Estimation of the effect of responsive movement and missed animals from independent observer experiments for Dall's porpoise on the HOKUSEI MARU and the MILLER FREEMAN Cruises

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INTRODUCTION

Population abundance from line transect methods may be underestimated due to missing animals near the transect line. An attempt to quantify this bias by relating the number of sightings of Dall's porpoise per transect length at various visibility conditions was presented in Turnock (1987a). Another method of estimating this bias is to use independent observers on the same ship. This paper presents results from two surveys in 1987 where independent observer experiments were conducted.

Another major bias in population estimates of Dall's porpoise is due to responsive movement of animals before being sighted by the observer, which has the effect of overestimating abundance. Dall's porpoise are attracted to vessels resulting in overestimates of population abundance (Turnock, 1987a and 1987b). Data from the independent observer experiments may also be used to estimate this bias.

The estimation of the effect of movement requires an adequate sample size over all the perpendicular distances at which the distribution of animals may be altered due to the responsive movement of the animals. Given adequate data, the distribution of animals with respect to the transect line can be estimated using mark-recapture methods, or alternatively, the average density can be estimated. A correction for movement can be accomplished by either using a decomposition method (Turnock and Quinn, in prep), or by a correction factor method which is estimated from the ratio of the line transect density to the average density from mark-recapture methods (Turnock 1987a).

In this paper, estimates of the probability of sighting a group of Dall's porpoise given it is at some small perpendicular distance from the track line (termed g(0)), will be presented. The data were collected during two research cruises on which independent observer experiments were conducted: the HOKUSEI MARU, a University of Hokkiado research vessel, and the MILLER FREEMAN, a U.S. NOAA vessel. A correction for responsive movement of Dall's porpoise is also estimated based on the MILLER FREEMAN cruise data. The HOKUSEI MARU cruise occurred from July 13 to August 12, 1987 in the western north Pacific ocean, and the MILLER FREEMAN from October 8 to November 8, 1987, in the eastern North Pacific Ocean in the high seas squid driftnet fishing area (Figures 1 and 2).

METHODS

Observations of marine mammals during the HOKUSEI MARU cruise were conducted by 1 U.S. observer on the flying bridge, and independently by the Japanese crew and University students on the bridge. The U.S. observer measured distances with 7x50 binoculars with reticles, and angles were measured using a built-in compass in the binoculars. The crew estimated distances both by eye and with the aid of a hand-held plexiglass distance gauge, while angles were estimated by eye.

During the MILLER FREEMAN cruise two observers were on the flying bridge and one observer was on the bridge. Observers rotated between the flying bridge and the bridge. Distances were measured using 7x50 binoculars with reticles, and angles were measured using "angle boards", consisting of a piece of plywood with angles marked by 1 degree increments, mounted on a tripod. A pointer was lined up with the observed animals and the angle read from the board.

When the Beaufort state was less than 3, 20x power binoculars were used to observe animals as far ahead of the ship as possible. This was to assess the feasibility of using high power binoculars to reduce the effect of attraction of the animals on density estimates by attempting to observe animals before they had reacted to the vessel.

Methods of estimation of g(0) follow Buckland (1986), where mark-recapture methods are adapted to estimate the probability of sighting a group given it is within some perpendicular distance, u, from the transect line.

n_a = number of groups sighted by observer A within perpendicular distance u

n_b = number of groups sighted by observer B within perpendicular distance u

n_{ab} = number of groups sighted by both observer A and observer B within perpendicular distance u

N = total number of groups available to be seen within perpendicular distance u.

$$\hat{N} = \frac{n_a \; n_b}{n_{ab}}$$

The probability of seeing an animal within perpendicular distance u for observer A is,

$$g_a(0) = n_a/\hat{N} = n_{ab}/n_b,$$

and for observer B,

$$g_b(0) = n_b/\hat{N} = n_{ab}/n_a.$$

The variance can be estimated by using the hypergeometric distribution:

$$\text{Var}\ (n_{ab}) = n_a\ n_b\ (1 - n_{ab}/n_b)\ (1 - n_{ab}/n_a)\ /\ (\hat{N} - 1)$$

$$\text{Var}\ (g_a(0)) = \text{var}\ (n_{ab})/n_b^2, \text{ and}$$

$$\text{Var}\ (g_b(0)) = \text{var}(n_{ab})/n_a^2.$$

The density of groups of Dall's porpoise is estimated by

$$\hat{D}_g = \frac{n\ \hat{f}(0)}{\hat{g}(0)\ 2\ L}.$$

Where n is the number of groups sighted
L is the transect length
f(0) is the inverse of the effective transect width.

The data from both the MILLER FREEMAN and the HOKUSEI MARU cruise were used to estimate g(0). Data from the MILLER FREEMAN were also used to estimate a correction for responsive movement of Dall's porpoise. The sample size and the distances at which animals were sighted were too small for the HOKUSEI MARU data to be used in this manner.

Sightings data were mostly collected at visibility codes 3, 4 and 5 for the MILLER FREEMAN cruise. There was only a small amount of time when visibility was better, with visibility codes of 1 or 2. Data collected during conditions with higher than visibility code 5 were omitted from the analysis. The data collected during the HOKUSEI MARU cruise include observations at visibility codes 2 through 5.

RESULTS

Estimates of g(0)

HOKUSEI MARU Cruise

During the periods when two observers were on watch, a total of 33 groups of Dall's porpoise were observed by the U.S. observer and 15 by the Japanese observers. The perpendicular distances of observed animals were much greater for the U.S. observer than for the Japanese observers (Figures 3 and 4). The U.S. observer saw 8 groups within 100 meters perpendicular distance, the bridge watch saw 7 groups and 6 were seen by both (Table 1). The perpendicular distance estimated by the U.S. observer was used for the perpendicular distance of the duplicate sightings. The estimated probability of sighting a group at small perpendicular distances ($\hat{g}(0)$) for the U.S. and Japanese observers were 0.86 (cv = 0.0817) and 0.75 (cv = .0817) respectively (for u = 100 meters). The perpendicular distances of animals observed by the U.S. observer during this cruise were larger than for the combined sightings data for all observers from 1980 to 1986 in the western North Pacific area (Figures 3 and 5).

MILLER FREEMAN Cruise

A total of 49 groups of Dall's porpoise were sighted by observers on the flying bridge of the MILLER FREEMAN, 45 by observers on the bridge, and 31 by both observers during the independent observer experiment. In estimating n_{ab}, sightings that were judged as definitelyseen by both observers were counted as 1, and those that were possibly seen by both observers were counted as 0.5. There were 27 positive links and 4 possible, resulting in an estimate of n_{ab} of 29 (Table 2). The estimate of g(0) for the flying bridge was 0.75 (cv = 0.1622) and from the bridge, 0.66 (cv = 0.040) (for u=100 meters).

Estimation of the Correction for Movement

A mark-recapture estimate by distance interval is an estimate of the distribution of animals with respect to the transect line (Figure 6). Data were grouped by distance interval so that the values for n_a, n_b, and n_{ab} were at least 3. If animals do not react to the vessel, then a uniform distribution over the distances would be expected. In Figure 6, however, the distribution of animals estimated from the data during the MILLER FREEMAN cruise is skewed toward small perpendicular distances, indicating that animals are attracted to the vessel, which would result in an overestimate of population abundance.

The ratio of n_{ab} to n_a or n_b by distance interval is an estimate of the probability of sighting a group by distance interval (Figure 7). The probability remains fairly high out to the maximum perpendicular distances at which animals were sighted (1600 meters).

The estimate of the density from line transect methods corrected for missed animals can be compared to the density from mark-recapture methods to estimate a correction for movement (Table 3). Since the probability of sighting a group did not change appreciably with perpendicular distance, the data were pooled over all perpendicular distances. The mark-recapture estimate of the number of groups in the area sampled (1641 nm long by 3200 meters width) is 76 (cv = 0.068), a density of 0.0268 groups/nm^2 (cv = 0.068). For observations from the bridge, the correction for movement is 0.33 to 0.34 depending on whether the Fourier series, Hermite polynomial or the hazard rate model is used to estimate f(0). For the observations from the flying bridge the correction for movement is 0.24 to 0.30. Density corrected for movement would then be,

$$D_c = D_g\ C$$

Where D_c is density corrected for movement,
D_g is density corrected for missed animals from the

equation on page 3, and
C is the correction factor for movement.

Based on the same data and using the ratio estimator developed in Turnock (1987a), the correction factors for movement are 0.4271 (cv = 0.331) and 0.5573 (cv =0.286), for the flying bridge and the bridge respectively. The lower correction factors estimated using these mark-recapture methods indicates a larger effect on abundance estimates from attraction than is estimated using the ratio estimator (Turnock 1987a).

No Dall's porpoise were observed while using the 20x binoculars, however, sighting effort was very low due to poor weather conditions.

DISCUSSION

The estimates of g(0), and of the average density from mark-recapture methods assume that the sightings by the two observers are independent. The mark-recapture method estimates that portion of the population that is available to be observed. If animals are underwater for a large percentage of time, or cannot be detected for some other reason, then the mark-recapture method may result in an underestimate of the abundance, which would result in an underestimate of the correction for movement and an overestimate of corrected abundance. The estimate of average density presented here based on the mark-recapture method also assumes that the distribution of animals is unaffected by movement beyond 1600 meters perpendicular distance, which was the maximum perpendicular distance for observed animals. In previous experiments to assess the effect of movement, a helicopter was used to sight animals, and animals were observed to about 2200 meters perpendicular distance from the transect line (Turnock, 1987b). The frequency of estimated groups by perpendicular distance from data obtained on the MILLER FREEMAN cruise is similar to the distribution of animals from the helicopter-ship survey (Figure 8) reported in Turnock (1987b), indicating that the effect of movement was similar for the two surveys.

The estimate of the number of groups from mark-recapture methods by perpendicular distance interval (Figure 6) may indicate that as the perpendicular distance increases only those animals exhibiting a very strong sighting cue are seen. This would increase the number of groups seen by both observers, decreasing the estimate of the number of groups ($\hat{N}$) at larger distances, resulting in the apparent decline in density at larger perpendicular distances as seen in Figure 6. However, all groups except one were initially sighted rooster-tailing, indicating that sighting cues may have been similar at all perpendicular distances. This may mean that all slow rolling animals were missed due to weather conditions. In this case the estimated number of groups of Dall's porpoise by distance interval may only reflect the distribution of rooster tailing animals and not all animals..

Turnock (1987a) estimated a correction for responsive movement of animals based on mark-recapture methods, and for missed animals due to sea state and visibility conditions. The correction for missed animals (g(0)) was 0.36 to 0.29 for visibility conditions 2 and 3 respectively. This was based on comparing the number of sightings per transect length at different visibility codes to that at visibility code 1 (the best conditions). However, the results from the HOKUSEI MARU and MILLER FREEMAN cruises indicate that $\hat{g}(0)$ may be much higher (0.66 to 0.86). There may be several factors that contributed to the difference in estimates between the two studies. The sample size for the HOKUSEI MARU estimate of g(0) is small. In addition, the sighting platform on the MILLER FREEMAN is higher than most other vessels used for Dall's porpoise sighting surveys, and so it may have been easier to see animals than on the Japanese high seas salmon catcherboats used in Turnock (1987a).

Future Studies

Future studies are needed to develop sighting techniques that reduce the effect of responsive movement on density estimates and that can estimate the remaining bias due to movement. The results from the MILLER FREEMAN cruise indicate there is a possibility for estimation of the bias due to movement using independent observers. If high power binoculars can be used rather than 7x50 binoculars, it may be possible to sight animals at larger perpendicular distances than in the present study. If this is not possible, then further studies using a helicopter and ship may be needed to assess the effect of movement.

The large difference between estimates of g(0) in Turnock (1987a) and the present study indicate that vessel type may be a major factor in the probability of sighting animals close to the transect line, however, more independent observer experiments are needed before conclusions can be drawn.

A large part of the variance in current abundance estimates for Dall's porpoise corrected for movement and missed animals is due to the large variance of the correction factors (Turnock 1988). Additional experiments to increase the numbers of groups sighted are needed to reduce the variances of the correction factors.

References

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Table 1. Duplicate sightings for the HOKUSEI MARU cruise July 13 to August 12, 1987.

U.S. observer					Japanese observers				
time	perp	sight	angle	G	time	perp	sight	angle	G
0617	74	849	355	3	0617	43	500	355	3
0642	106	250	335	7	0643	57	80	45L	6
0803	103	300	340	5	0805	50	100	30L	7
0957	260	300	60	4	0953	103	300	20R	2
1104	776	849	294	2	1100	495	700	45L	5
1432	252	300	57	4	1431	141	200	45R	6
0605	8	10	310	2	0606	9	10	60R	2
1021	312	441	315	2	1021	250	500	30L	2
1214	115	150	50	3	1213	230	300	50L	3
1248	75	150	330	4	1247	96	150	40L	4
1512	51	580	355	3	1511	87	500	10L	3
0800	75	150	30	5	0800	35	40	60R	6
0846	172	225	50	4	0851	87	100	60R	3
1630	26	100	345	3	1629	69	200	20L	4

perp is the estimated perpendicular distance
angle is the estimated angle
G is the group size
Sight is the estimated sighting distance.

Table 2. Duplicate sightings for the Miller Freeman cruise from October 8 to November 8, 1987.

flying bridge					bridge				
time	perp	sight	angle	G	time	perp	sight	angle	G
825	1111	1450	50	6	824	1520	2650	35	6
1109	620	3570	10	15	1107	0	2650	0	10
1627	150	580	15	4	1627	274	800	20	4
1804	507	1200	25	7	1803	400	800	30	7
1805	78	300	15	5	1805	414	420	80	4
1055	1457	2060	45	2	1052	860	1500	35	2
1211	305	3500	5	5	1210	305	3500	5	6
1326	115	200	35	2	1326	140	280	30	2
1426	155	600	15	9	1427	77	120	40	8
1515	92	270	20	7	1513	44	500	5	5
1625	0	8000	0	5	1627	1149	1500	50	4
1626	100	200	30	3	1625	142	550	15	5
1711	287	500	35	8	1714	498	550	65	9
830	63	150	25	6	830	161	250	40	5
1455	188	200	70	9	1458	574	1000	35	4
1747	150	300	30	3	1747	566	800	45	3
1750	115	200	35	7	1751	201	350	35	5
1242	35	40	60	3	1243	13	150	5	3
1357	240	340	45	5	1355	500	1000	30	4
1429	684	2000	20	7	1428	919	1200	50	8
1445	0	600	0	4	1442	860	1500	35	3
1319	1	30	1	5	1320	130	170	50	3
1355	86	250	20	5	1354	35	70	30	3
911	1268	3000	25	6	913	707	1000	45	6
917	324	1250	15	4	916	274	800	20	5
1344	1286	2000	40	8	1344	1039	1200	60	5
1337	43	250	10	7	1337	150	300	30	5
937	39	60	40	4	936	25	50	30	5
1459	44	500	5	9	1459	321	500	40	6
1514	217	250	60	4	1515	270	420	40	9
1555	131	1500	5	5	1555	338	800	25	8

perp is the estimated perpendicular distance
angle is the estimated angle
G is the group size
Sight is the estimated sighting distance.

Table 3. Density estimates from line transect methods and estimates of the correction factor for movement based on the ratio of the line transect density and mark-recapture density estimates. (D_g is density of groups, D_c is density of groups corrected for missed animals, C is the correction factor for movement = Density from mark-recapture/D_{cg}, cv is coefficient of variation).

Bridge						
	D_g	cv	D_c	cv	C	cv
Fourier series	.054	.236	.082	.239	.327	.249
Hermite Polynomial	.052	.294	.079	.297	.339	.304
Hazard Rate	.053	.295	.081	.298	.331	.305

Flying Bridge						
	D_g	cv	D_c	cv	C	cv
Fourier series	.069	.188	.091	.248	.295	.257
Hermite Polynomial	.082	.238	.109	.288	.246	.296
Hazard Rate	.086	.294	.114	.336	.235	.343

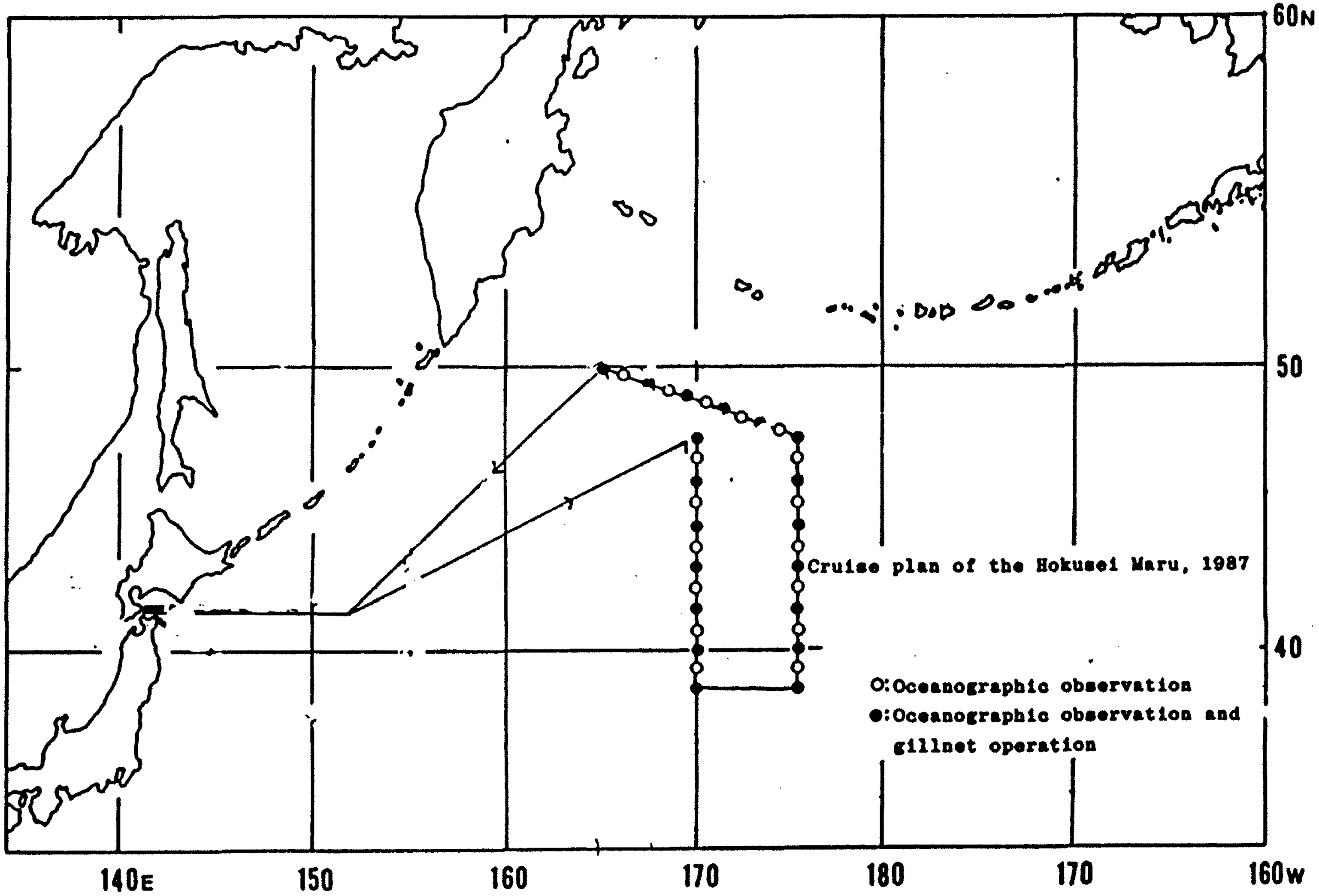

Figure 1. Cruise tracks for the HOKUSEI MARU, July 13 to August 12, 1987.

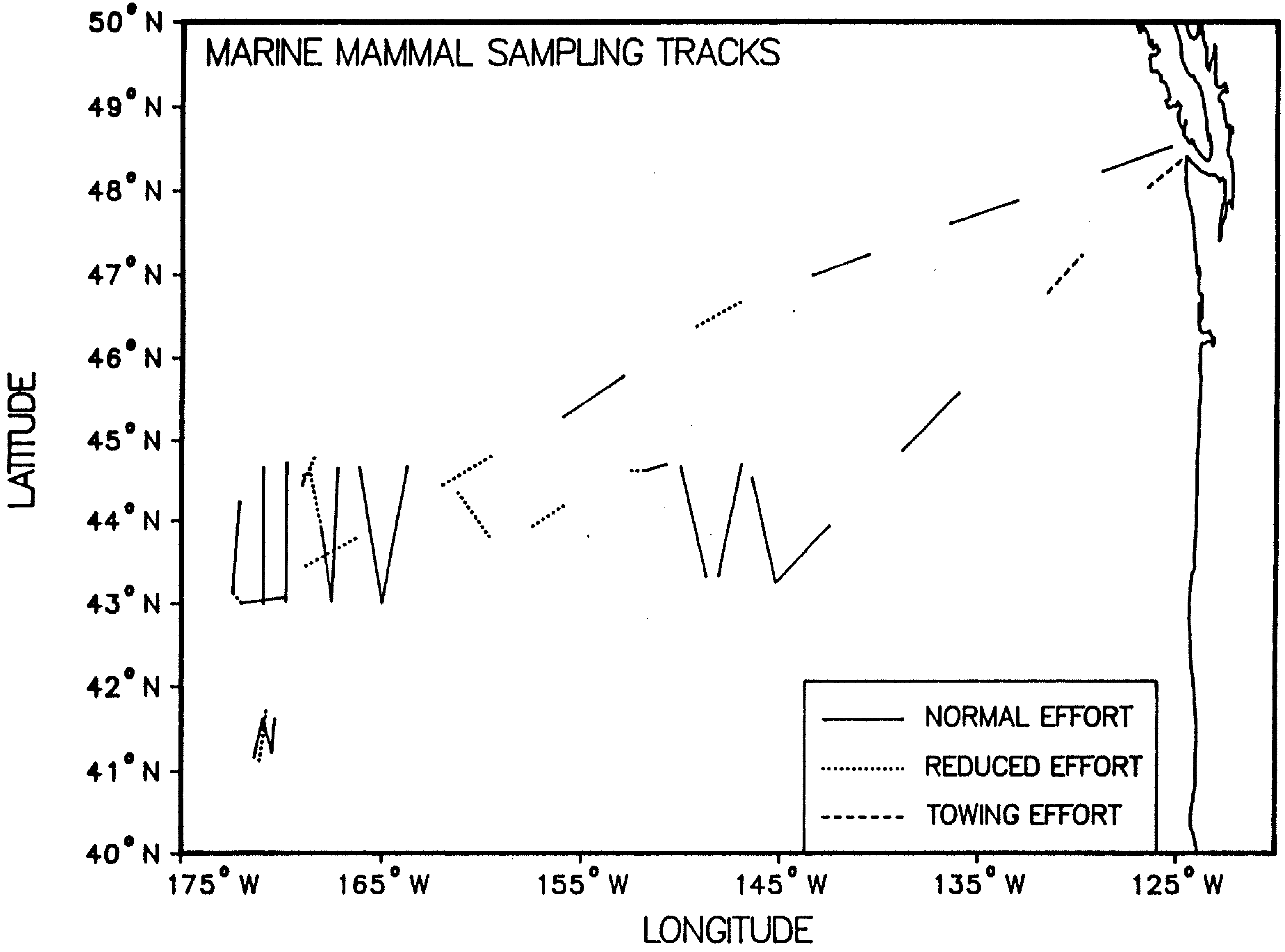

Figure 2. Cruise tracks for the MILLER FREEMAN, October 8 to November 8, 1987.

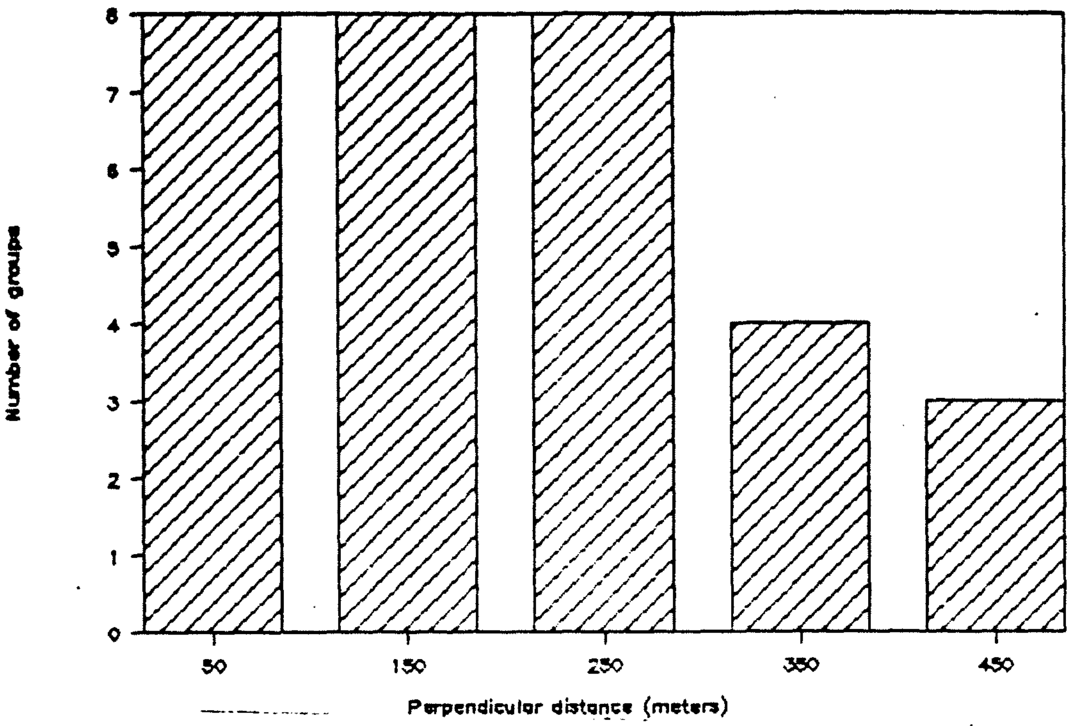

Figure 3. Frequency of perpendicular distances of groups of Dall's porpoise observed by the US observer on board the HOKUSEI MARU, July 13 to August 12, 1987, in the western North Pacific Ocean.

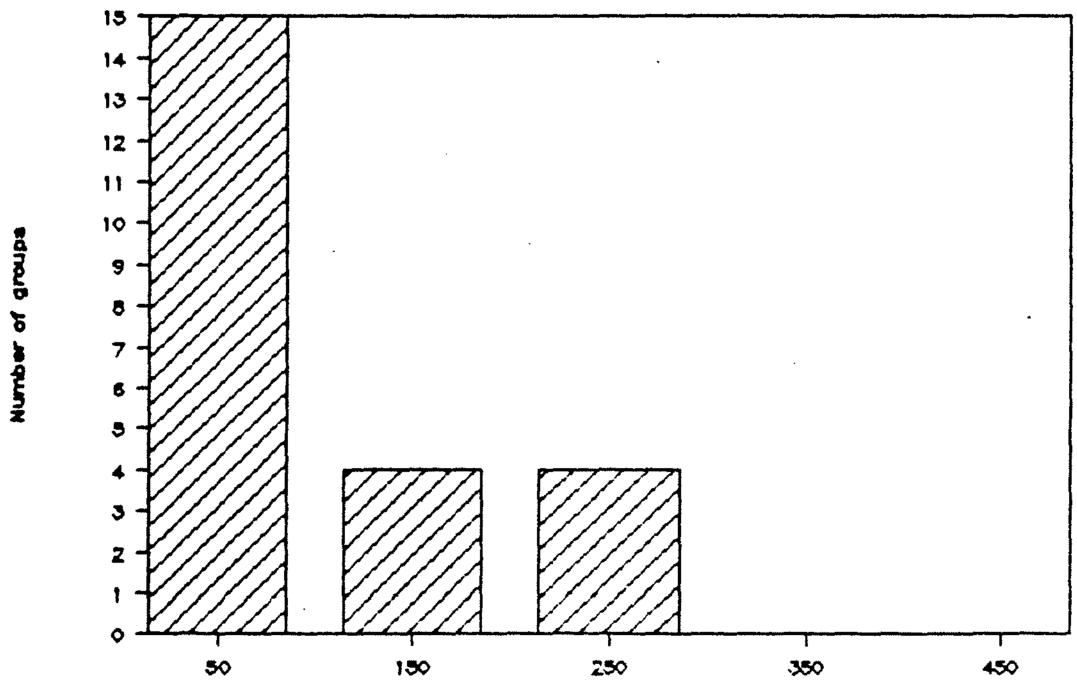

Figure 4. Frequency of perpendicular distances of groups of Dall's porpoise observed by the Japanese observers on board the HOKUSEI MARU, July 13 to August 12, 1987, in the western North Pacific Ocean.

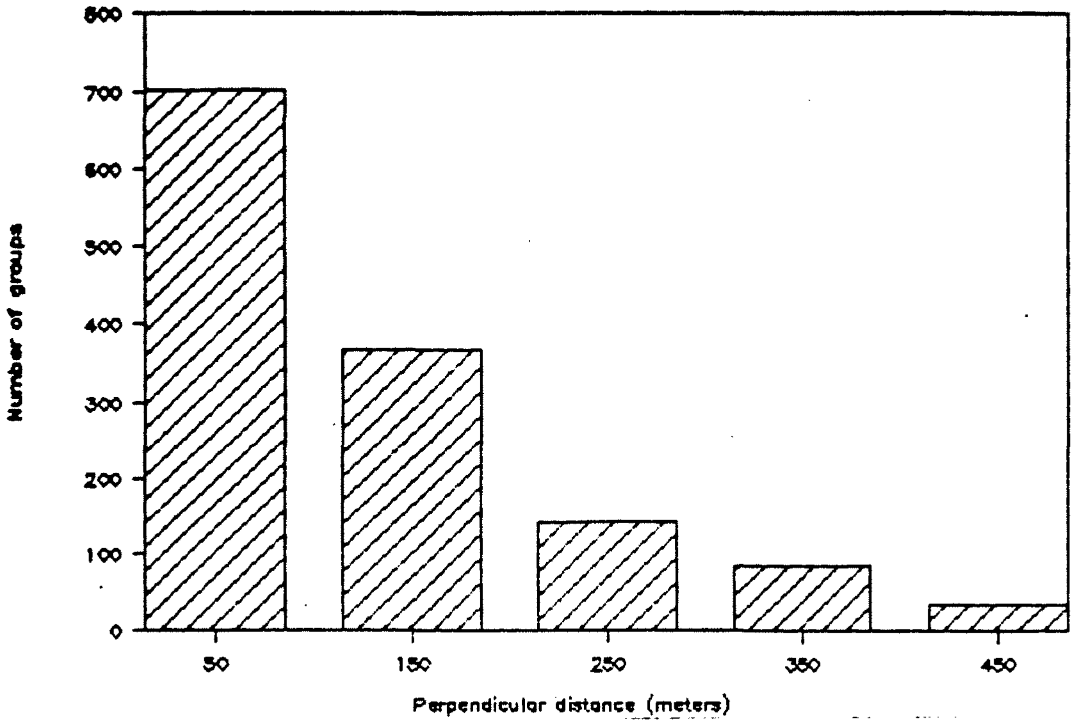

Figure 5. Frequency of perpendicular distances of groups of Dall's porpoise observed by US observers on all cruises in the western central North Pacific Ocean from 1980 to 1986.

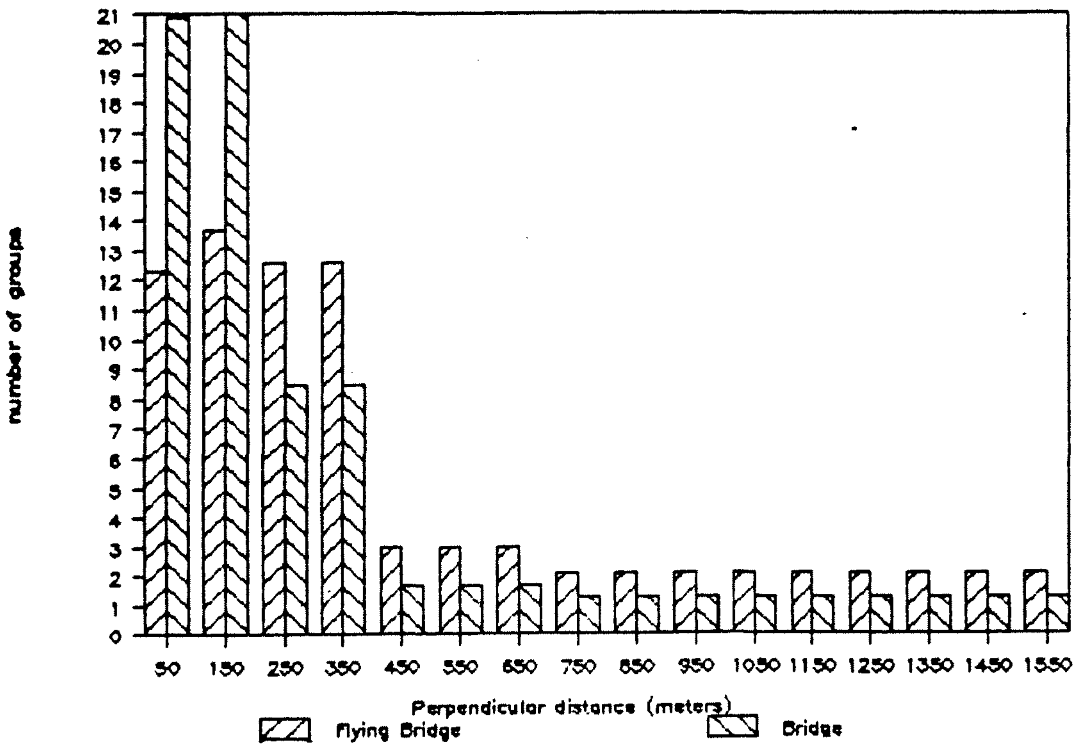

Figure 6. Estimated number of groups from mark-recapture methods for the observers on the flying bridge and bridge during a research cruise of the U.S. NOAA vessel, MILLER FREEMAN, October 8 to November 8, 1987 in the North Pacific Ocean.

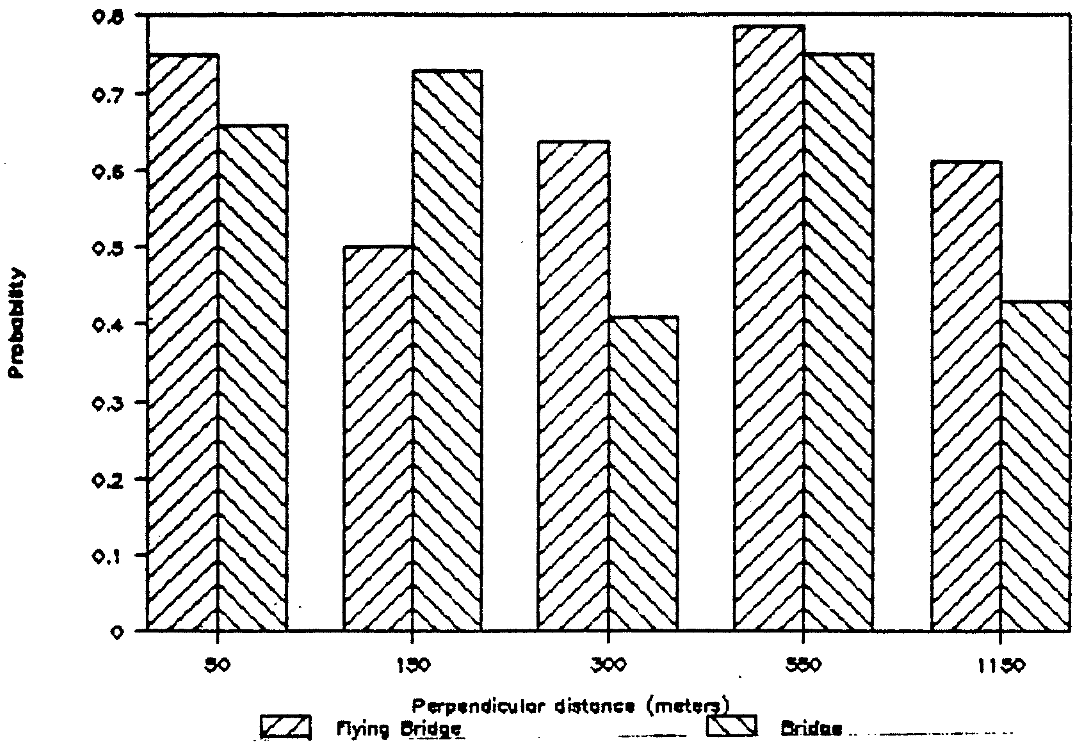

Figure 7. Probability of sighting a group by distance interval for the observers on the flying bridge and bridge during a research cruise of the U.S. NOAA vessel, MILLER FREEMAN, October 8 to November 8, 1987 in the North Pacific Ocean.

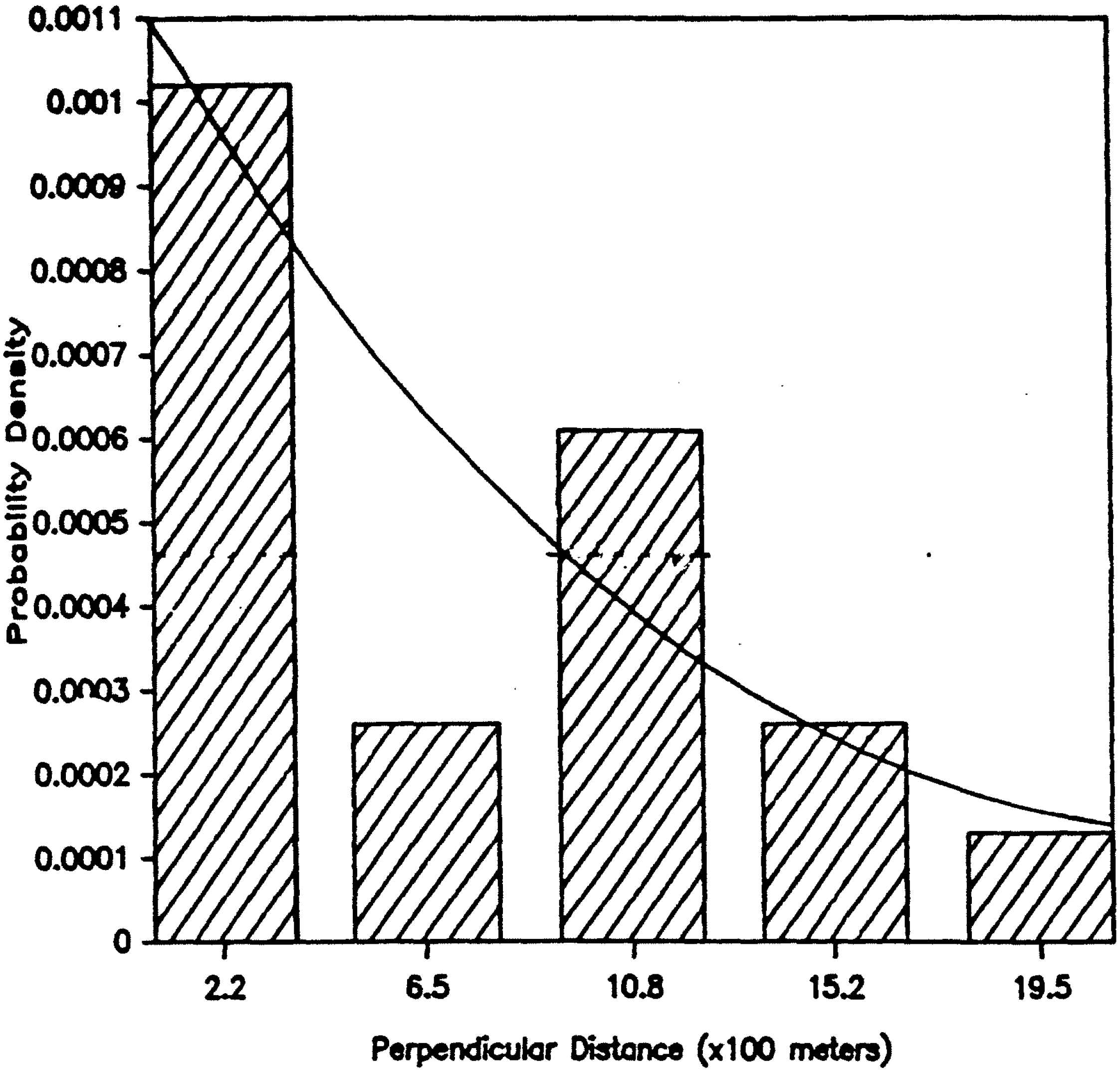

Figure 8. Perpendicular distances of groups of Dall's porpoise after movement for the 1983 helicopter-ship survey in Prince William Sound (from Turnock 1987).