
Figure 10. Subareas used for population estimation. a. "Limited Bering Sea zone", b. "Limited western-central North Pacific Ocean Zone", c. "Fishzone".
Figure 11. Fit of the Fourier series to the sighting data from standard shipboard surveys for the western North Pacific area pooled 1980 to 1984.