NOAA Technical Memorandum NMFS

AUGUST 1994

THE ESTIMATION OF PERPENDICULAR SIGHTING DISTANCE ON SWFSC RESEARCH VESSEL SURVEYS FOR CETACEANS: 1974 TO 1991

Jay Barlow
Tim Lee

NOAA-TM-NMFS-SWFSC-207

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

NOAA Technical Memorandum NMFS

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

AUGUST 1994

THE ESTIMATION OF PERPENDICULAR SIGHTING DISTANCE ON SWFSC RESEARCH VESSEL SURVEYS FOR CETACEANS: 1974 TO 1991

Jay Barlow
Tim Lee

La Jolla Laboratory, SWFSC
National Marine Fisheries Service, NOAA
P.O. Box 271
La Jolla, California 92038-0271

NOAA-TM-NMFS-SWFSC-207

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service
Rolland A. Schmitten, Assistant Administrator for Fisheries

THE ESTIMATION OF PERPENDICULAR SIGHTING DISTANCE ON SWFSC RESEARCH VESSEL SURVEYS FOR CETACEANS: 1974 TO 1991

Jay Barlow and Tim Lee
Southwest Fisheries Science Center
P.O. Box 271, La Jolla CA 92038

ABSTRACT

We review the methods used to estimate sighting angles and distances on line-transect surveys for cetaceans conducted by the Southwest Fisheries Science Center between 1974 and 1991. We base our inference on the observed patterns of rounding found in the data. We conclude that angles and distances were estimated "by eye" from 1974 to 1979. Beginning in 1980 (Cruise 598), angles were estimated using a calibrated collar on the base of the 25x binoculars. Beginning in 1982 (Cruise 798), surveys on the research vessel *JORDAN* began using ocular reticles to estimate sighting distances based on a theoretical formula derived by Smith (1982). That formula was found to be biased, and beginning in 1986 (Cruises 989 and 990), a new formula was used to estimate sighting distances. A simple method is presented for correcting biased distances that were based on Smith's earlier formula. Measures made "by eye" may also be biased as is indicated by comparing cumulative distributions of angles and distances, but there is no simple way to correct this bias.

INTRODUCTION

Estimation of the distance from a transect line to the object being censused is pivotal in line transect surveys (Buckland et al. 1993). A bias in estimating this distance results directly in a bias in the estimated density and abundance. Typically in ship surveys for cetaceans, the distance of a group of animals from the transect line (referred to perpendicular distance: d_p) is calculated from estimates of the distance of the group from the survey vessel (referred to as radial distance: d_r) and the angular deviation of the group from the transect line (referred to as sighting angle: α), both measured at the location of the ship at the time the group is first sighted. Perpendicular distance is estimated using the simple formula: $d_p = d_r * \sin(\alpha)$. In this paper, we examine how methods of estimating radial distance and sighting angle have changed on research vessel surveys conducted by the Southwest Fisheries Science Center (SWFSC) since 1974, and how those changes might affect bias and precision in estimating perpendicular distance.

Initially on SWFSC dolphin surveys, radial distance and sighting angles were estimated "by eye". The first surveys used Navy-surplus 20x binoculars that were suspended on a frame with elastic (bungee) cords; this allowed for considerable lateral movement of the binoculars in their mounts and made the measurement of angle very difficult. Those binoculars did not have ocular reticles, and therefore distances were also difficult to estimate.

The 20x binoculars were replaced in 1979 by Fujinon 25x150 binoculars, which have a more rigid mount and a calibrated collar which allows estimation of angles to the nearest 1 degree. They also have ocular reticles which allow measurement of the declination angle between the horizon and the dolphin school. The reticle value can be converted to a measure of radial distance using a formula based on spherical geometry and the height above sea level. A reticle-to-distance conversion for these binoculars was first developed by Smith (1982) based on theoretical formulae. This was tested in the field using a radar to measure the true distance to objects, and consistent errors were found[1]. Barlow[2] developed a new formula that gave a better fit to the field data and this formula was used on subsequent surveys. Reticle values were not recorded in the computer record for surveys prior to 1991. No attempt has been made to correct distance estimates that were made with the biased formula of Smith.

Fujinon 7x50 hand-held binoculars were purchased for a harbor porpoise cruise in 1985. These binoculars also have ocular reticles, but they are not numbered. Each mark was taken to be one reticle, with major marks corresponding to even numbered reticles and minor marks corresponding to odd numbered reticles. These 7x binoculars were used as the primary observation instrument for all observers on the 1985 and 1986 harbor porpoise cruises and have been used since 1986 by the data recorders and since 1991 by the independent observers on dolphin surveys. A reticle-to-distance conversion formula has also been developed for these 7x50 binoculars based on fitting field data. Sighting angles were always estimated "by eye" when sightings were made with 7x binoculars, but since 1985 a protractor has sometimes been mounted in front of the observers as an aid in estimating angles.

Although the above information is known, the actual dates when transitions were made from one method to another have not been well documented in cruise reports. There were approximately 31 research vessel cruises conducted for cetaceans by the SWFSC from 1974 to 1985 (Lee 1993) and an additional 15 cruises from 1986 to 1991 (Holt and Jackson 1987, 1988; Holt and Sexton 1987, 1988, 1989; Sexton et al. 1989; Hill et al. 1990a, 1990b, 1991a, 1991b; Hill and Barlow 1992). The purpose of this report is to determine (by inference) which cruises used which methods, to present the data and methods used for estimating the reticle-to-distance formulae that are currently being used, and to develop a method to convert distances estimated with the previous, biased reticle formula to values that are comparable to the new formula.

---

[1] Barlow, J. 1985. Cruise Report DS-85-09 of the harbor porpoise survey in California, Oregon, and Washington. Available from the SWFSC, P.O. Box 271, La Jolla CA 92038.

[2] Memo dated 20 January 1987 from Jay Barlow to marine mammal researchers at the SWFSC.

METHODS

Fitting Reticle-to-Distance Conversion Formulae

The formula used to convert from reticle value, r, to radial distance, d_r is based on spherical geometry (Smith 1982):

$$d_r = h \cdot \tan(\arctan(89.173 / \sqrt{h}) - c \cdot r) \quad (1)$$

where h= height above the water (in nmi.), and
c= conversion factor for reticles to degrees.

Reticle value is treated as a measure of the arc angle between the horizon and the object whose distance is being estimated. Smith (1982) measured the true arc angle of one reticle on the Fujinon 25x binoculars to be 0.0823 degrees (thus c = 0.0823). Smith measured the binocular height on the research vessel *DAVID STARR JORDAN* to be 35 feet (thus h = 0.00576 nmi). The reticle-distance relationship based on these parameter values is given in Table 1 and is illustrated in Figure 1.

Empirical data on the reticle-distance relationship were gathered on a 1985 harbor porpoise survey[1] and on a 1986 dolphin survey (W. Parks, unpubl. data). Data for both studies were collected from the flying bridge of the *JORDAN* at a viewing height of 10.7m; weather conditions were good on both occasions. On the harbor porpoise survey, reticle values and radar distances were recorded to a navigation buoy near the mouth of San Diego Harbor at ranges from 0.3 to 1.4 nmi. On the dolphin survey, reticle values and radar distances were measured to a small boat near Hawaii at ranges from 0.3 to 4.4 nmi. These empirical data are given in Table 2. Similar data were collected for the Fujinon 7x binoculars on the 1985 harbor porpoise survey[1] and are presented in Table 3.

The parameters h and c in Equation 1 were fitted to the empirical reticle-distance data (Tables 2 and 3) by minimizing the sum of squared differences between the observed and predicted distances using a non-linear fitting routine based on the Marquardt (1963) algorithm. For the 7x binoculars, h was assumed fixed at 10.7m and only c was fit (because refraction was assumed to be negligible at the closer distances observed with 7x binoculars). [Note: fitting was done by treating distance as the dependent or predicted variable and using reticle as the independent or predictor variable. Because measurement error is likely larger in reticle estimation than in radar distance estimation, this method of fitting is not optimal.]

Inferring Transition Dates for Methods of Measurement

The methods used to estimate sighting angles and radial distances on a given survey can be inferred from the data recorded on that cruise. Angles and distances always tend to be rounded to the nearest convenient unit, and the pattern of rounding reveals what method was used. For distances, when estimating "by eye", there is a tendency to round to the nearest nautical mile or half-mile. When using ocular reticles, there is a tendency to estimate distances to the nearest reticle or (for distant sightings made with the 25x binoculars) to the nearest tenth of a reticle. These rounded reticle values will, when converted to distance and recorded to the nearest tenth of a nautical mile, be different from values that are simply rounded to the nearest nautical mile. For example, if distant sightings are rounded to 0.1 reticle, a mode in sighting distances would be found at 5.8 nmi (using Smith's original conversion formula) or at 4.8 nmi (using the Barlow's conversion formula). Similarly, when angles are estimated "by eye", angles will tend to be rounded to the nearest 10 degrees. When angles are estimated using a calibrated collar on the binocular mount, angles will be rounded to the nearest calibration mark, typically 1 degree.

A FORTRAN program ANG (Appendix 1) and a Paradox (TM) script program GRAPHDST (Appendix 2) were written to extract angle and distance information (respectively) from survey data. We used survey data that had been converted from a variety of initial formats to the standard DAS format that is currently being used at the SWFSC (Lee 1993). On-effort sighting data were tallied for each cruise to produce frequency distributions of angles and radial distances. Spread sheet macros were then written to import the summary files and to graph these data.

RESULTS

Fitting Reticle-to-Distance Conversion Formulae

The best fit of the reticle-distance conversion formula (Eq. 1) based on empirical data for the Fujinon 25x binoculars was obtained with parameters h= 0.003942 nmi and c= 0.06233 degrees per reticle. This fit is illustrated in Fig. 1, along with predictions from the original formula given by Smith (1982). Clearly the new formula appears to fit the empirical data better than the previous formula. Distances predicted from the new formula are less than those predicted from the old formula, especially at long distances. From this we conclude that the formula given by Smith and used on some SWFSC dolphin surveys is biased. Distances corresponding to common reticle values are given in Table 1 for both formulae.

The best fit for the Fujinon 7x binoculars was obtained with parameter value c= 0.395 (the height above the water was assumed to be known, h= 0.00576 nmi (10.7 m or 35 ft)). Distances corresponding to common reticle values are given in Table 1.

Inference Regarding Methods Used on Past Cruises

The distribution of radial distances and sighting angles for past SWFSC surveys from 1974 to 1991 are given in Figures 2 and 3 (respectively). These data show a general trend towards less rounding of angle and distance measures.

On early cruises, most distances are rounded to the nearest 1.0 nmi and (to a lesser extent) to the nearest 0.5 nmi. A clear change in this pattern occurred on Cruise 716 (May-July 1981) and Cruise 798 (April 1982). On Cruise 716, there was less rounding of distance estimates than on previous cruises, but the modes do not correspond to Smith's formula; it is likely that a modification of Smith's formula was used to account for the higher survey height on the *OCEANOGRAPHER* (the vessel used on that survey)[3]. On Cruise 798, distance modes occur at 5.8 and 6.7 nmi, which correspond to reticle values of 0.0 and 0.1 using Smith's conversion formula. Clearly reticles were used with this formula on Cruise 798. Modes at 5.8 and 6.7 nmi also appear on Cruises 801 and 843, indicating that Smith's formula was used on those surveys. Cruise 852 was on the *JORDAN* and the *SURVEYOR*, and distances were rounded to the nearest 0.5 nmi, perhaps indicating that distances were estimated "by eye". On Cruises 874 and 905, modes in sighting distance appear at 2.5 and 3.7 nmi, which correspond to reticle values of 0.5 and 1.0 using Smith's formula. It is likely that reticle values were rounded to the nearest 0.5 reticle on those two surveys. Cruise 910 was a harbor porpoise survey that primarily used hand-held 7x binoculars; the few sightings shown in Fig. 2 only reflect a short transect through the Southern California Bight using 25x binoculars. Common distance modes on Cruises 989 and 990 appear at 2.2, 3.2, 4.3, and 5.5 nmi. These correspond to reticle values of 1.0, 0.5, 0.2, and 0.0 using Barlow's newer conversion formula. [Although these cruises were in 1986 and Barlow's formula was developed in Jan 1987 using data from these cruises, Alan Jackson (pers. comm.) reports that observers recorded reticle values on these cruises which were later translated to distances during data editing]. Subsequent Cruises 1080, 1081, 1164, 1165, 1267, 1268, 1369, and 1370 all show common modes at 2.2, 3.2, 3.5, 3.8, 4.3, 4.8, and 5.6 nmi which correspond to reticles of 1.0, 0.5, 0.4, 0.3, 0.2, 0.1, and 0.0 using Barlow's formula.

Sighting angles were initially rounded to the nearest 5 and 10 degrees. Sighting angles were frequently recorded to the nearest 1 degree beginning on Cruise 598 (Jan-Mar 1980) and continuing for all subsequent cruises (Fig. 3).

Transforming Biased Distance Data

Based on the above, it appears that Smith's biased formula was used to estimate distances on Cruises 798, 801, 843, 874, and 905. Reticle values were not recorded on these cruises, so it is not a simple matter to recalculate distances. However, because the formula is known, it is possible to back-transform to get reticle values and then use the newer formula for estimating distances. When distances estimated by Smith's formula are plotted against distances estimated from the new formula, values nearly fall on a straight line (Fig. 4). This indicates that the bias in Smith's formula is roughly constant. Regression through the origin of the values in Figure 4 yields a slope of 1.177. The bias in perpendicular distance data from Cruises 798, 801, 843, 874, and 905 can be eliminated by dividing by 1.177. If these biased

[3] Report on cetacean studies conducted from R/V Oceanographer, Porpoise Cruise 716, May 19 - July 29, 1981. Available from the SWFSC, P.O. Box 271, La Jolla, CA 92038.

perpendicular distances are used (ungrouped) to estimate f(0) for line transect abundances, f(0) would be underestimated by a factor of 1.177.

Comparisons of Distance Measures Among Cruises

Distances estimated prior to Cruise 798 were estimated "by eye" and may also be biased. To examine potential biases in estimating distances "by eye", we plot the cumulative distribution of sighting distances for 6 groups of surveys stratified by methods used, survey vessel, and location (Fig. 5). The first two groups include surveys on the *JORDAN* during which distances were estimated "by eye" in the eastern tropical Pacific (ETP) (Cruises 463 and 598) and in California and Baja California (Cruises 564 and 646). The third group includes ETP surveys on the *JORDAN* during which Smith's formula was used to estimate distances (Cruises 801 and 843). The fourth group includes ETP surveys on the *JORDAN* which used Barlow's formula for estimating distances (MOPS Cruises 989, 1080, 1164, 1267, and 1369). The fifth group includes ETP surveys on the *McARTHUR* which used Barlow's formula (MOPS Cruises 990, 1081, 1165, 1268, and 1370). The sixth group includes a California survey on the *McARTHUR* which used Barlow's formula (CAMMS Cruise 1426). These cumulative distributions show differences in distance estimates <u>between different areas</u> and <u>between methods of estimating distance</u>, but there are no apparent differences between vessels.

Distributions of sighting distances are affected by the method used to estimate distances. Two outliers are seen in the plots of cumulative distances (Fig. 5): ETP surveys which did not use reticles to estimate distance and a California cruise which used reticles and the most current formula for converting reticles to distance. These two outliers have similar distributions of radial distance, but have almost nothing else in common; they were on different vessels, in different areas, and used different methods to estimate distance. On the *JORDAN*, the ETP surveys without reticles are significantly different from ETP (MOPS) surveys with reticles (Kolmogorov/Smirnov Test, $p < 0.01$). Similarly, the California surveys on the *JORDAN* without reticles are significantly different from the recent California survey (CAMMS) on the *McARTHUR* (K/S test, $p < 0.01$). The distances estimated without reticles were, however, in one case greater and in one case less than distances estimated with reticles in the same area. These inconsistent results may indicate that distances estimated "by eye" are not consistent between cruises.

Distributions of sighting distances appear to differ between areas. Sighting distances from the *McARTHUR* in the offshore ETP are consistently and significantly (Kolmogorov/Smirnov test, $p < 0.01$) less than sighting distances from the *JORDAN* in more inshore areas of the ETP <u>despite the fact that both surveys used exactly the same methods and even the same observers</u>. This, together with the even larger difference in the distribution of distances between California and the ETP, lends credence to the hypothesis that sighting distances really do differ between areas. The differences between areas could be caused the larger number of small groups of porpoises and whales in California that can only been seen when they are close to the vessel. The differences between California and ETP cruises persist, however, and are statistically significant (K/S test, $p < 0.01$) even when sightings are limited to those with groups sizes of 20 or greater (Fig. 6).

Comparison of Angles Measures Among Cruises

Cumulative distributions of sighting angles were also plotted for 6 similar groups of surveys (Fig. 7). These data indicate that the distribution of angles at which cetaceans were first sighted remained remarkably similar throughout the 1980-91 period. The greatest deviations occurred in 1979 surveys during which angles were estimated "by eye"; this difference is statistically significant for the comparison of the 1979 ETP cruise on the *JORDAN* with the much larger sample of 1986-90 ETP cruises on the *JORDAN* (K/S test, $p < 0.01$). In the observed distribution of angles, method appears to be more important than the location of the cruise.

DISCUSSION

Distances Estimated "By Eye"

Cumulative distributions of sighting distances estimated "by eye" (without reticles) are substantially different from those estimated with reticles in the same area (Fig. 5); however, the direction of this difference is not consistent between surveys. In estimating distances by eye, it is likely that observers are influenced by fellow observers, resulting in consistency within a cruise, but not necessarily between cruises.

Angles Estimated "By Eye"

Distributions of sighting angles are very similar among all cruises when estimated with calibrated collars on the base of 25x binoculars. The only cruises which showed large deviations were those on which angles were estimated "by eye". The bias in estimating angles "by eye" (if any) do not appear consistent, being overestimated on one cruise and underestimated on another.

Distance Estimation from Ocular Reticles

It appears that Smith's reticle-distance formula is biased. Smith (1982) noted, himself, that his formula appears to overestimate distances relative to field measurements. The formula derived by Barlow[2] uses the same equation, but fits the parameters to empirical data rather than using their theoretical values. This fits the observed data much better. The fit suggests, however, that the effective height above the water on the R/V *DAVID STARR JORDAN* is only 24 feet. It is not clear why the theoretical formula performs so poorly. Taylor and Krogman (1985) found that atmospheric bending of light causes an error of up to 23% in estimating distances in arctic environments. Smith's formula does, however, account for some atmospheric bending and does give the same estimated distance to the horizon (6.8 nmi from an altitude of 35 ft) as predicted by Bowditch (1975) for "average" atmospheric conditions.

Tim Gerrodette (pers. comm.) has collected a large number of additional observations of reticle measurements and associated radar distances under a variety of sea conditions, and these data may help resolve what is causing the apparent bias in the theoretical formula. Daniel Fink and Tim Gerrodette (pers. comm.) report progress on deriving a reticle/distance formula that more explicitly considers atmospheric bending of light.

A difference in the distributions of sighting distances exists between areas even when reticles are used consistently with the same formula for estimating distance. We conclude, therefore, that these differences are real and may be related to differences in sighting characteristics of the species that are present or differences in visibility, sea state, etc. of the specific areas. In the ETP, most dolphins groups swim away from a survey vessel and in California waters most are attracted. Within the ETP, the species mix and characteristic group sizes change between inshore and offshore, and the presence of birds (a sighting cue that can be seen at great distances) associated with groups of dolphins varies geographically. Haze and fog are more frequently a problem in California waters. Clearly there are still many unexplained sources of variation in distributions of radial sighting distance. Until we understand these better, there is little hope for developing correction factors for those surveys on which distances were estimated "by eye". Given an apparent bias in distances estimated "by eye", caution should be used in interpreting results from those cruises.

ACKNOWLEDGEMENTS

We thank Al Jackson and Tim Gerrodette for the information and helpful insights given in the course of this study. These data would not be available if not for the dedicated marine mammal observers, cruise leaders, data editors, officers and crew who participated in the surveys we describe. This manuscript was reviewed by K. Forney, T. Gerrodette, and R. Holt.

LITERATURE CITED

Bowditch, N. 1975. American Practical Navigator: An Epitome of Navigation. Volume II. Defense Mapping Agency Hydrographic Center. 716pp.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance Sampling: Estimating abundance of biological populations. Chapman and Hall. London. 446pp.

Hill, P. S. and J. Barlow. 1992. Report of a marine mammal survey of the California coast aboard the research vessel *McARTHUR* July 28-November 5, 1991. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-169. NTIS #PB93-109908. 103pp.

Hill, P. S., A. Jackson, and T. Gerrodette. 1990a. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan*, July 29-December 7, 1989. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-142.

143pp.

Hill, P. S., A. Jackson, and T. Gerrodette. 1990b. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur*, July 29-December 7, 1989. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-143. 132pp.

Hill, P. S., A. Jackson, and T. Gerrodette. 1991a. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur*, July 28-December 6, 1990. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-159. 142pp.

Hill, P. S., R. C. Rasmussen, and T. Gerrodette. 1991b. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan*, July 28-December 6, 1990. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-158. 133pp.

Holt, R. S. and A. Jackson. 1987. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur*, July 29-December 6, 1986. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-77. 161pp.

Holt, R. S. and A. Jackson. 1988. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur*, July 30-December 10, 1987. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-116. 143pp.

Holt, R. S. and S. N. Sexton. 1987. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan*, July 29-December 5, 1986. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-76. 171pp.

Holt, R. S. and S. N. Sexton. 1988. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan*, August 8-December 10, 1987. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-117. 137pp.

Holt, R. S. and S. N. Sexton. 1989. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *David Starr Jordan*, July 28-December 6, 1988. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-129. 129pp.

Lee, T. 1993. Summary of cetacean survey data collected between the years of 1974 and 1985. NOAA Tech. Mem. NOAA-TM-NMFS-SWFSC-181. 184pp.

Marquardt, D. W. 1963. An algorithm for least-squares estimation of nonlinear parameters. J. Soc. Indust. Appl. Math. 11(2):431-441.

Sexton, S. N., R. S. Holt, and A. Jackson. 1989. Report of a marine mammal survey of the eastern tropical Pacific aboard the research vessel *McArthur*, July 28-December 6, 1988. NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-128. 125pp.

Smith, T. D. 1982. Testing methods of estimating range and bearing to cetaceans aboard the R/V *D. S. Jordan.* NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-20, avail. from NTIS. 30pp.

Taylor, B. S. and B. Krogman. 1985. Examination of theodolite error in the visual census of bowhead whales. Abstracts of the 6th Biennial Conference on the Biology of Marine Mammals, November 22-26, 1985. Vancouver, British Columbia.

Table 1. Predicted distance (nmi) for common reticle values based on the original formula of Smith (1982) for 25x binoculars, the newer formula for 25x binoculars, and the formula for 7x binoculars. Parameters refer to Eq. 1.

	Smith's Formula 25x	Barlow's Formula 25x	Barlow's Formula 7x
h=	0.00576	0.003942	0.00576
c=	0.0823	0.06233	0.395
Reticle	Predicted Distance		
0.0	6.768	5.599	6.768
0.1	5.790	4.849	3.739
0.2	5.060	4.277	2.583
0.3	4.493	3.826	1.973
0.4	4.040	3.460	1.596
0.5	3.670	3.159	1.340
0.6	3.363	2.905	1.155
0.7	3.102	2.690	1.015
0.8	2.880	2.504	0.905
0.9	2.687	2.342	0.816
1.0	2.518	2.200	0.744
1.5	1.916	1.688	0.515
2	1.547	1.369	0.393
2.5	1.297	1.151	0.318
3	1.116	0.994	0.267
4	0.873	0.780	0.203
5	0.717	0.642	0.163
6	0.608	0.545	0.136
7	0.528	0.474	0.117
8	0.467	0.419	0.103
9	0.418	0.376	0.091
10	0.379	0.340	0.082
11	0.346	0.311	
12	0.318	0.286	
13	0.295	0.266	
14	0.275	0.247	

Table 2. Data used to fit the reticle-distance formula for 25x binoculars.

Reticle	Radar Distance (nmi)
0.2	4.38
0.4	3.30
0.7	2.50
1.0	2.50
1.7	1.48
1.9	1.41
1.9	1.48
2.4	1.08
2.6	1.08
2.6	1.15
3.0	1.05
3.3	0.94
3.6	0.85
4.0	0.80
4.1	0.80
4.5	0.73
5.2	0.64
5.8	0.59
6.0	0.53
6.0	0.59
8.2	0.45
8.5	0.44
10.2	0.32
13.0	0.29
14.0	0.29

Table 3. Data used to fit the reticle-distance formula for 7x binoculars.

Reticle	Radar Distance nmi
0.4	1.41
0.4	1.41
0.4	1.41
0.6	1.15
0.6	1.15
0.6	1.15
0.6	1.05
0.7	1.05
0.7	1.05
0.8	0.94
0.8	0.94
0.9	0.94
1.0	0.85
1.0	0.85
1.0	0.85
1.1	0.72
1.1	0.72
1.2	0.72
1.3	0.64
1.3	0.64
1.4	0.64
1.4	0.53
1.5	0.53
1.7	0.53
1.8	0.46
2.1	0.46
2.2	0.46
2.7	0.31
2.7	0.31
2.8	0.31
3.5	0.27
3.5	0.27
3.8	0.27
5.0	0.19
8.0	0.12
8.2	0.12
8.2	0.12

Figure 1. Radial sighting distance as a function of reticle value for Fujinon 25x150 binoculars based on Smith's (1982) formula and Barlow's formula, and for Fujinon 7x50 binoculars based on Barlow's formula.

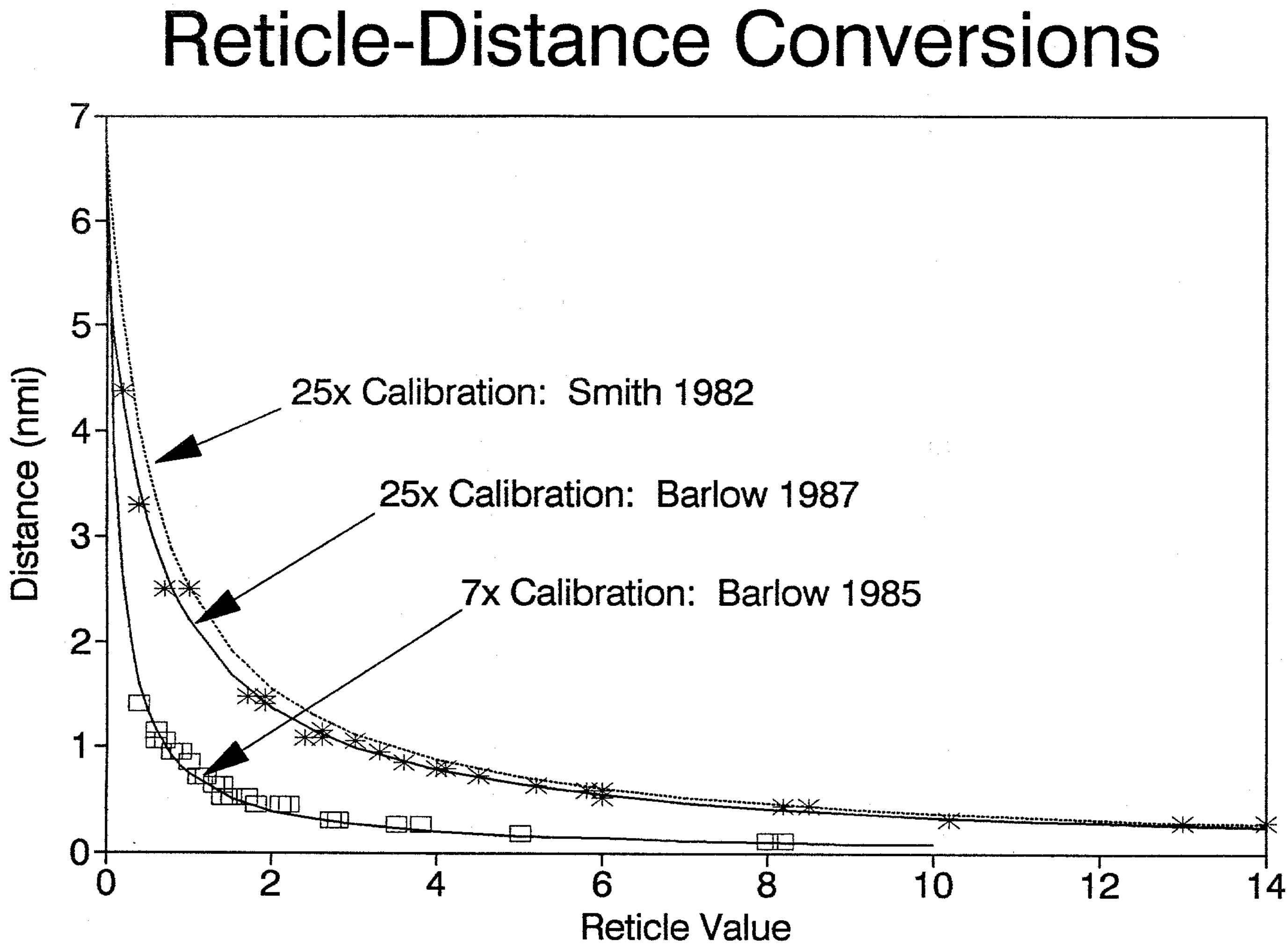


Figure 2. Distributions of radial sighting distances for all on-effort sightings made on cruises 84 through 1426, including sightings made with 25x and 7x binoculars and by unaided eyes.

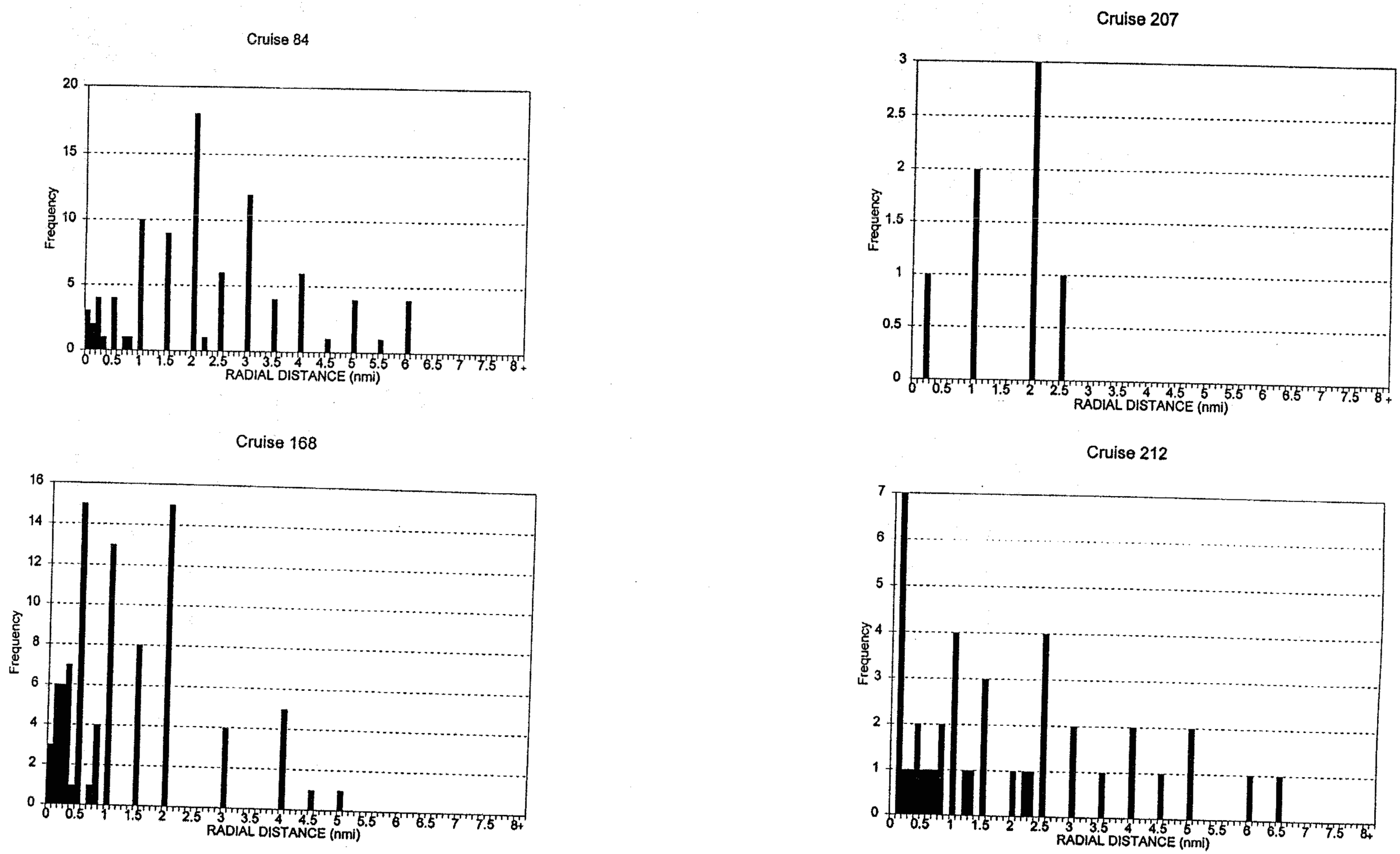


Figure 2. (cont.)

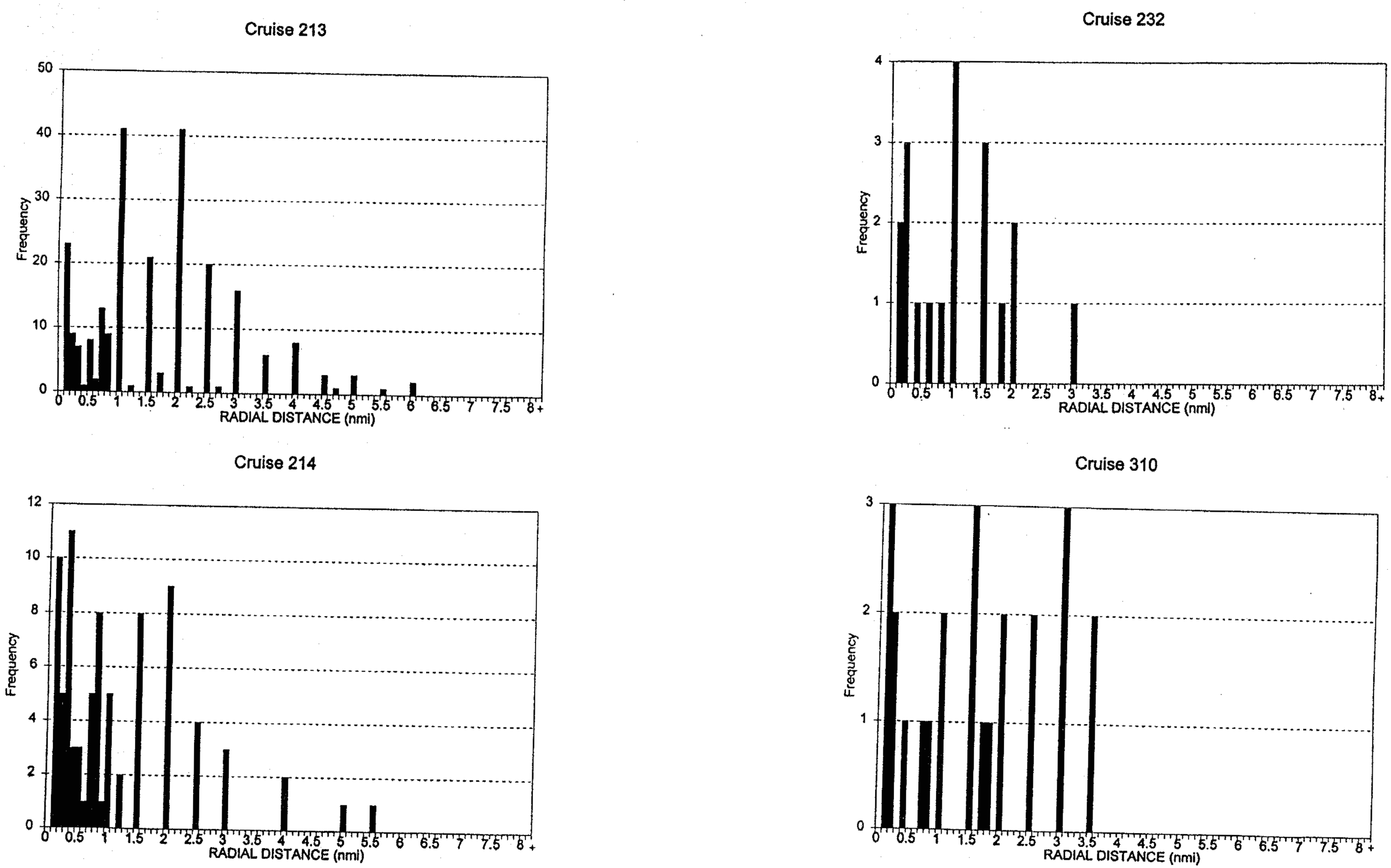


Figure 2. (cont.)

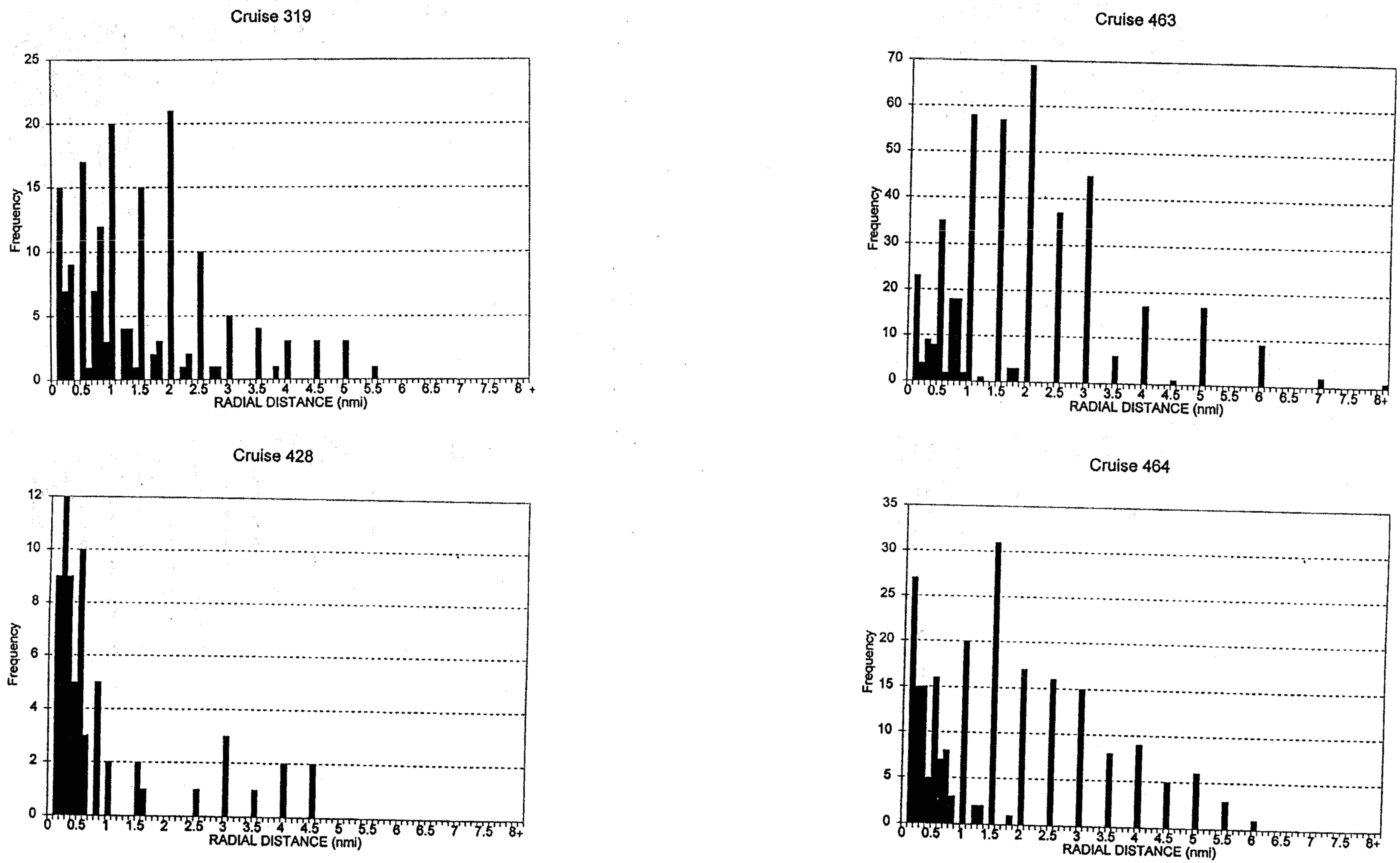
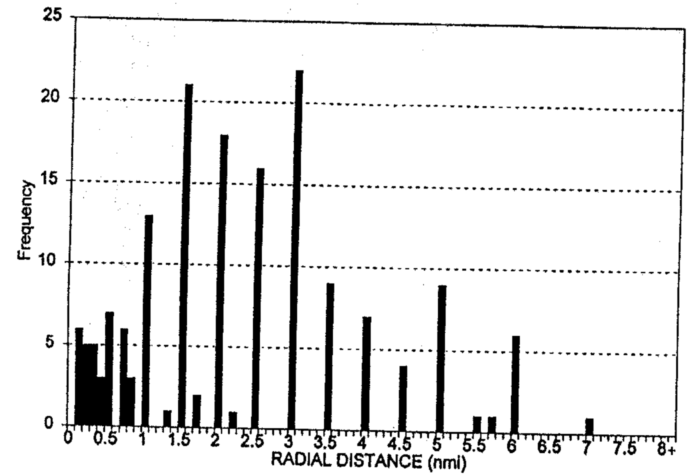
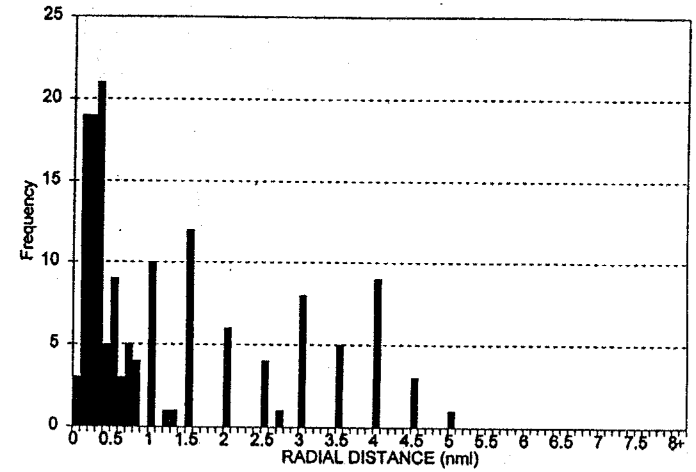


Figure 2. (cont.)

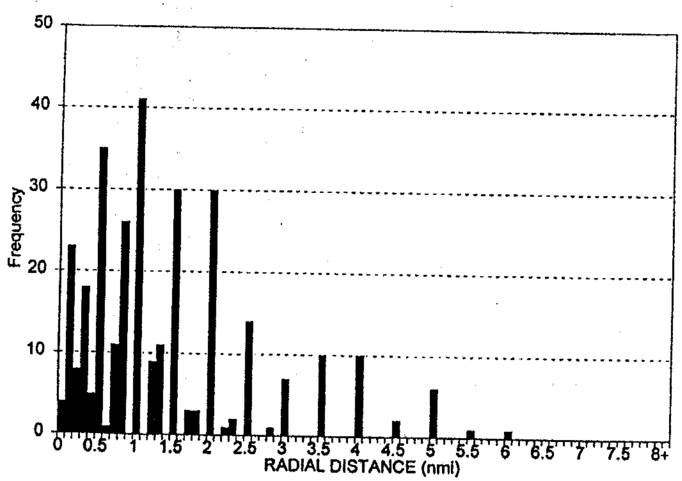
Cruise 564



Cruise 599



Cruise 598



Cruise 642

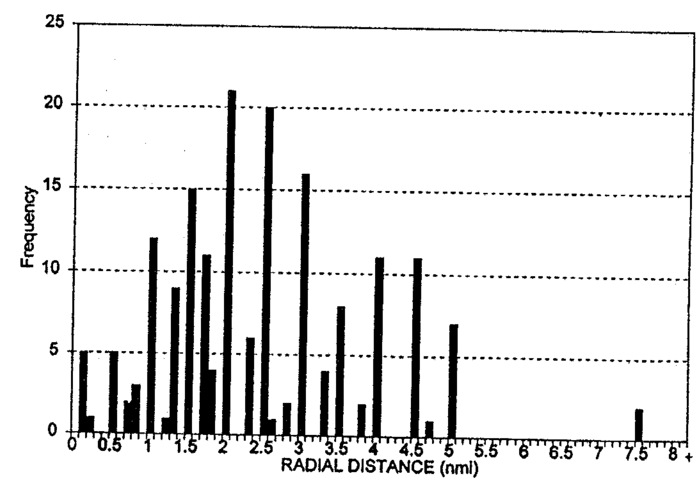


Figure 2. (cont.)

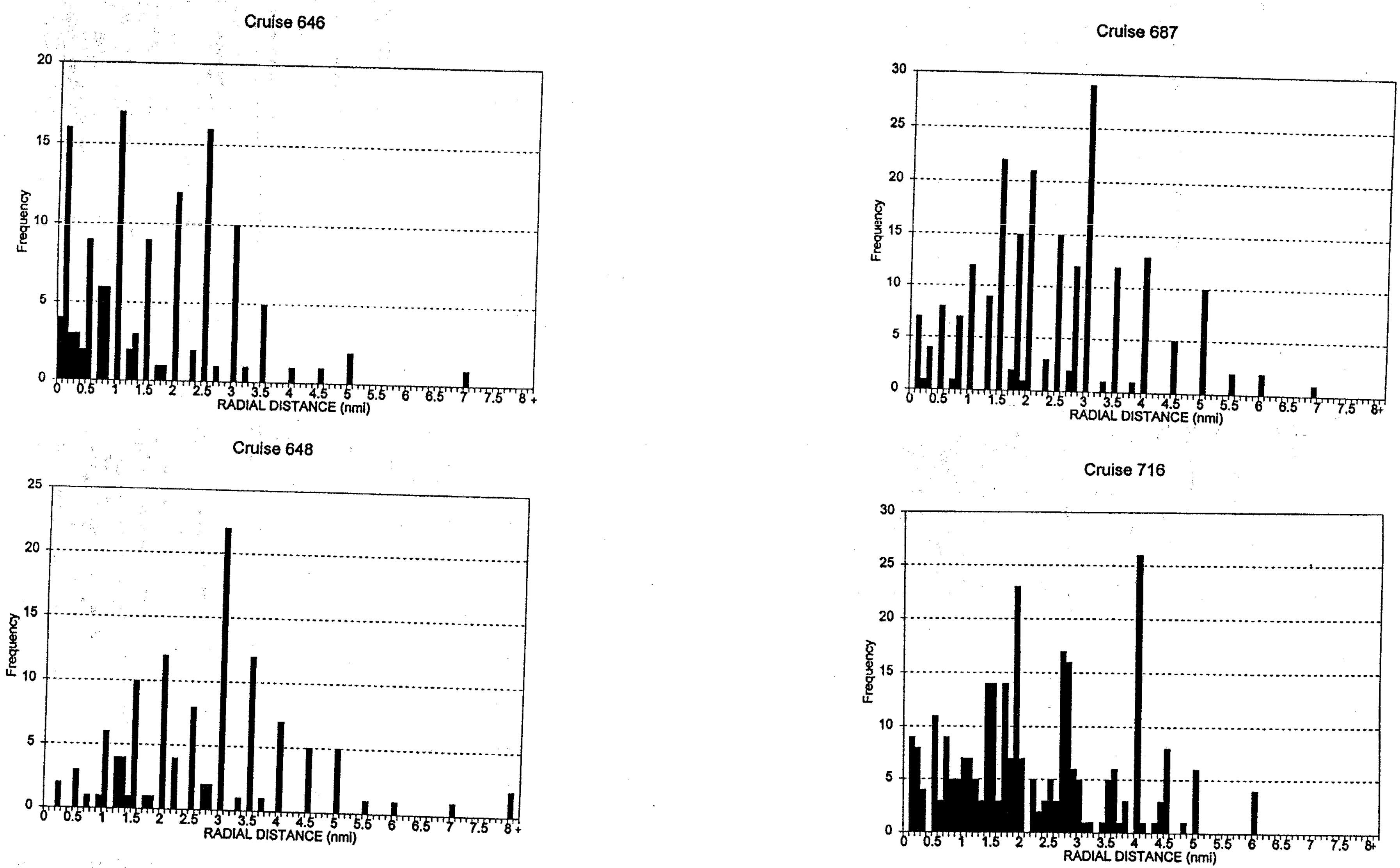


Figure 2. (cont.)

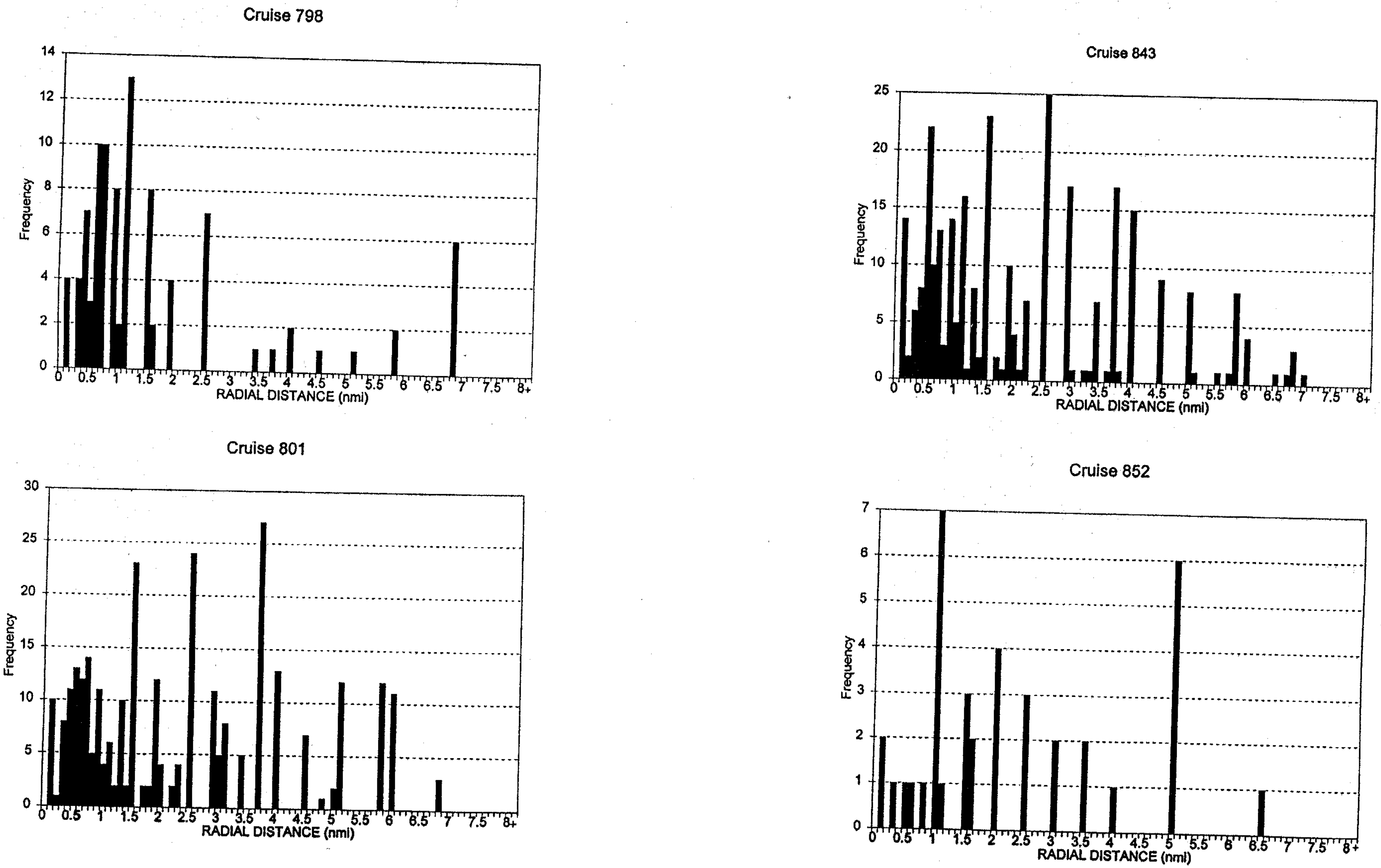


Figure 2. (cont.)

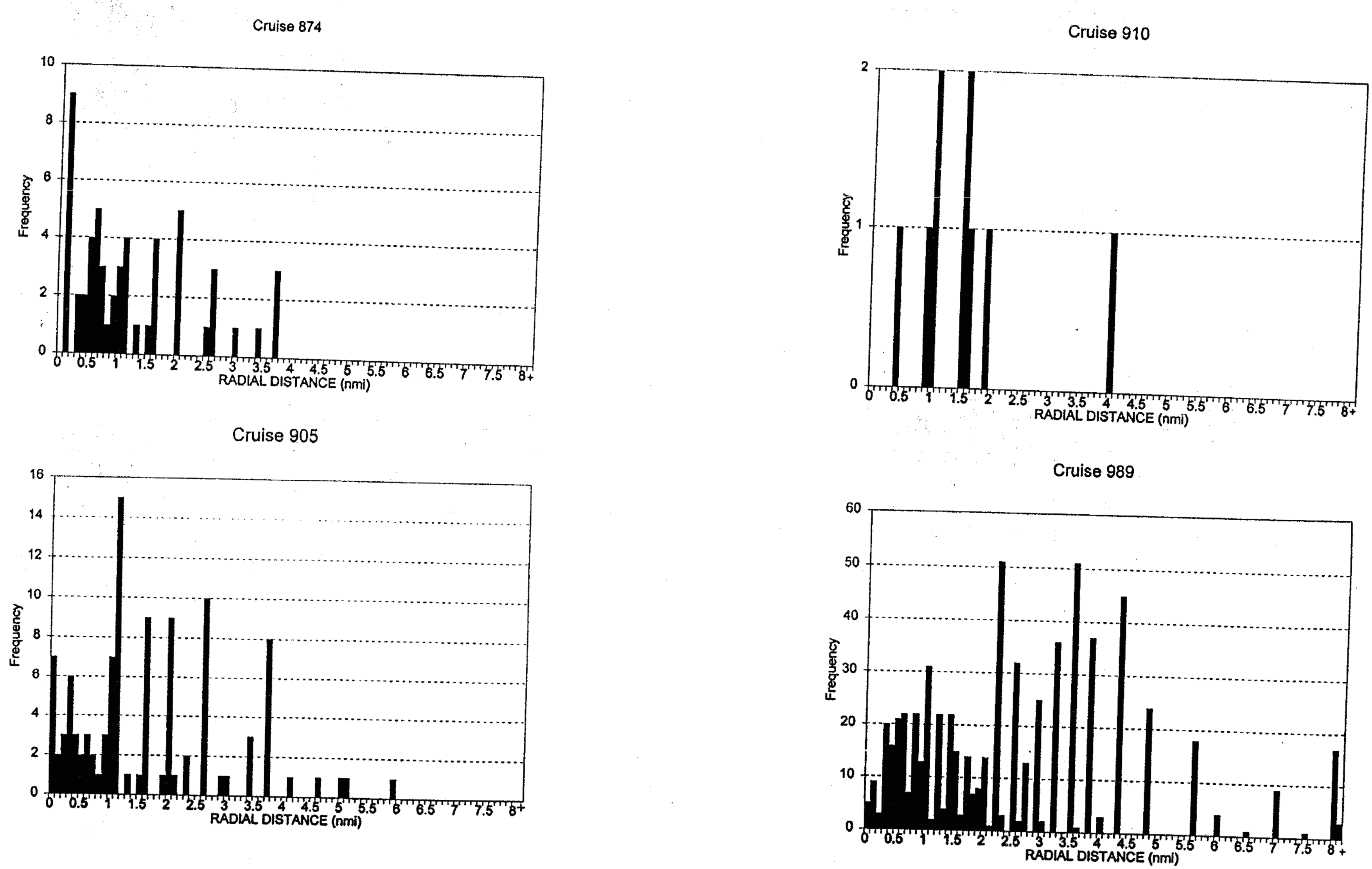
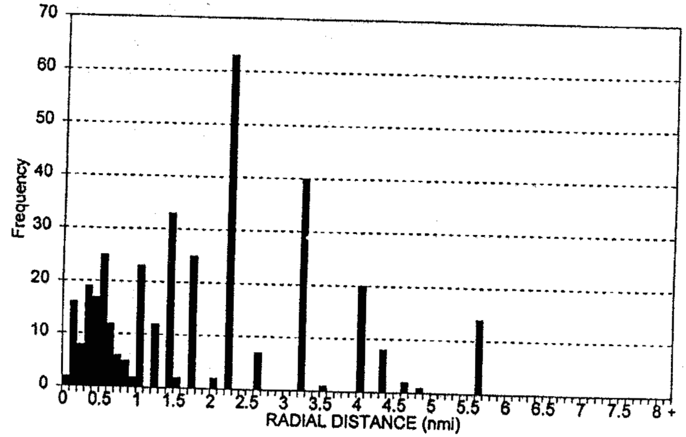
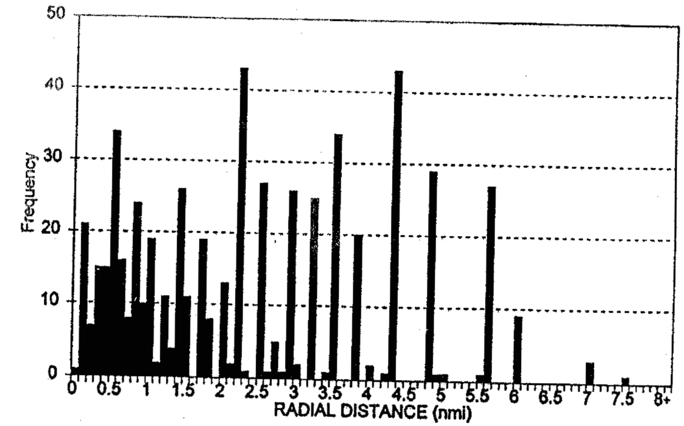


Figure 2. (cont.)

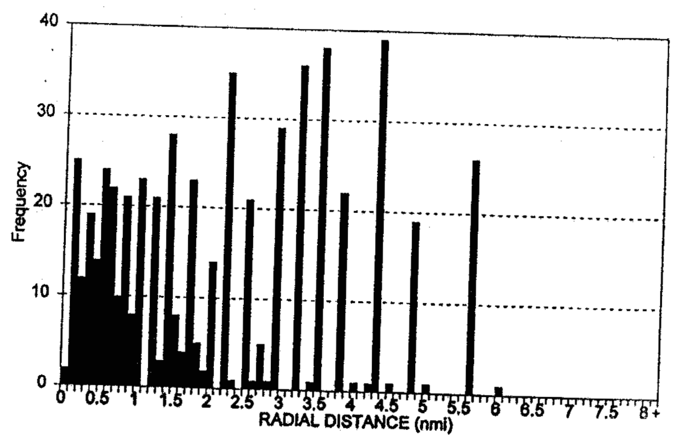
Cruise 990



Cruise 1081



Cruise 1080



Cruise 1164

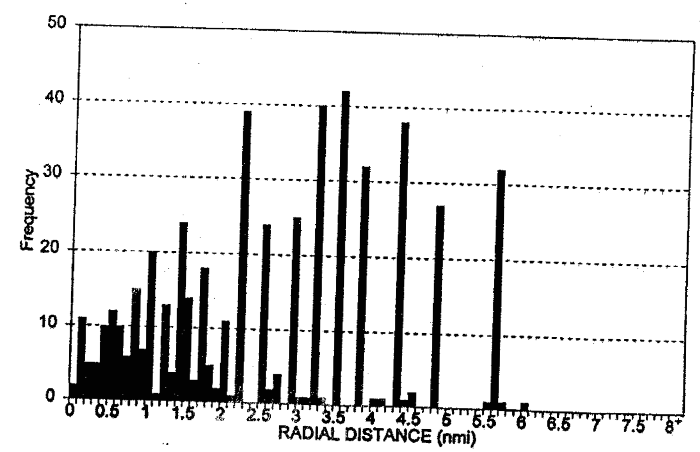


Figure 2. (cont.)

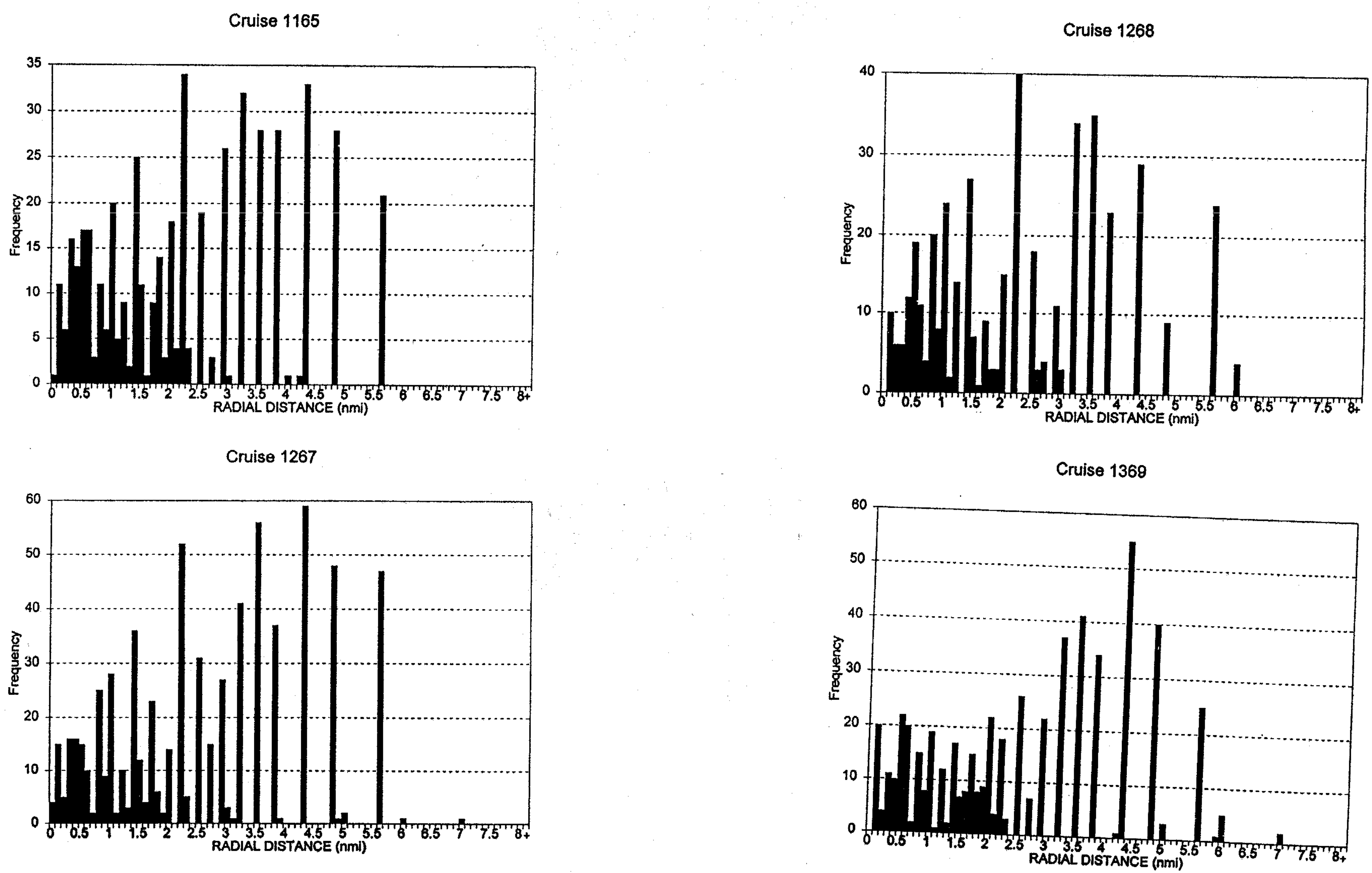
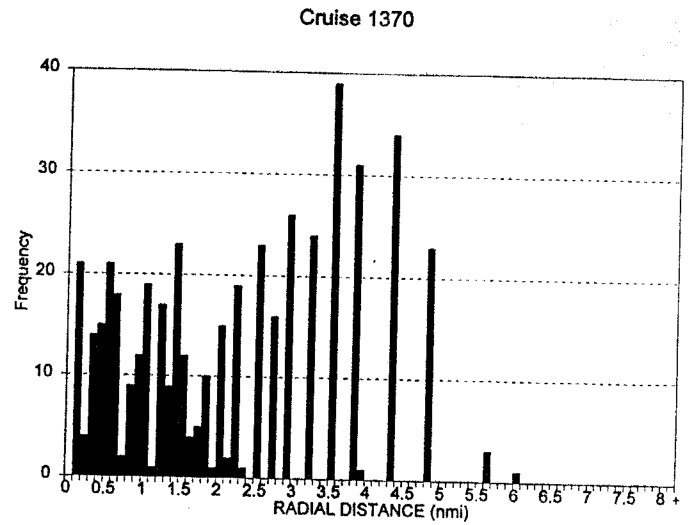


Figure 2. (cont.)



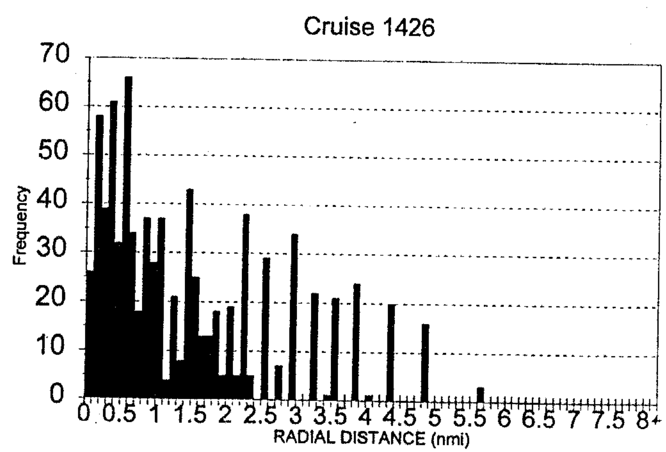


Figure 3. Distributions of sighting angles for all on-effort sightings made on cruises 84 through 1426, including sightings made with 25x and 7x binoculars and by unaided eyes.

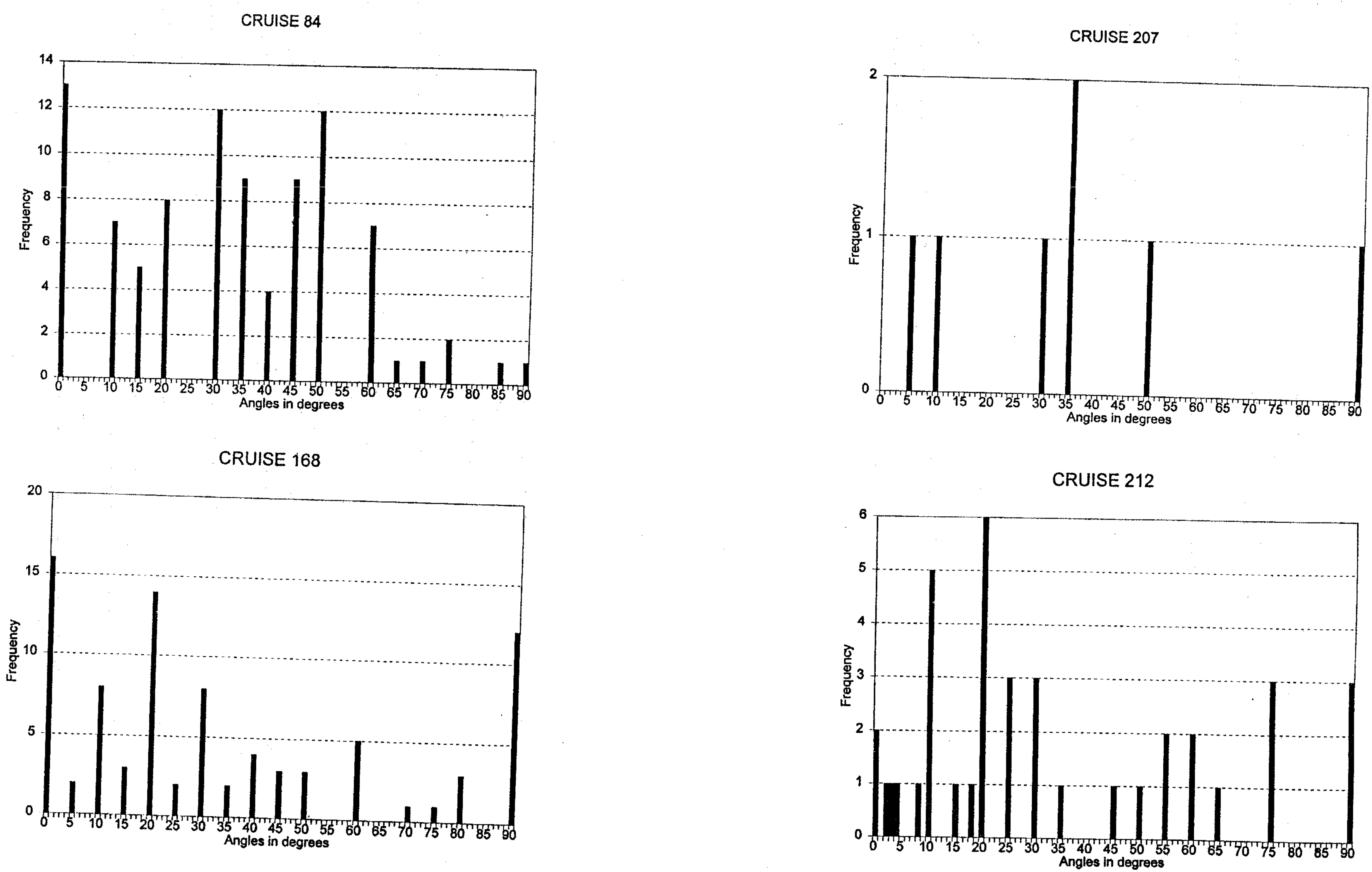


Figure 3. (cont.)

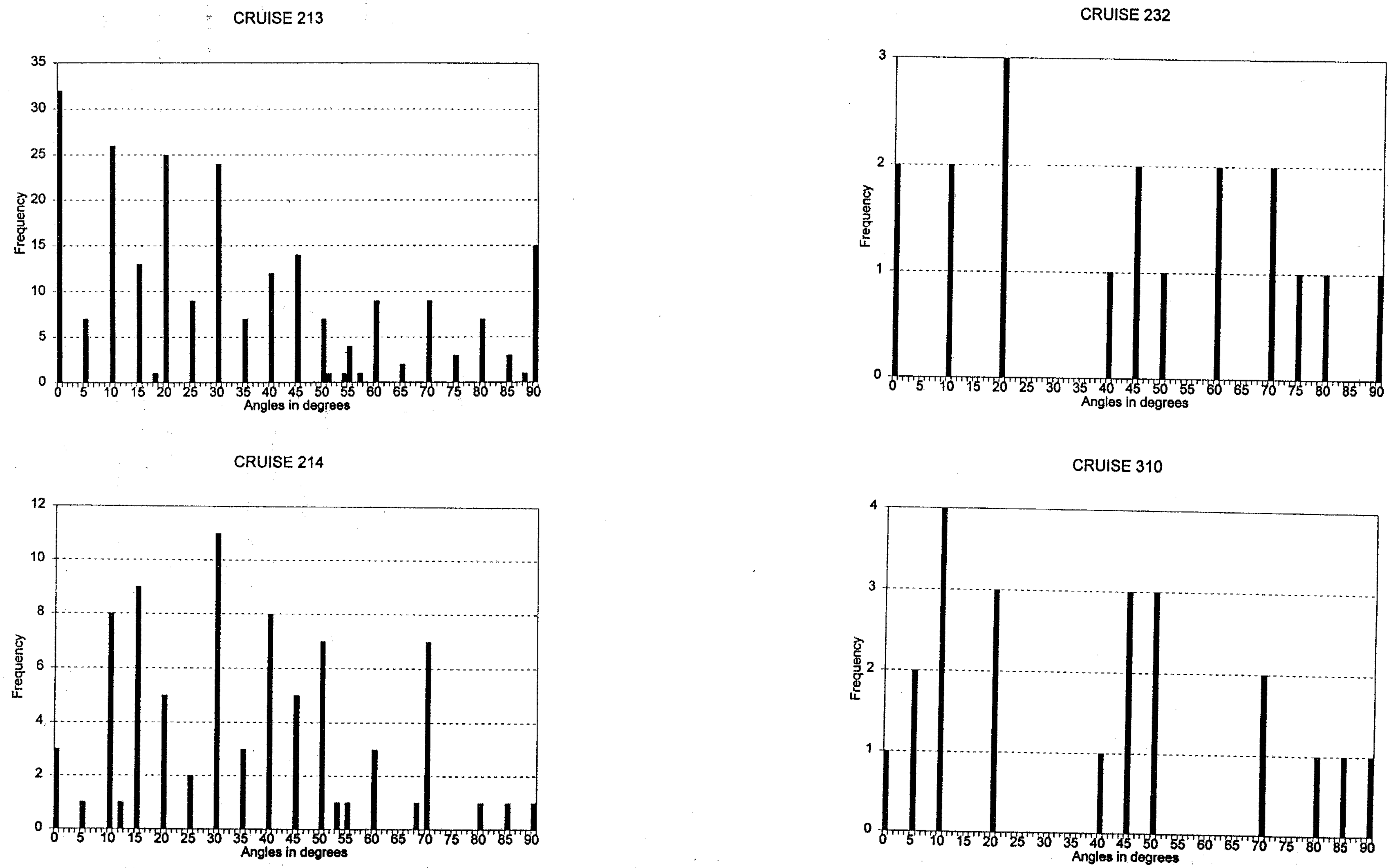


Figure 3. (cont.)

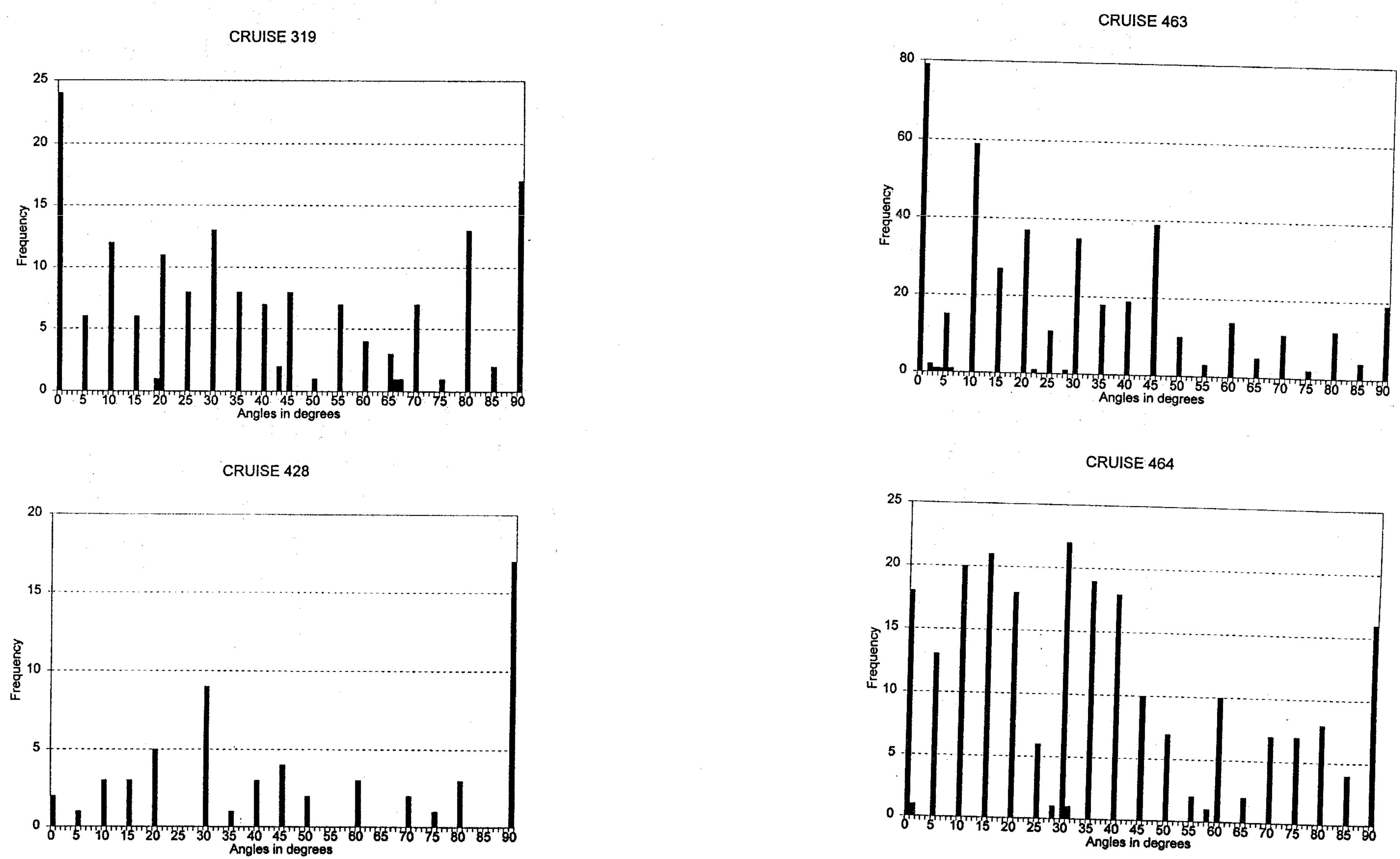
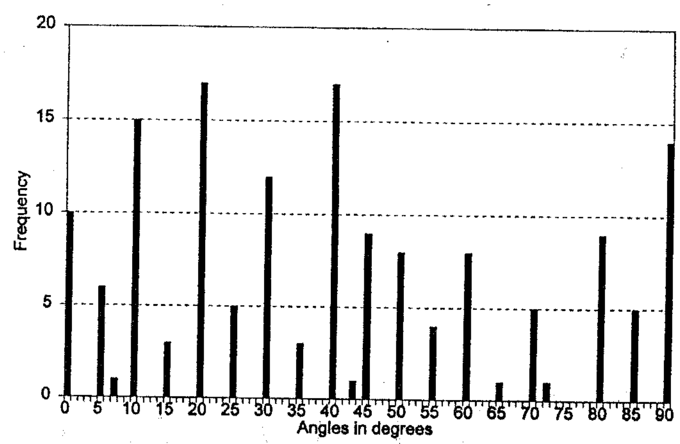
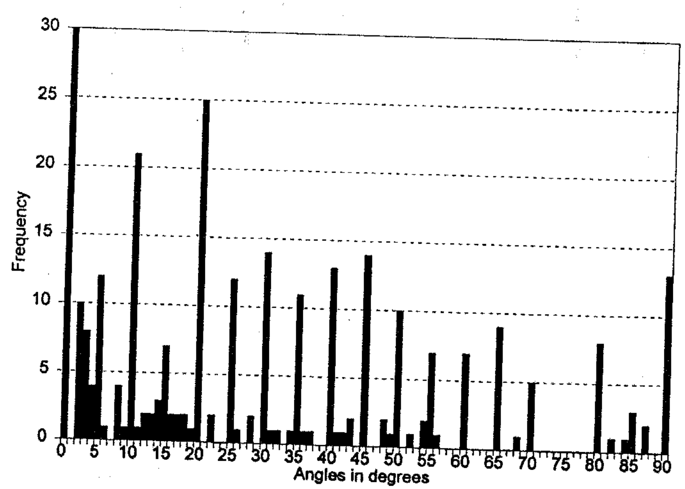


Figure 3. (cont.)

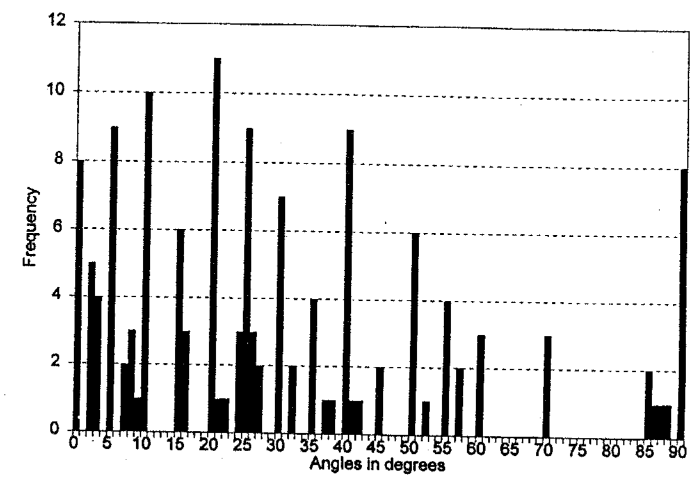
CRUISE 564



CRUISE 598



CRUISE 599



CRUISE 642

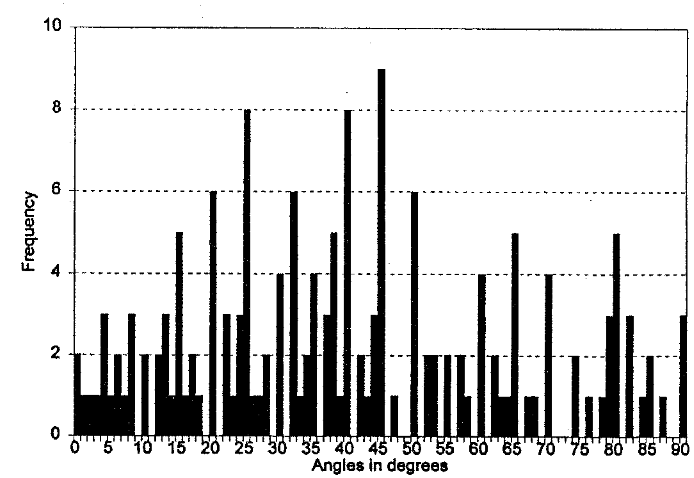


Figure 3. (cont.)

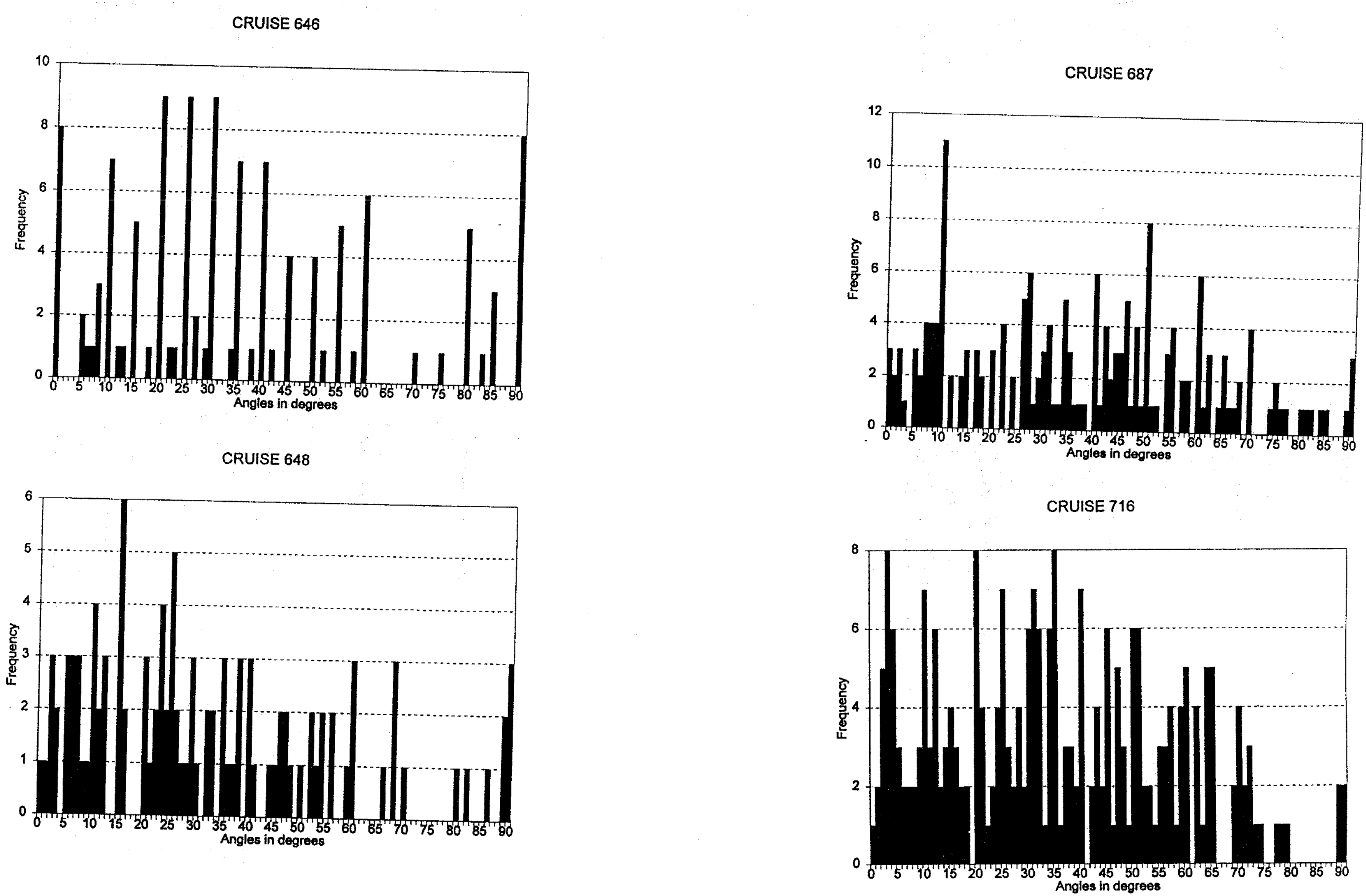


Figure 3. (cont.)

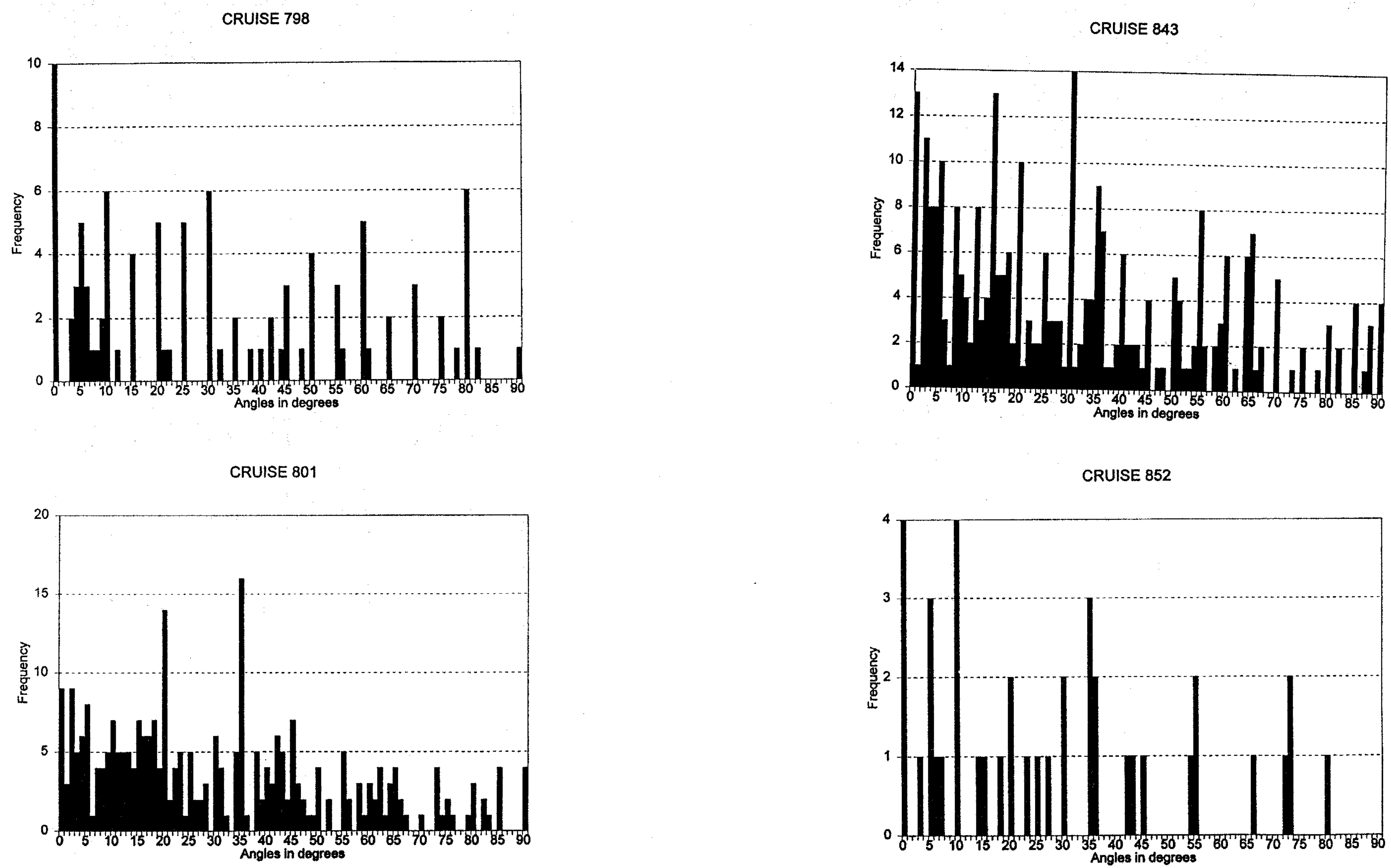


Figure 3. (cont.)

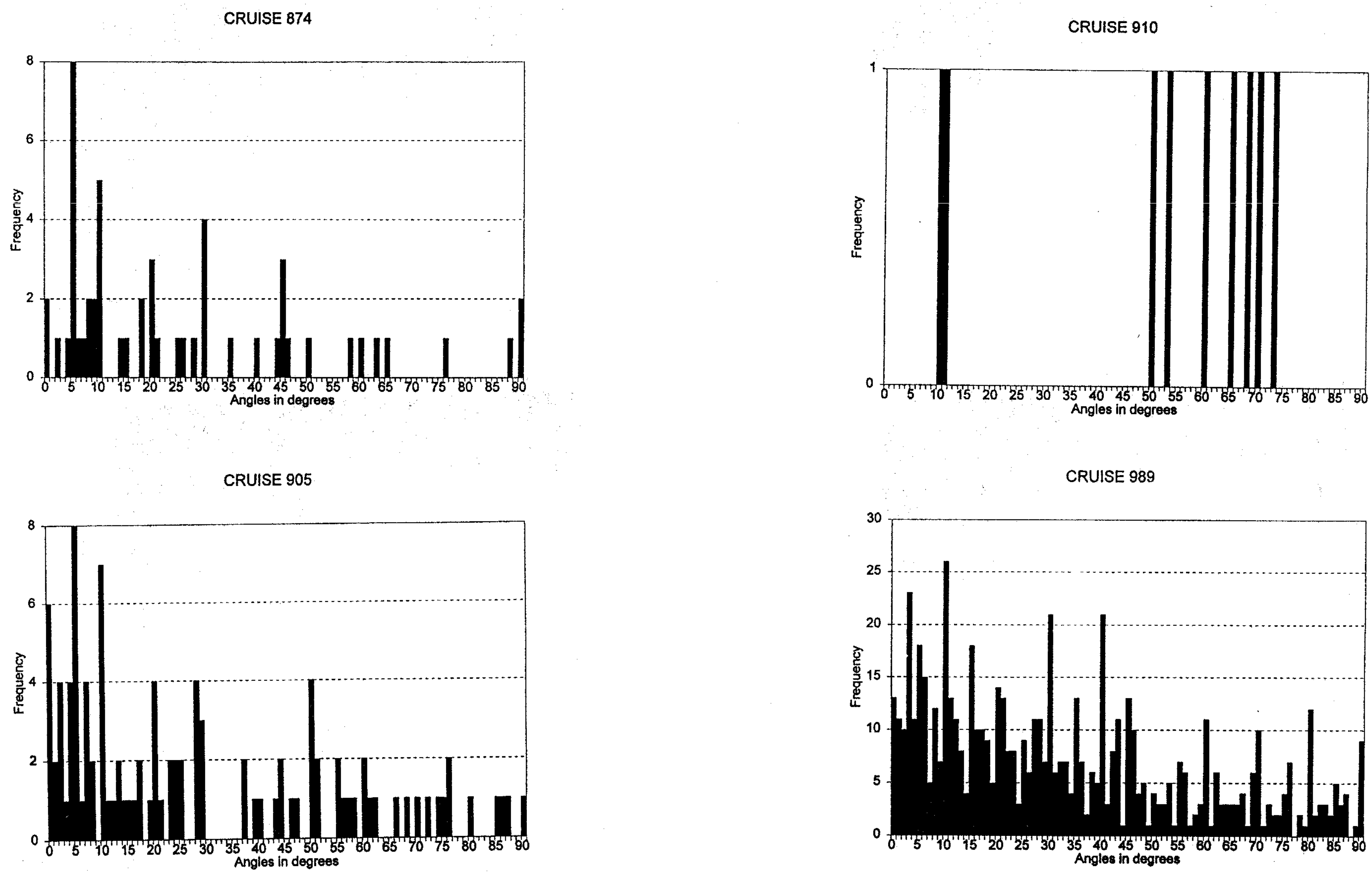


Figure 3. (cont.)

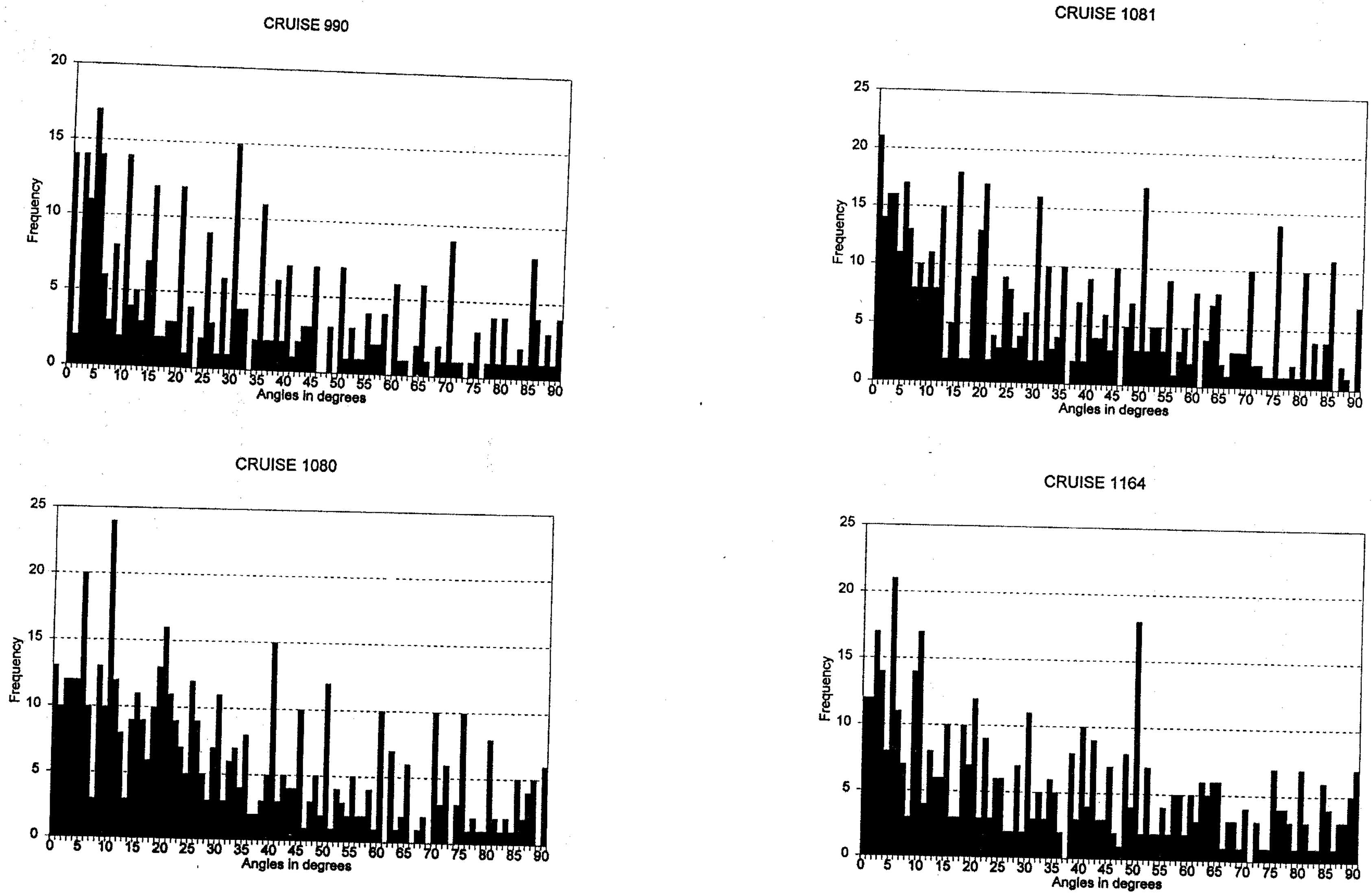


Figure 3. (cont.)

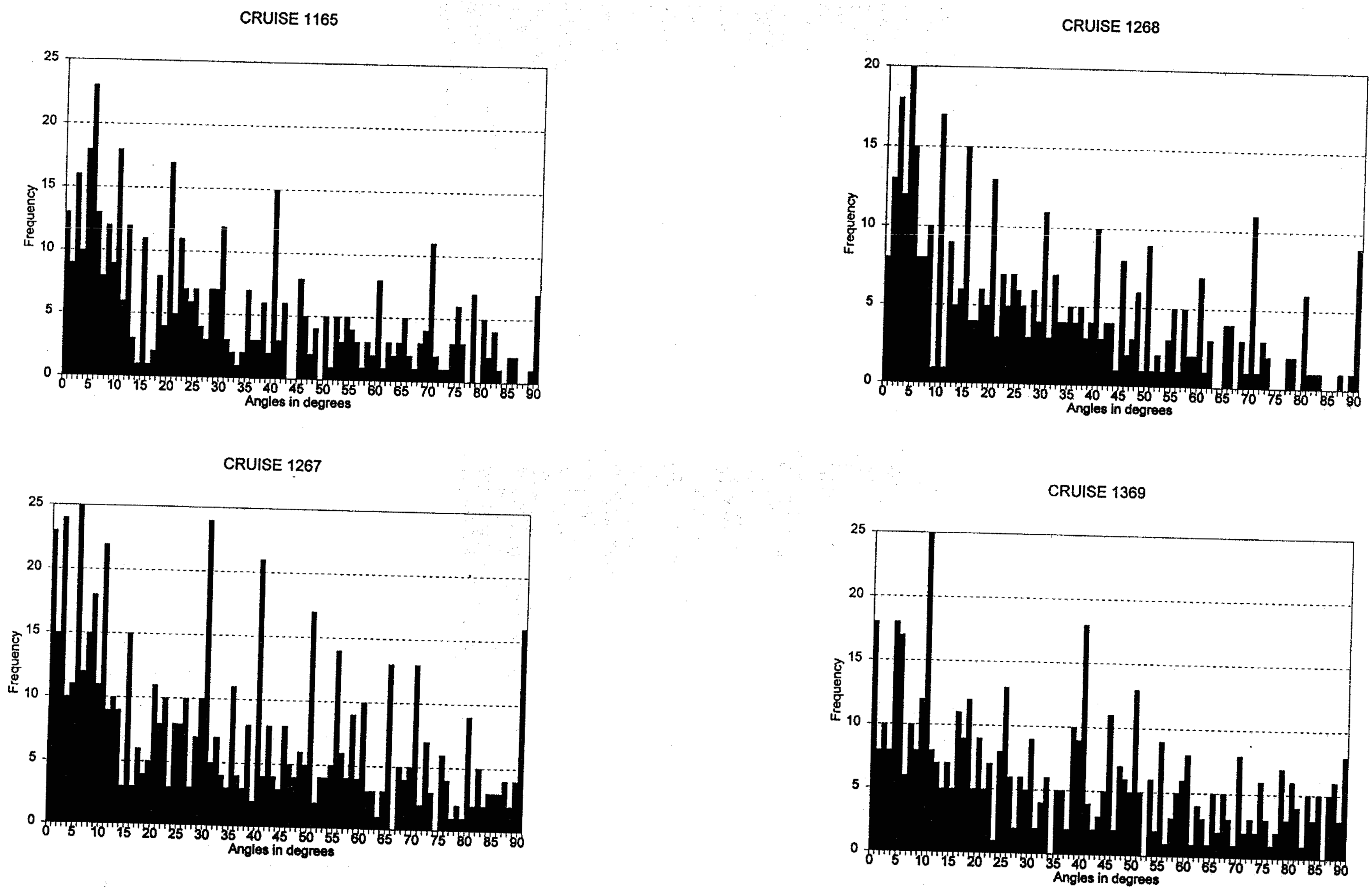
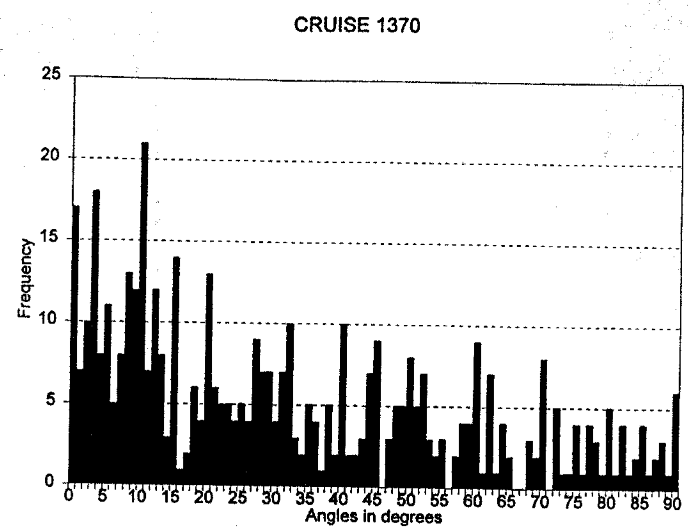


Figure 3. (cont.)



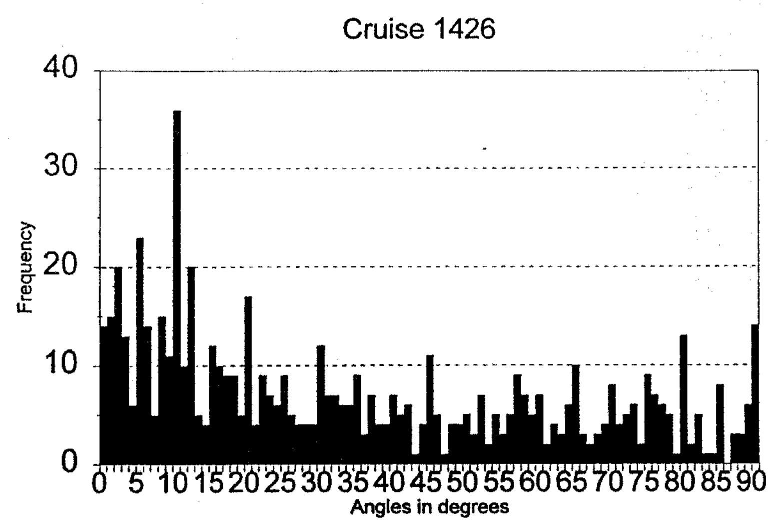


Figure 4. Relationship between distances estimated using Smith's (1982) formula and distances estimated with Barlow's formula for reticle values from 0 to 14.

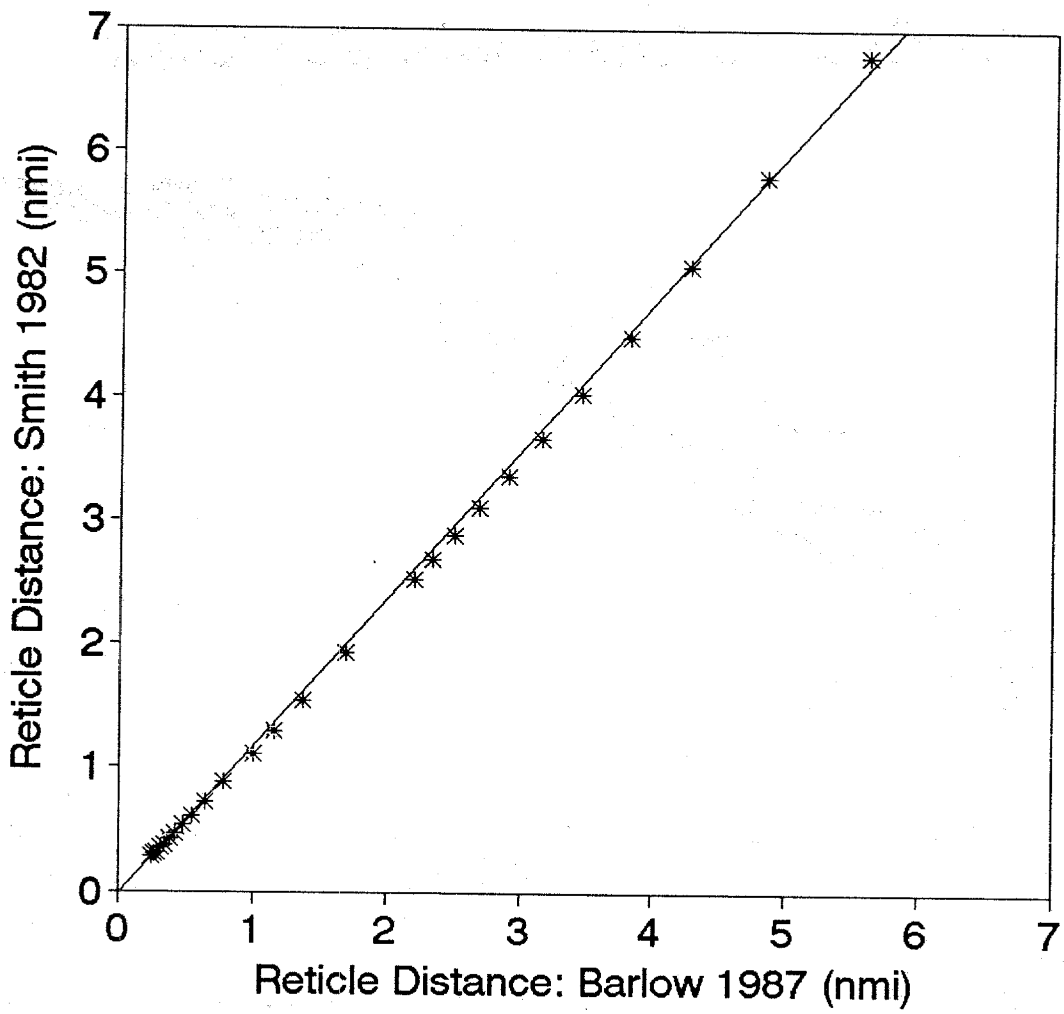


Figure 5. Cumulative distributions of on-effort sighting distances on SWFSC cruises for sightings made with 25x binoculars: a) ETP surveys on the *DAVID STARR JORDAN* (DSJ) without reticles (cruises 463 and 598; n=565); b) California surveys on the *JORDAN* without reticles (cruises 564 and 646; n=203); c) ETP surveys on the *JORDAN* using Smith's formula (cruises 801 and 843; n=498); d) ETP surveys on the *JORDAN* using Barlow's formula (cruises 989, 1080, 1164, 1267, and 1369; n=2,247); e) ETP surveys on the *McARTHUR* (Mac) using Barlow's formula (cruises 990, 1081, 1165, 1268, and 1370; n=1,881); and f) a California survey on the *McARTHUR* using Barlow's formula (cruise 1426; n=643).

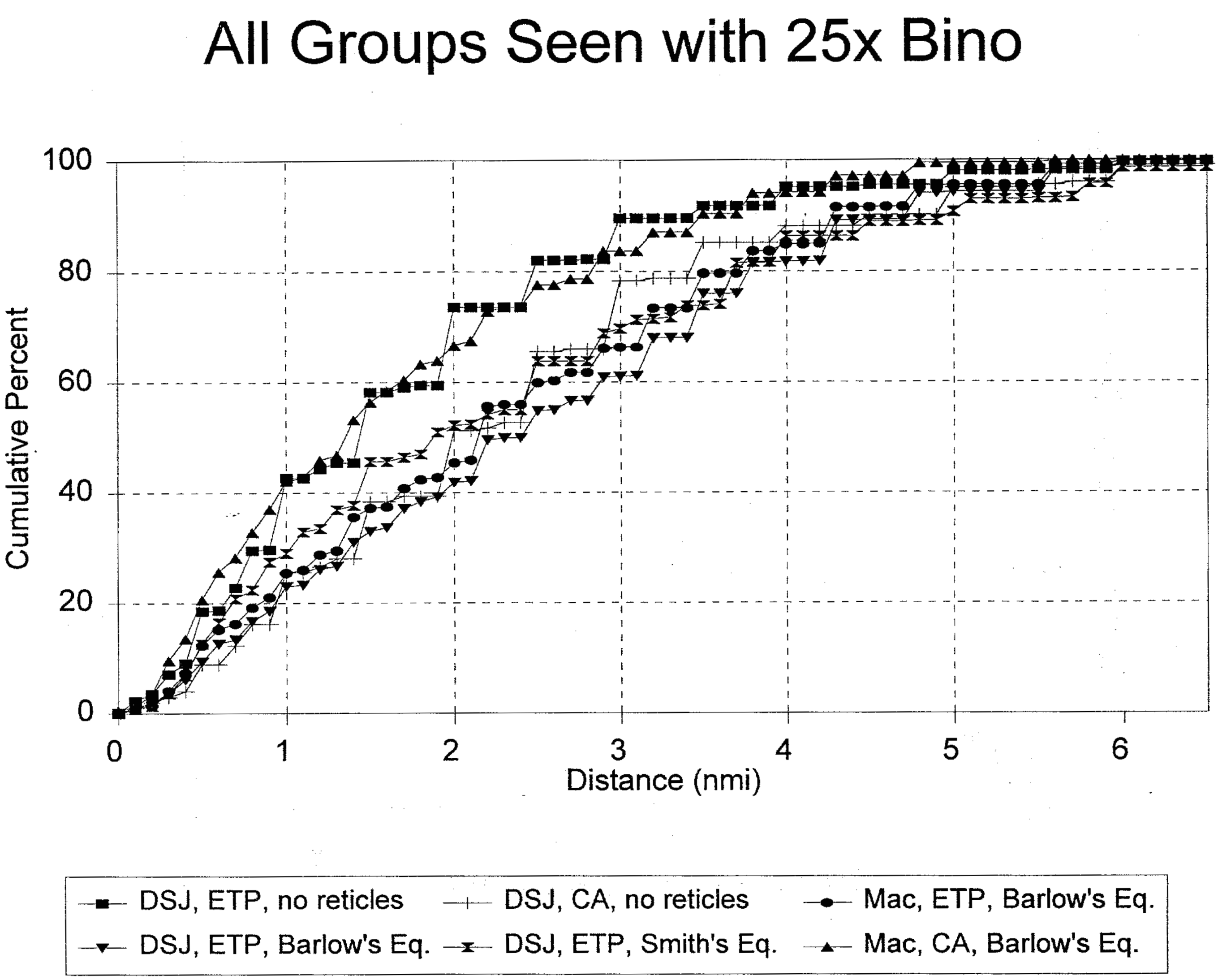
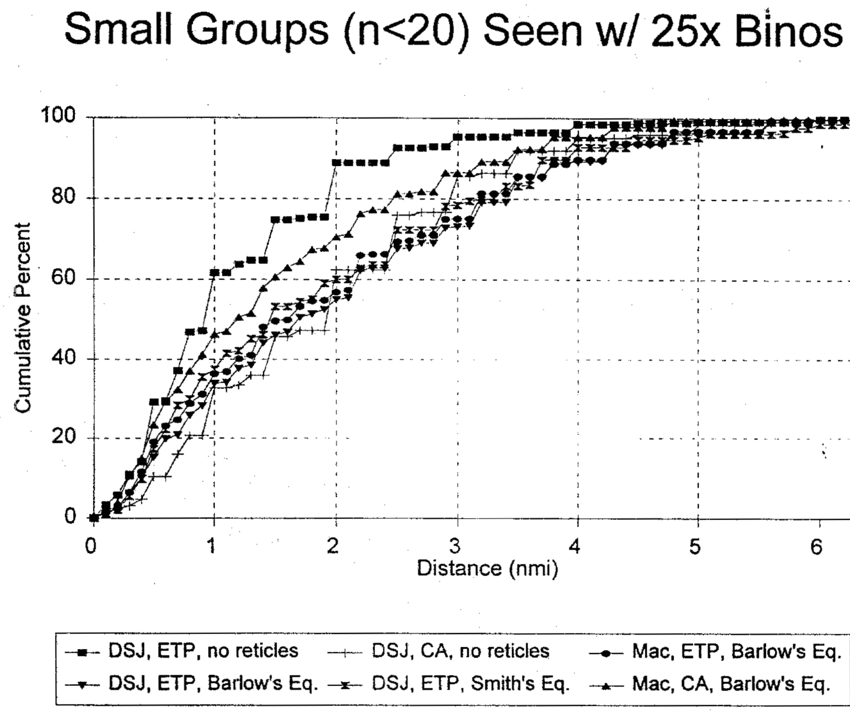


Figure 6. Cumulative distribution of on-effort sighting distances on SWFSC cruises for sightings made with 25x binoculars of groups with a) less than 20 individuals and b) more than 20 individuals. Surveys are grouped as in Figure 5.



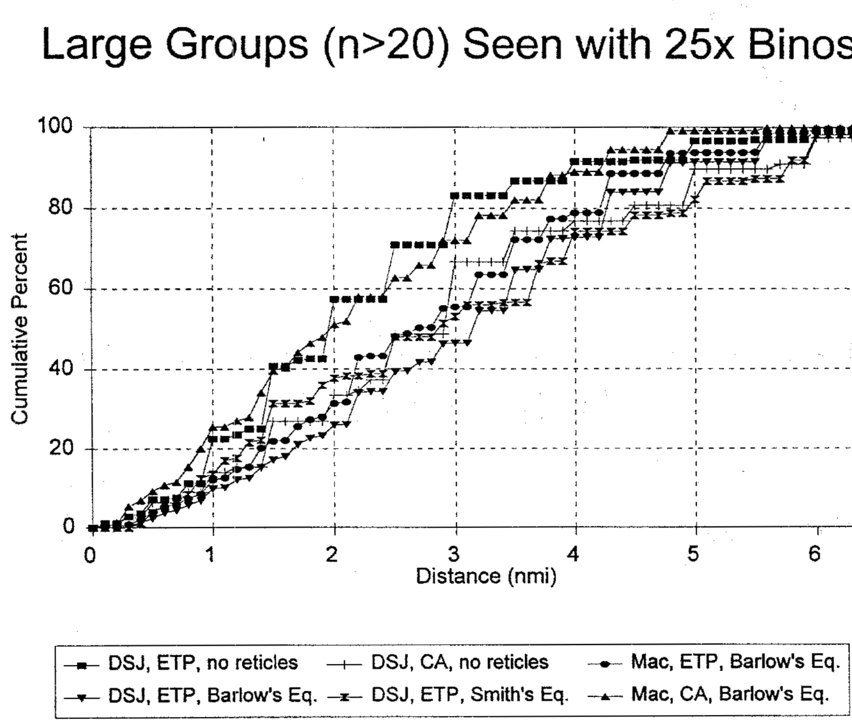
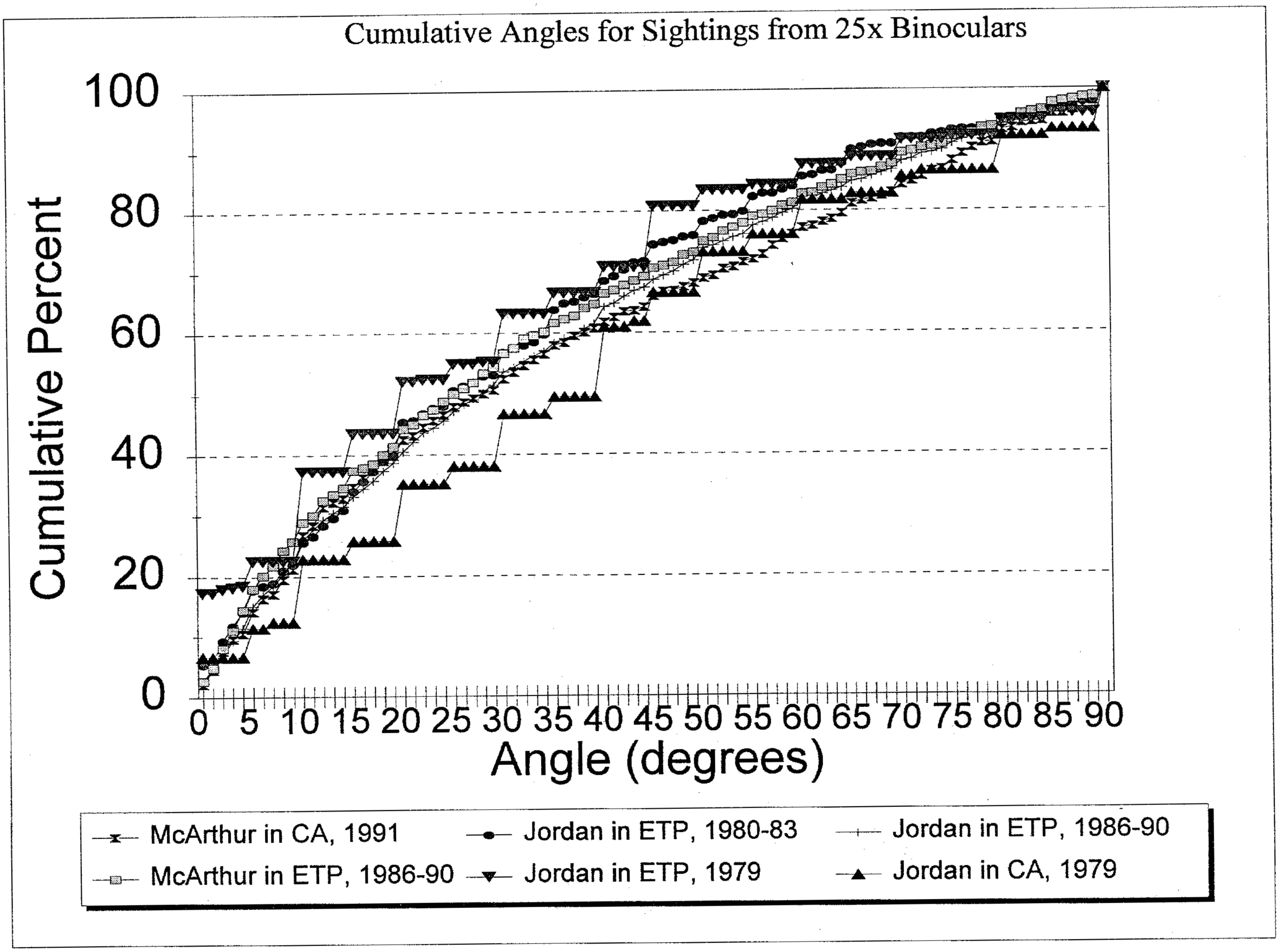


Figure 7. Cumulative distributions of on-effort sighting angles on SWFSC cruises for sightings made with 25x binoculars: a) an ETP survey on the *JORDAN* in 1979 (cruise 463; n=351); b) a California survey on the *JORDAN* in 1979 (cruise 564; n=105); c) ETP and California surveys on the *JORDAN* in 1980-83 (cruises 598, 798, 801, 843, and 905; n=793); d) ETP surveys on the *JORDAN* in 1986-90 (cruises 989, 1080, 1164, 1267, and 1369; n=2,676); e) ETP surveys on the *McARTHUR* in 1986-90 (cruises 990, 1081, 1165, 1268, and 1370; n=2,073); and f) a California survey on the *McARTHUR* in 1991 (cruise 1426; n=642). Angles were estimated "by eye" in 1979 only and were estimated with a calibrated collar after that year.



Appendix 1. FORTRAN program ANG used to extract distributions of sighting angles.

```
**************************************************************************
* THIS PROGRAM OPENS A STREAM TO CRUZDATA FILES AND SUMMARIZES THE  *
* FREQUENCY THAT ANGLES ARE REPORTED. FOR INSTANCE                  *
* THE ANGLE 45 DEGREES WAS REPORTED 15 TIMES
 •
*                                                *
* WRITTEN BY TIMOTHY LEE                                      *
* JUNE 22, 1993                                        *
*                                                *
* This program was modified so as to include only on effort         *
* sightings.                                         *
* Modified by, Timothy Lee                                 *
* Nov 18, 1993                                         *
*                                                *
* Date Last Modified                                     *
* May 9, 1994                                          •
**************************************************************************

*******************************************************************************
*                                                    *
* The input file is of the format                              *
* Angle output file                Name of file to contain all *
*                              the angle data            *
* input file                        Cruise data input file in  *
*                              camms format             *
* input file                        Additional input files     *
* input file                        Additional input files     *
*                                                    *
*                                                    *
*  All of the data from the input files is summarized in one output file *
*  in other words, all counts are accumulations of all the data found in *
*  all the output files.                                      *
*******************************************************************************
      program Ang_for

      character line*100, infile*30, outfile1*30,code*1
      integer Angle(0:360),bearing, total
      logical good_bear, on_eff


****************FORMAT STATEMENTS***********************************************

15    FORMAT(A)
16    format(a7,i3,a7,i3)
17    format(a9,f4.1,a7,i3)

****************MODULE FOR OPENING FILES******************************************
      open(unit=10,file='ang.inp',form='formatted',status='old')
      print*,'open'

      read (10,'(a30)',end=650) outfile1
      print*,'Outfile :', outfile1
30    read (10,'(a30)',end=650) infile
```

```
      print*,'Infile :',infile
      open(unit=1,file=infile,status='old')
      open(unit=2,file=outfile1,status='unknown')
      open(unit=4,file="AngDist.err",status='unknown')

****************INITALIZATIONS**************************************************
      do 40 i=0,360
       angle(i)=0
40     continue

      total=0
      on_eff=.false.

****************MAIN PROGRAM******************************************************

50     read(1,15,end=610) line
      code=line(4:4)

****Determining whether sighting was made on or off effort**********************
    If(code.eq.'B' .or. code.eq.'R') then
      on_eff=.true.
    endif

    if(code.eq.'E') then
    on_eff=.false.
    endif
****If the sighting wasn't on effort skip and read next line*******************
    if(.not.on_eff) goto 50
       if(code.ne.'S') goto 50
**READ IN THE BEARING AND DISTANCE. This next line checks that there is
*a bearing recorded and that the observers were on a 25x binoculars.
*If want to include the angles recorded by all observers, remove
* the " .and. line (59:59).eq.'4' " statement
        if(line(61:64).ne.'    '.and. line(59:59).eq.'4') then
          read(line(61:64),'(i4)')bearing
          good_bear=.true.
        else
         print*,'no bearing or not observer on 25x binocs'
         good_bear=.false.
         write(4,15) line
        endif

        if(good_bear) then
         if(bearing.gt.180) bearing=abs(bearing-360)
         Angle(bearing)=Angle(bearing)+1
        endif

      goto 50

610   close(1)
     read (10,'(a30)',end=500) infile
     open(unit=1,file=infile,status='old')
     goto 50
```

```
500    continue

c WRITNG THE OUTPUT TO THE FILES. THE ANGLES ARE ONLY SUMMARIZED FOR
c 0-90 DEGREES. IF YOU WANT 0-180 CHANGE THE PARAMETERS OF THE DO LOOP
c to i=0,180.
      do 550 i=0,90
       write(2,16)'ANGLE: ',i,' COUNT ',Angle(i)
550    continue



650    end
```

Appendix 2. Paradox script program GRAPHDST used to extract distributions of sighting distances.

```
method run(var eventInfo Event)
{This program summarizes the reported distances for cruise data in the "DAS"
format. It was written in ObjectPAL the Paradox for Windows application
language.
 Written by Timothy Lee for the SWFSC
 Last Modified May 9, 1994
}

 var
  DasFile, OutputSpecs Textstream
  IndexNames Array[] String
  inputLine, Code, TableName, Groupsize, SeaState, Strat, DataFileName  String
  StratBySeaState, StratByGSize, on_eff, validSighting Logical
  TableArray DynArray[] TABLE
  TempTable Table
  Beauf, dist, NumOfTables,Total Number
  position LongInt
  group_size DynArray[] number
  DistTableTC, ErrorTC TCursor
 endVar

;Initializations
 SeaState=""
 GroupSize=""
 On_Eff=FALSE
 Total=0
 ValidSighting=FALSE
 ErrorTC.open("Error.db")


 OutputSpecs.open("angdist.inp","R") ;Opening the file input spec file in read only.

;Reading in the StratBySeaState
 OutputSpecs.readline(inputLine)
 StratBySeaState=logical(inputLine)

;Reading in StratByGSize option
 OutPutSpecs.readline(inputLine)
 StratByGSize=logical(inputLine)

;Reading the name of the output tables
 OutPutSpecs.readLine(TableName)


;Determining the number of tables to create.
Switch
 case(StratByGSize and StratBySeaState) : Strat="Stratified "
                                           NumOfTables=4
 case(StratByGSize): Strat="Stratified "
                     NumOfTables=2
 case(StratBySeaState): Strat="Stratified "
                        NumOfTables=2
 otherwise: Strat="Lumped"
            NumOfTables=1
endSwitch
```

```
;creating the number of tables to be filled with data
 for i from 1 to NumOfTables
  if (StratByGSize and not StratBySeaState) then
   if i.mod(2)=0 then
    GroupSize="BigGroup"
   else
    GroupSize="SmallGroup"
   endif
  endif

  if(StratBySeaState and not StratByGSize) then
   if i.mod(2)<>0 then
    SeaState="BadBeauf"
   else
    SeaState="GoodBeauf"
   endif
  endif

  if(StratBySeaState and StratByGSize) then
   if i>2 then
    SeaState="BadBeauf"
   else
    SeaState="GoodBeauf"
   endif

   if i.mod(2)=0 then
    GroupSize="BigGroup"
   else
    GroupSize="SmallGroup"
   endif
  endif
  TableArray[Strat+SeaState+GroupSize]=CREATE (TableName+string(i)+".db")
                               like "Template.db"
                                  key "Distance"
                               endCreate
  DistTableTC.open(TableArray[Strat+SeaState+GroupSize])
  DistTableTC.edit()
  DistTableTC.insertRecord()
  Description=Strat+ SeaState + GroupSize
  DistTableTC.Description=Description
   for dist from 0 to 8.1 step .1
    DistTableTC.insertRecord()
    DistTableTC."Distance"=dist
    DistTableTC."Count"=0
   endFor

  DistTableTC.close()
 endfor

;Reading in the name of the cruise data files
 while (not OutputSpecs.eof() )
  OutputSpecs.ReadLine(DataFileName)
  DasFile.open(DataFileName,"r") ;Opening the stream to the data file

  while(not DasFile.eof())
   DasFile.readLine(inputLine) ;read in a data line
```

```
   code=inputLine.substr(4,1) ;get the event code


   if code="B" or code="R" then ;Begining of effort
    on_eff=TRUE
   endif

   if code="E" then ; End of Effort
    on_eff=FALSE
   endif

   if (not on_eff) then
    loop
   endif
;get the Beauf
   if (StratBySeaState) then ;if stratifying by seastate
    if code="V" and inputLine.size() >=44  then      ;then get the beufort from the 'v' line
     if(inputline.substr(43,2)="  ") then
      ErrorTC.edit()
      ErrorTC.insertRecord()
      ErrorTC."Error Line"=inputLine
      ErrorTC."Description"="No Beauf"
      loop
     endif

     Beauf=number(inputline.substr(43,2) )
     if Beauf<4 then
      Seastate="GoodBeauf"
     else
      SeaState="BadBeauf"
     endif
    endif
   endif

;Getting the distance
  if (code="S") then
   switch
   case inputLine.size() < 74:
    validSighting=FALSE
   case inputLine.substr(71,4)="  . " or inputLine.substr(71,4)="    ":
    validSighting=FALSE
   case inputLine.substr(59,1)<>"4":
    validSighting=FALSE
   otherwise:
    dist=number(inputLine.substr(71,4) )
    dist=dist.round(1)
    if dist>8.1 then dist=8.1 endif
    validSighting=TRUE
;Advance past the "A" line
    DasFile.readline(inputLine)
    loop
   endswitch
  endif

;Get the group size estimate
   if (StratByGSize and ValidSighting) then ;If they have requested to stratify by group size
```

```
    if code="1"  then
     position=DasFile.position()
     if(inputline.substr(46,4)="    ") then ;and there is a value in the group size estimate
      ErrorTC.edit()
      ErrorTC.insertRecord()
      ErrorTC."Error Line"=inputLine
      ErrorTC."Description"="No Group Size"
     else
      group_size[code]=number(inputLine.substr(46,4) ) ;store the 1st estimate in an array
     endif


     while(not DasFile.eof())
      DasFile.readLine(inputLine) ;read in a data line
      nextcode=inputLine.substr(4,1)
      if nextcode <> String(int(code) + 1)  then ;if the next line is not another observers
       DasFile.SetPosition(position)             ; estimate. Go back to previous line. then
       quitLoop                                  ; make group size estimate
      else
       if(inputline.substr(46,4)="    ") then ;if there is no group size estimate flag an error
        ErrorTC.edit()
        ErrorTC.insertRecord()
        ErrorTC."Error Line"=inputLine
        ErrorTC."Description"="No Group Size"
        code=NextCode
       else
        position=DasFile.position() ;line has valid estimate-> extract est. & move place holder
        group_size[NextCode]=number(inputLine.substr(46,4) )
        code=NextCode
        loop
       endif
      endif
     endWhile
;Calculating the estimated group size. The average of the observers best est.
     Group_Size.getKeys(IndexNames)
      if IndexNames.size() <> 0 then
       for i from 1 to IndexNames.size()
        Total=Total + Group_Size[IndexNames[i]  ]
       endfor
       AvgGroupSize= Total/IndexNames.size()

;Reset all the values. Clear board for next calculation
       Total=0
       IndexNames.empty()
       Group_Size.empty()
       if AvgGroupSize<20 then
        GroupSize="SmallGroup"
       else
        GroupSize="BigGroup"
       endif
      else
       validsighting=FALSE
      endif; if indexNames.size()<>0
    endif;if (code="1")
   endif ;if (stratbyGsize and ValidSighting)
```

```
    if(ValidSighting) then
     DistTableTC.open(TableArray[Strat+SeaState+GroupSize])
     DistTableTC.edit()
     DistTableTC.Locate("Distance", dist)
     DistTableTC.Count=(DistTableTC.Count + 1)
     DistTableTC.close()
     ValidSighting=FALSE
    endif



   endWhile

  endWhile



endmethod
```

RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167. Paper copies vary in price. Microfiche copies cost $9.00. Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-197 Hook-and-line fishing study at Cordell Bank, California, 1986-1991.
M.B. ELDRIDGE
(February 1994)

198 Small cetacean dissection and sampling: A field guide.
T.A. JEFFERSON, A.C. MYRICK, JR., and S.J. CHIVERS
(April 1994)

199 A recharacterization of the age-length and growth relationships of Hawaiian snapper, *Pristipomoides filamentosus.*
E.E. DEMARTINI, K.C. LANDGRAF, and S. RALSTON
(May 1994)

200 Report on cetacean sightings during a marine mammal survey in the eastern tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan.*
K.F. MANGELS and T. GERRODETTE
(May 1994)

201 Research plan to assess marine turtle hooking mortality: Results of an expert workshop held in Honolulu, Hawaii, November 16-18, 1993.
G.H. BALAZS and S.G. POOLEY
(June 1994)

202 Recent information on the status of odontocetes in Californian waters.
K.A. FORNEY
(June 1994)

203 Recent information on the status of large whales in California waters.
J. BARLOW
(June 1994)

204 Development of an airborne LIDAR system to detect tunas in the eastern tropical Pacific purse-seine fishery.
C.W. OLIVER, W.A. ARMSTRONG, and J.A. YOUNG
(June 1994)

205 An assessment of the 1994 status of harbor porpoise in California.
J. BARLOW and K. FORNEY
(June 1994)

206 The Hawaiian monk seal on Laysan Island, 1990.
K.B. LOMBARD, B.L. BECKER, M.P. CRAIG, G.C. SPENCER, and K. HAGUE-BECHARD
(June 1994)