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TESTING METHODS OF ESTIMATING RANGE AND BEARING TO CETACEANS ABOARD THE R/V D. S. JORDAN

Tim D. Smith

NOAA-TM-NMFS-SWFC-20

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

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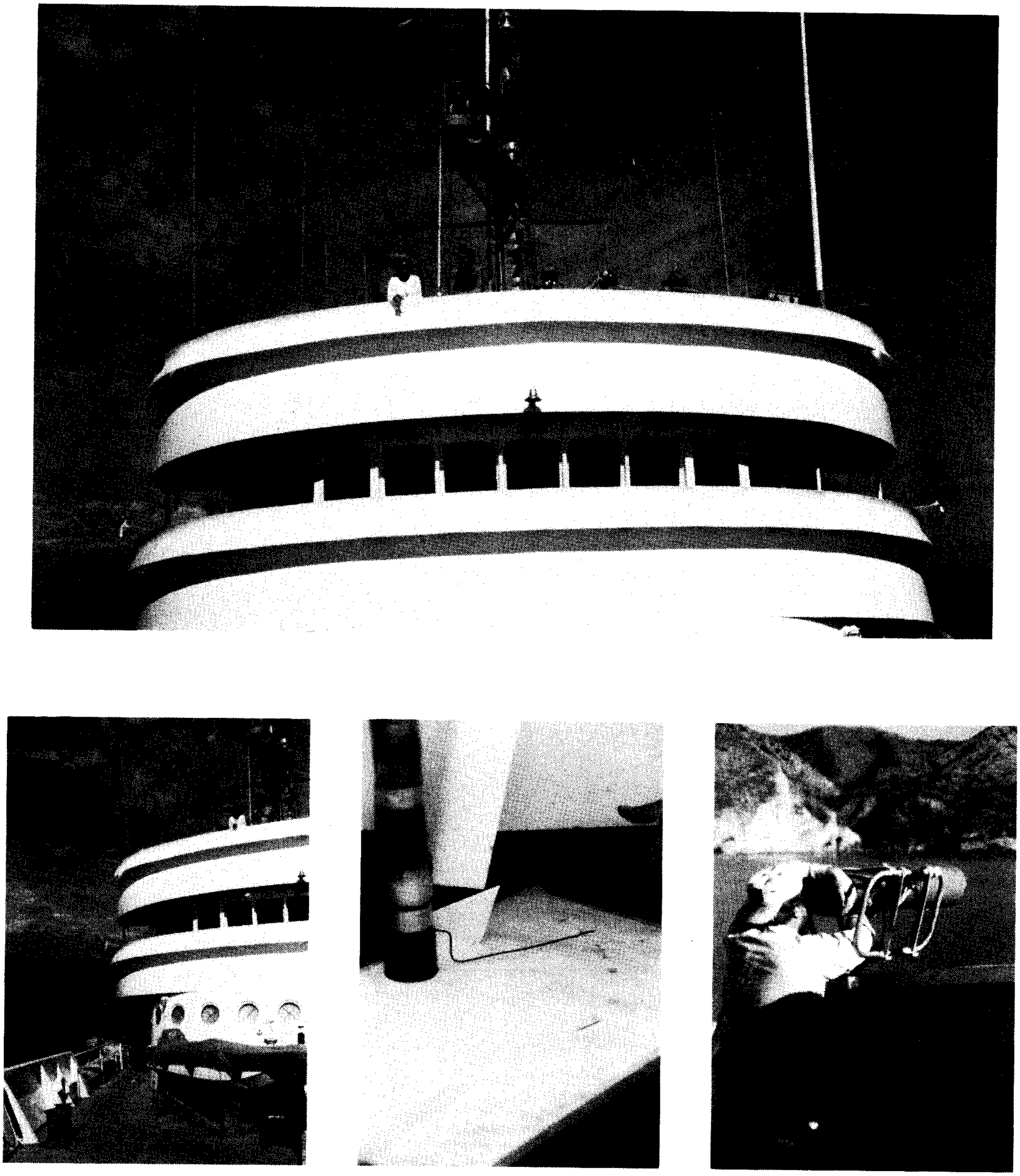

PLACEMENT AND USE OF 25 POWER BINOCULARS BOARD THE R/V D. S. JORDAN DURING SIGHTING SURVEYS IN THE EASTERN TROPICAL PACIFIC.

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INTRODUCTION

There have been several attempts to apply line-transect density estimation theory to shipboard cetacean sighting data. The primary interest has been in obtaining absolute or relative estimates of the density of cetaceans. Line transect techniques use information on the distances at which cetaceans are sighted to account implicitly for visibility limitations. In general, a decreasing fraction of the cetaceans is detected with distance from the ship and its trackline. The rate of decrease of the probability of detecting cetaceans with distance varies with visibility conditions.

Line transect theory was developed with the assumption that all of the objects or animals which are directly on the trackline being searched are detected. When sighting cetaceans from a ship, this assumption can be violated if some of the animals are missed because they are submerged, or if they simply are not seen as the ship approaches. An additional assumption made in line-transect theory is that the animals do not move away from the trackline prior to being detected. If either of these assumptions is violated, the number of animals sighted directly on the trackline will not be representative of the number which were actually on the trackline, and the distance to the animals will not be representative of the true distances from the trackline.

An important aspect of line transect theory is that the location of the sighted animals relative to the ship must be determined. Early developments of the theory assumed that the distance from the sighted object to the observer or to the trackline being traversed was determined without error. In practice aboard ships, the distance and the bearing to sighted cetaceans are determined at best inexactly, and with crude precision.

If the assumptions of line transect theory are met, it is theoretically possible to obtain estimates of absolute abundance of cetaceans solely from shipboard sighting data. This has been attempted recently by Best and Butterworth (1980) and Horwood (1980) for southern hemisphere minke whales, using data from Japanese whale scouting vessels. These authors had difficulties in fitting line transect models to their sighting data and they speculated on several possible violations of the theory's key assumptions.

Smith (1975[1]) used sighting data collected aboard tuna fishing vessels in 1974, in conjunction with sighting data from an aerial survey, to obtain an absolute abundance estimate of spotted and spinner dolphins, concluding that absolute estimates from the ship data alone were not possible. Hammond (1981[2]) used sighting data collected aboard tuna fishing vessels from 1974 through 1979 to examine possible trends in abundance of dolphins, concluding that several questions must be answered before absolute abundance estimates are possible from these data. Both authors used the available data pooled for all cruises within years. A reassessment of this data set is currently underway, starting with a by-cruise examination of data consistency, accuracy, area sampled, and sea state, and including data on other aspects of the fishing trip.

Holt and Powers (MS[3]) analyzed similar dolphin sighting data collected aboard research vessels, concluding that it was not possible to use those data in line transect models. They noted an unexpected shape of the frequency distribution of right angle distances, possibly due to schools avoiding the ship as noted above. In lieu of using line transect methods in a relative context, Holt and Powers used numbers of sightings per trackmile searched, stratified by sea state, as a measure of relative density of schools.

The right angle distances (D) from the trackline to the cetaceans have generally been estimated from estimates of range (R) and bearing (B) at the time of sighting, as D = R Sin (B). The estimates of R and B have usually been visual, made without an actual measuring device. In the Antarctic minke whale studies, ranges to sighted whales were estimated from the time needed to approach the sighted whale and the vessel speed. These estimates do not appear to be very precise, generally with angles recorded to 5 or 10 degrees and distances to half mile intervals, and are properly treated as grouped data. The statistical properties of the derived right angle distances D are unknown. Additionally, visual estimates of distances at sea are generally difficult, with large differences between observers, low precision and possible bias.

The purpose of this paper is to report results of a series of brief experiments I made aboard the R/V _David Starr Jordan_ in October 1979, SWFC cruise 564, aimed at exploring the problems with visual estimation, and evaluating two methods for actually measuring angles and distances to

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[1]Smith, T. D. 1975. Estimates of Two Populations of Porpoise (_Stenella_) in the eastern tropical Pacific Ocean. _Southwest Fisheries Center Admin. Rep._ LJ-75-67.

[2]Hammond, P. 1981. Estimating the density of dolphin populations in the eastern tropical Pacific using data collected aboard tuna purse seiners. Draft internal report of the Inter-American Tropical Tuna Commission, La Jolla, California.

[3]Holt, R. and J. Powers. 1981. Abundance estimation of dolphin stocks involved in the eastern tropical Pacific yellowfin tuna fishery determined from aerial and ship surveys (Manuscript).

cetaceans.

MATERIALS AND METHODS

The ship used for the experiments was the R/V D. S. Jordan. It is 171 feet long, 900 tons displacement, and cruises at approximately 10 knots. Searching is conducted from the flying bridge, through two 25x sling mounted binoculars (Fuji Meibo 25 x 150) and with smaller hand held binoculars. The large binoculars have a 2.7^{o} field of view. The flying bridge is approximately 30 feet above the water, and the binoculars are mounted approximately 5 feet above the deck. The sighting team members alternate between searching with the 25x binoculars and hand-held binoculars, and search for dolphins in a sweep from slightly across the bow to directly behind the ship. Search patterns within this field are determined by the individual scientists.

The five-person sighting team on SWFC cruise 564 carried out three separate experiments under my direction. After the cruise a fourth experiment was conducted on land to check the calibration of the reticles.

To obtain more accurate measurements of bearing to the sighted cetaceans, a device consisting of a stiff wire that rotated with the binoculars was attached to the right-hand 25x binoculars stand. Paper was attached to the deck around the binoculars stand, and pencil marks were made to record the position of the wire. Angular measurements were made from the paper later, using a protractor.

To obtain more accurate measurements of the distance to sighted cetaceans, the 25x binoculars were equipped with eyepieces containing a series of equally spaced horizontal marks (reticles), arranged vertically. Counts of the number or fraction of marks from the horizon down to the object of interest were recorded. These counts can be related to angle from the horizon to the object, and thence via trigonometric relationships to the distance to the object.

In addition to these devices, the ship's radar was used to measure the range and bearing to some objects, and an alidade on the repeating gyro compass on the flying bridge was used to measure the angle to some objects. The alidade is a sighting device without optics, and could only be used for objects which were large or at close range.

EXPERIMENT 1, Range and Bearing to a Buoy

An anchored buoy approximately 15 feet high was located near Santa Barbara Island. At varying distances and angles of approach to the buoy, the angle as indicated by the alidade, the radar and the wire device was recorded. Similarly, distance to the buoy was measured using radar and the reticles, and was estimated visually. Measurements were made with the vessel at complete stop, but allowed to drift. The sea was completely calm with no wind, and drift was negligible during the course of a set of observations. Replicate measurements of angles by individual observers were made by swinging the binoculars away from the target each time, thus minimizing serial correlation of consecutive measurements.

EXPERIMENT 2, Range and Bearing to Approaching Ships

The bearing and range to the bow of ships transiting at angles to the R/V D. S. Jordan were measured, using the radar and the wire device, and the radar and reticles, respectively, while the R/V D. S. Jordan was underway. There were some difficulties in making the reticle measurements while underway, especially at the closer ranges where the relative motion of the two vessels caused relatively rapid changes. The angle measurements using the wire device required 10 to 30 seconds time to complete. Replicates of the measurements were attempted, but vessel movement precluded true replication.

EXPERIMENT 3, Angle to Sighted Cetaceans

Angles to sighted cetaceans were estimated visually, and measured using the wire device. Replicate measurements were made as rapidly as possible by having the scientist looking through the binoculars indicate verbally when he was lined up on the cetaceans, and having someone else mark the position of the wire on the paper on the deck. A series of replicate measurements was made within 30 to 90 seconds following the first measurement.

EXPERIMENT 4, Reticle to Degree Conversion

The relationship between the reticle counts and the actual angle below the horizon was determined in an experiment conducted on shore. The binoculars were set up in an empty parking lot and focused on a large piece of paper at a distance of 53.1 m. The top and bottom of the image seen through the binoculars was marked on the paper, along with the position of each reticle mark. Subsequently the diameter of the field of view and the distance between the top reticle and each successive reticle was measured with a meter stick.

RESULTS

Calibration of Methods of Estimating Range

Shipboard Measurements

During experiment 1 radar measurements of the distance to the buoy, visual estimates of the distance to the buoy, and reticle counts were made (Table 1). Each observer made estimates independently, and none had any quantitative knowledge of how to interpret the reticle measurements in terms of distance.

The relationship between the mean visual estimates and the radar ranges is shown in Figure 1. The mean distance estimates follow the radar measurements fairly consistently, but the range of individual estimates is wide as indicated by the 90% confidence intervals. The mean visual estimates exceed the radar measurements slightly 10 of the 12 times. This is most consistent at distances less than 3 nm, with 8 of 10 overestimates occurring in this region. Between 3 and 5 nm equal numbers of observations are over and under the radar measurement.

The relationship between the reticle measurements and the radar measurements of distance is shown in Figure 2. Over the range of 0.3 nm to

Table 1. Mean visually estimated distance, mean reticle measurement and radar range to buoy, with sample size (N), standard deviations (SD), and coefficients of variation (CV) of reticle measurements.

Radar Distance (nm)	Visual Estimate N	Visual Estimate mean (nm)	Visual Estimate SD	Reticle Measurement N	Reticle Measurement mean (nm)	Reticle Measurement SD	Reticle Measurement CV
0.29	5	0.35	0.31	5	13.86	0.89	0.06
0.49	5	0.57	0.26	5	7.76	0.96	0.12
0.67	5	0.81	0.23	5	5.76	0.70	0.12
1.00	4	1.01	0.45	4	4.35	0.47	0.11
1.06	5	1.26	0.36	5	2.54	1.59	0.63
1.40	5	1.67	0.38	5	1.80	1.34	0.74
1.92	3	2.07	0.40	3	1.08	0.16	0.15
2.36	5	2.64	0.28	5	0.75	0.05	0.07
3.16	5	3.55	0.27	5	0.40	0.08	0.20
3.39	5	3.11	0.56	5	0.39	0.08	0.21
4.90	5	4.50	0.47	5	0.18	0.12	0.67
5.50	4	5.80	0.36	-	-	-	-

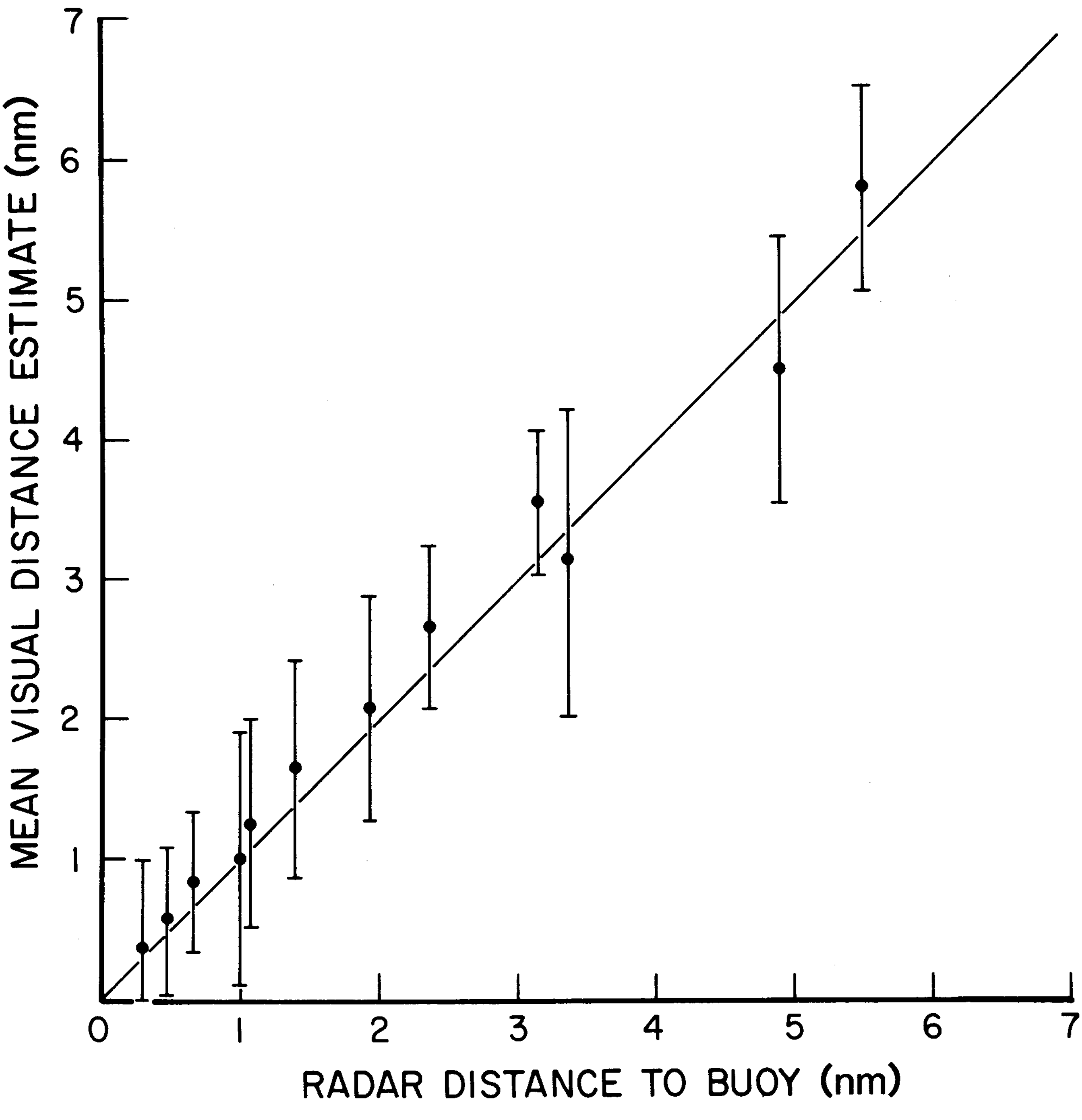

Figure 1. Mean visual estimates of distances to buoy versus distances measured by radar, with approximate 90% confidence intervals and line denoting equality shown.

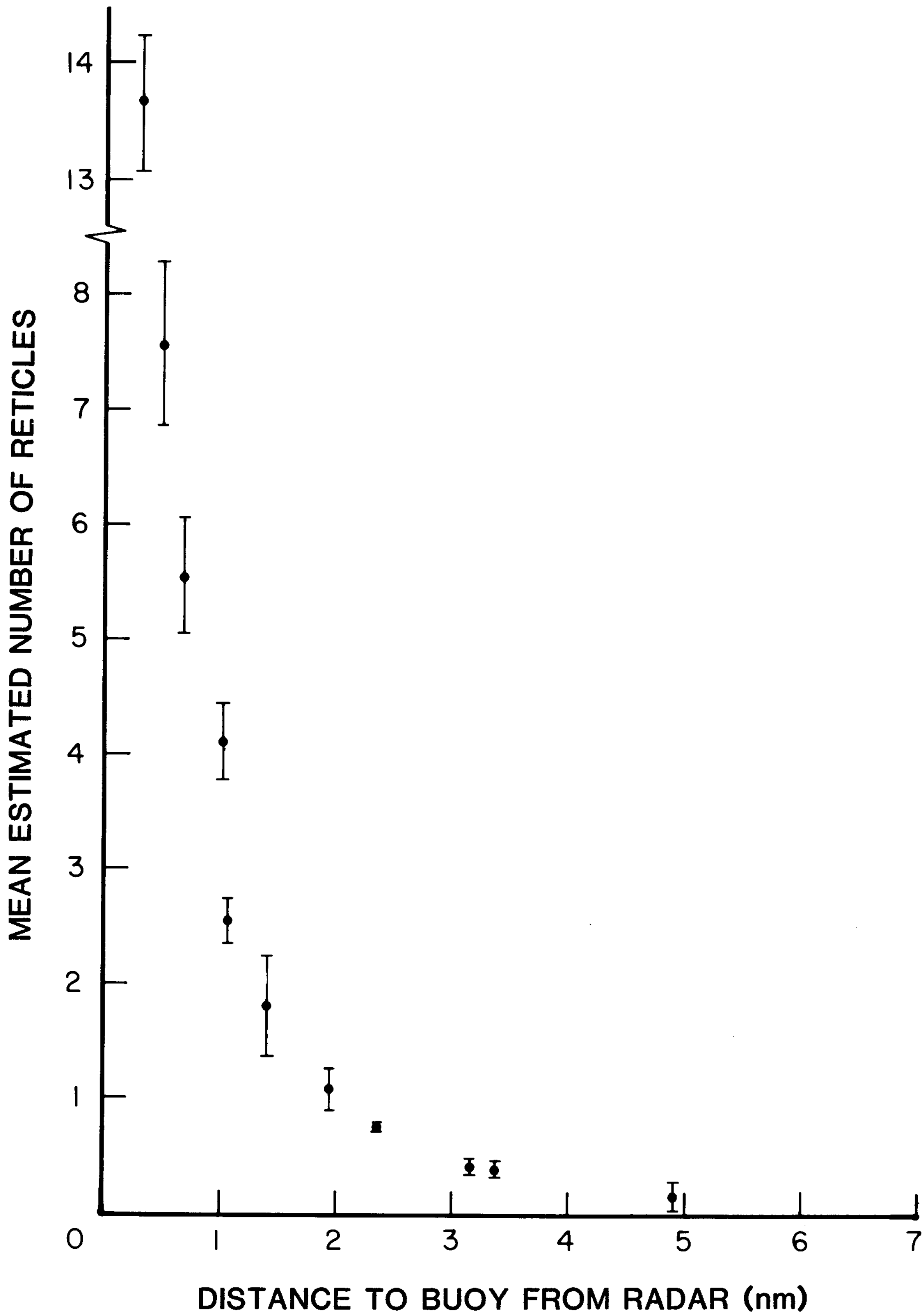

Figure 2. Mean estimated number of reticles at varying distance to buoy, with approximate 95% confidence intervals.

5 nm it is possible to make reticle measurements in a reasonably consistent manner, as indicated by the confidence intervals for the observations. Beyond 5 nm the change in reticle with distance is so small as to preclude using this device. The distance to the horizon at the 35 feet elevation of the binoculars on the R/V D. S. Jordan is approximately 6.2 nm, suggesting that this device is not likely to be useful beyond 5 nm. The reticles marked in the 25x binoculars cover approximately one half of the field of view. By covering more of the field of view it may be possible to measure distances smaller than 0.3 nm. The principal difficulty is that the observer must be able to count the large number of marks at a glance. A solution might be to include numbers near the reticles to assist in counting.

Reticle and Range Conversion

The relationship between the reticle counts and the range to sighted objects can be derived from the sighting geometry shown in Figure 3 and the results of experiment 4.

The relationship between the range a and the angle below the horizon c can be derived from Figure 3 following Heinemann (1981). Note that

$$a = b \tan(d), \tag{1}$$

and that d can be obtained from

$$\tan(c+d) = (a+e)/b, \tag{2}$$

$$d = \arctan\left(\frac{a+e}{b}\right) - c. \tag{3}$$

Substituting this expression into equation 1 yields

$$a = b \tan\left(\arctan\left(\frac{a+e}{b}\right) - c\right). \tag{4}$$

The distance to the horizon is given by Bowditch (1966) as proportional to the square root of the height of the eye, converting to nm,

$$a+e = 89.173\ b^{1/2}. \tag{5}$$

The relationship between the angle below the horizon to the sighted object, c, and the reticle marks was explored in Experiment 4. The measured distances from the topmost reticle to each successive reticle (d) (Table 2) were transformed to angles as arctan (d/53100) (Figure 4). These angles were fitted to the reticle number minus one (r) as

$$c = fr, \tag{6}$$

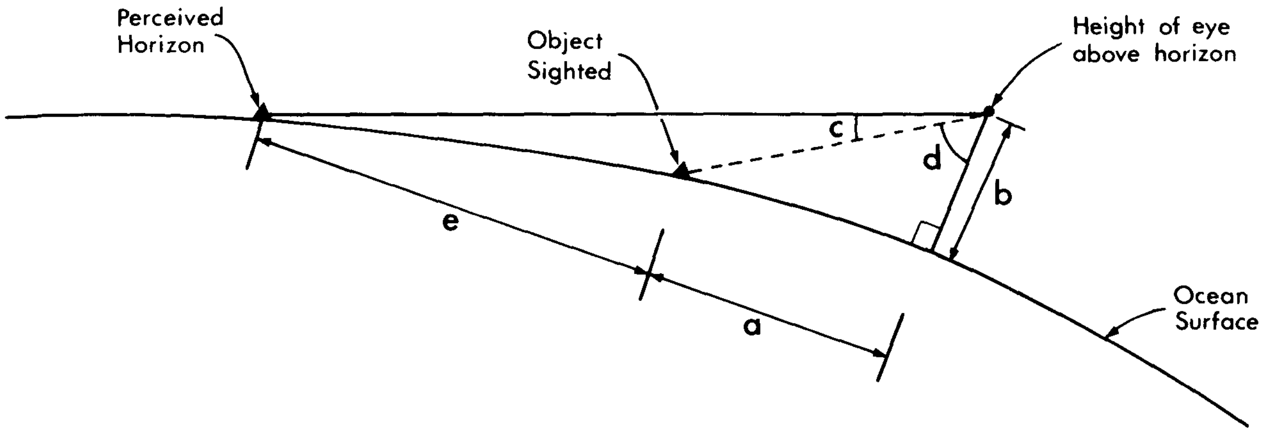

Figure 3. Diagram of relationship among horizon, sighted object, observers' eye and ship height, labeling angles and distances needed in theoretical development (see text).

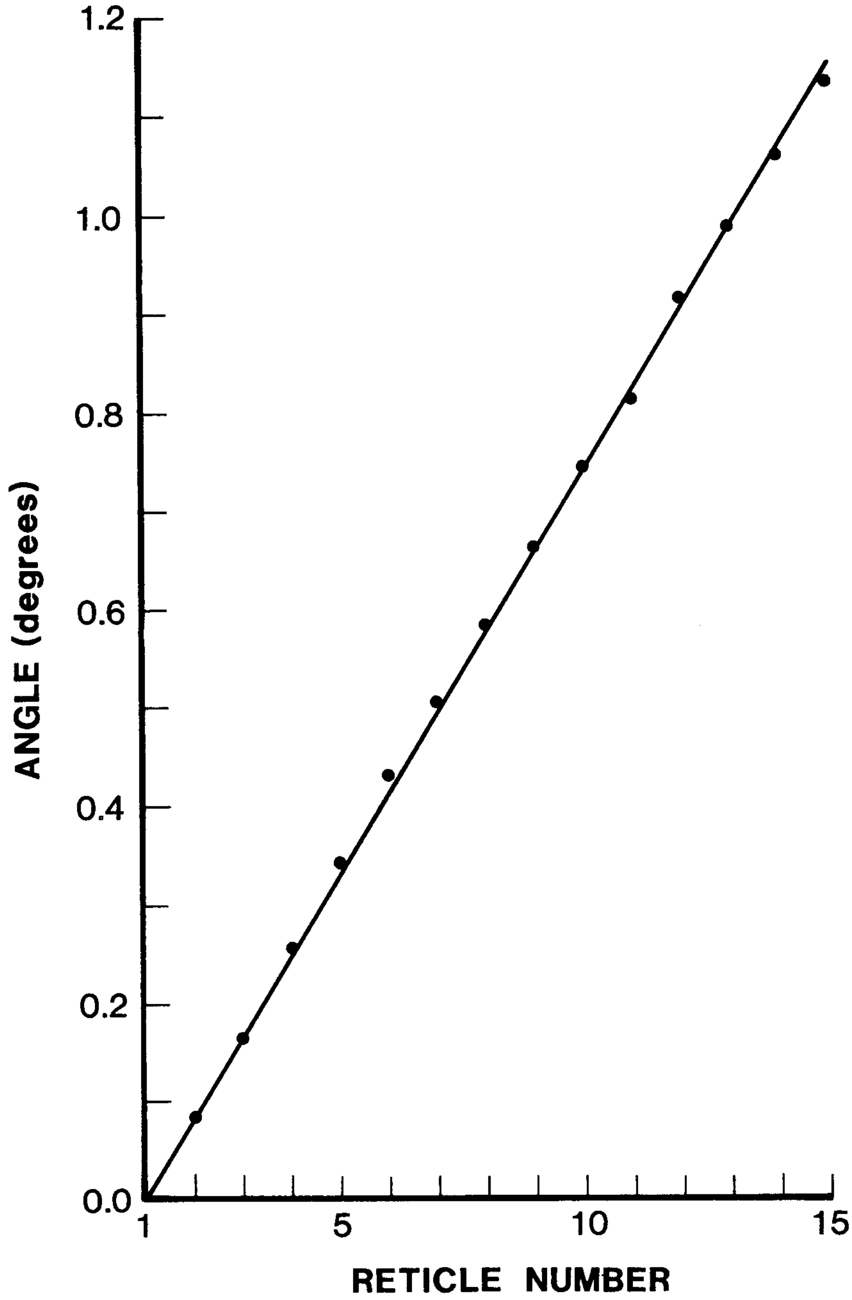

Figure 4. Angle (°) from top reticle to each lower reticle in 25x binoculars with fitted regression line.

Table 2. Distance from top most reticle to each lower reticle in 25x binoculars, measured in the field of view at 53.1 m.

Reticle	Distance (mm)
1	0
2	78.8
3	156.0
4	239.9
5	319.0
6	400.5
7	470.5
8	540.5
9	615.8
10	687.8
11	764.4
12	845.1
13	915.1
14	982.6
15	1051.1

using linear regression through the origin. The slope was estimated as 0.0823, with a standard deviation of the estimate of 0.00035.

Substituting equations 5 and 6 into equation 4 yields the relationship between the range and the reticles as

$$a = b \tan (\arctan (89.173/\sqrt{b}) - fr). \quad (7)$$

The variance of predicted ranges depends on the variability of the estimates of f and r approximately as

$$v(a) = (bfr \sec^4 (k - fr) \;\; /180)^2 \; (r^2 v(f) + f^2 v(r)), \quad (8)$$

where $v(\cdot)$ denotes the variance of the quantity within the parentheses, r denotes the number of reticles below the topmost reticle, and $k = \arctan (89.173/\sqrt{b})$.

The predicted distances to the buoy (equation 7) are plotted against the distances measured by radar (Table 1) in Figure 5. There is some consistent lack of fit at the intermediate ranges, the cause of which is not known. For illustration, the standard errors of the predicted distances (equation 8) are also shown, calculated assuming the observed variances of the reticles (Table 1). The range of sizes of these standard errors reflects the variability of the replicate reticle readings.

Calibration of Methods of Estimating Bearing

Measurements of the angles to a buoy were made during Experiment 1, in addition to the range measurements analyzed above. Angles were measured using the wire device attached to the binoculars stand, the alidade, and radar (Table 3). At each of 14 locations replicate measurements of the wire angle were attempted in order to determine sampling variability. Unfortunately, in most of the locations the vessel itself drifted and/or rotated slightly during the replicate, as indicated by changing radar angles within replicates (Table 3). Replicate variability was examined by computing variances for the data grouped to the nearest 5 degrees, and does not appear to vary consistently with either the size of the angle being measured, or the distance to the buoy.

The radar measurement of the angle to the buoy appears to be consistently greater than the alidade measurement (Figure 6). The ship's officers indicated that the radar angle is known to be in error due to the installation of the mechanism itself. Fitting a linear relationship to predict radar angle from alidade angle results in a intercept of 2.92 and a slope of 1.00. The standard deviations of these estimates are 0.192 and 0.0008 respectively. The fit is good and the residuals show no pattern with the alidade angle. The slope is clearly not different from unity, implying that a sufficient correction to the radar is to subtract the constant 2.92. The wire angles have been scaled against the radar in the field measurements, and so have

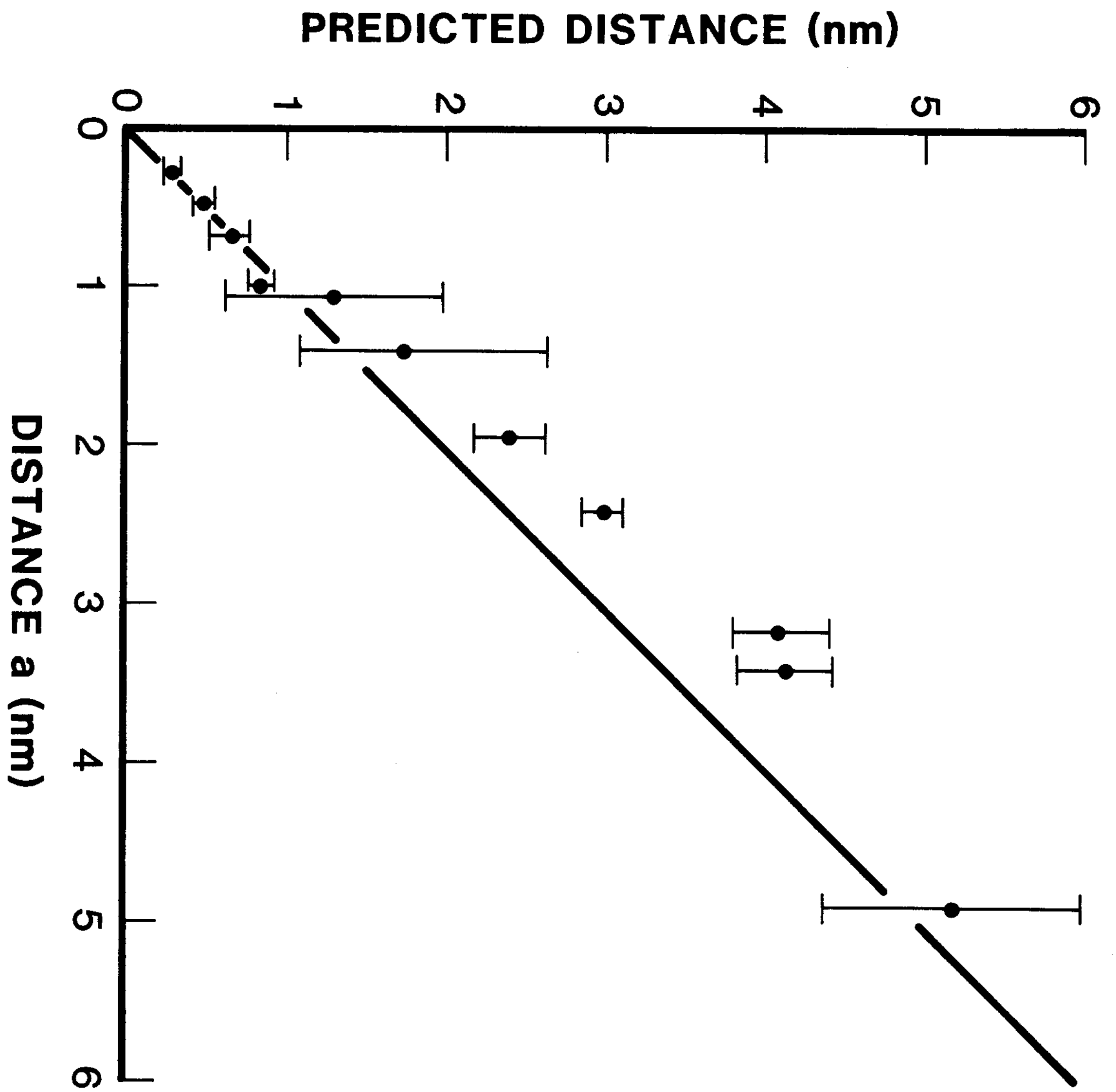

Figure 5. Predicted versus observed distances to buoy (Equation 7 and Table 1), with $\pm$ 1 standard error (Equation 8) and the equality line indicated.

Table 3. Wire angle, alidade angle, radar angle and radar distance to buoy recorded in Experiment 1.

Rep.	Distance (nm)	Radar Angle (°)	Alidade Angle (°)	Wire Angle (°)
1	---	23.0	---	21.8
1	---	23.0	---	21.4
1	---	23.0	---	20.7
1	---	24.5	---	22.5
1	---	27.5	---	24.8
1	---	29.0	---	26.0
1	---	29.5	---	27.7
1	---	29.5	---	28.8
1	---	30.0	---	29.7
1	---	32.0	---	31.9
1	---	32.5	---	29.2
1	---	33.5	---	32.5
1	---	34.5	---	30.7
1	---	35.0	---	32.0
1	---	35.5	---	34.5
2	4.6	86.0	---	85.5
2	4.6	87.5	---	86.5
2	4.6	88.0	---	88.2
2	4.6	89.0	---	83.2
2	4.6	90.0	---	84.0
2	4.6	100.0	---	87.5
2	4.6	102.0	---	98.0
2	4.6	105.0	---	102.0
3	4.6	67.0	---	67.6
3	4.6	67.0	---	64.3
3	4.6	67.0	---	64.5
3	4.5	67.5	---	65.3
3	4.5	69.0	---	69.5
3	4.5	74.0	---	71.0
3	4.4	79.0	---	74.0
3	4.4	89.0	---	84.0
3	4.4	97.0	---	96.3
3	4.4	98.5	---	96.3
4	4.9	3.0	---	3.5
4	4.8	3.0	---	3.0
4	4.8	3.0	---	3.0
4	4.7	3.0	---	2.0
4	4.7	3.0	---	1.5
4	4.7	5.0	---	5.0
4	4.6	4.0	---	4.8
4	4.5	3.0	---	2.7

Table 3. Continued

Rep.	Distance (nm)	Radar Angle (°)	Alidade Angle (°)	Wire Angle (°)
4	4.5	5.0	---	4.0
4	4.5	3.0	---	3.7
5	4.1	11.0	8	11.5
5	4.0	10.0	9	12.4
5	4.0	10.0	6	9.0
5	3.9	10.0	6	12.3
5	3.8	12.0	11	13.6
5	3.8	11.0	10	13.5
5	3.7	12.0	10	13.5
5	3.5	10.0	7	10.0
5	3.4	10.0	8	10.9
5	3.3	11.0	9	12.5
6	2.9	21.5	19	22.2
6	2.8	21.5	19	21.5
6	2.8	19.0	16	20.0
6	2.7	22.0	20	22.6
6	2.6	22.0	19	22.6
6	2.5	22.0	19	22.6
7	2.2	33.0	31	33.4
7	2.1	33.0	29	31.5
7	2.1	32.0	28	32.1
7	2.0	31.0	28	30.0
7	1.9	31.0	27	30.5
8	3.3	17.0	14	16.5
8	3.3	19.0	17	19.0
8	3.2	20.0	16	19.0
8	3.1	23.0	20	24.0
8	3.1	21.0	19	22.3
9	2.9	44.0	41	44.5
9	2.8	45.0	42	45.5
9	2.8	43.0	40	44.0
9	2.8	44.0	42	45.0
9	2.7	41.0	38	42.1
10	2.5	65.0	---	62.2
10	2.5	60.0	57	60.0
10	2.5	63.0	60	63.0
10	2.5	64.0	51	62.0
10	2.4	60.0	57	62.0
11	1.9	13.0	9	11.6
11	1.7	---	10	12.3
11	1.7	13.5	11	12.6
11	1.7	13.5	10	12.6
11	1.6	13.0	10	12.0
12	1.3	7.5	5	6.4
12	1.3	8.0	5	7.1
12	1.2	8.0	4	7.1
12	1.2	7.0	3	4.7
12	1.2	7.0	3	4.6

Table 3. Continued

Rep.	Distance (nm)	Radar Angle (°)	Alidade Angle (°)	Wire Angle (°)
13	1.1	18.0	16	18.7
13	1.0	18.5	15	18.6
13	1.0	18.5	15	17.6
13	1.0	18.7	15	17.1
13	0.9	19.5	16	18.5
14	0.8	92.5	---	89.4
14	0.8	96.0	---	94.3
14	0.8	98.0	---	96.8
14	0.8	98.0	---	97.6
14	0.8	98.5	---	97.1

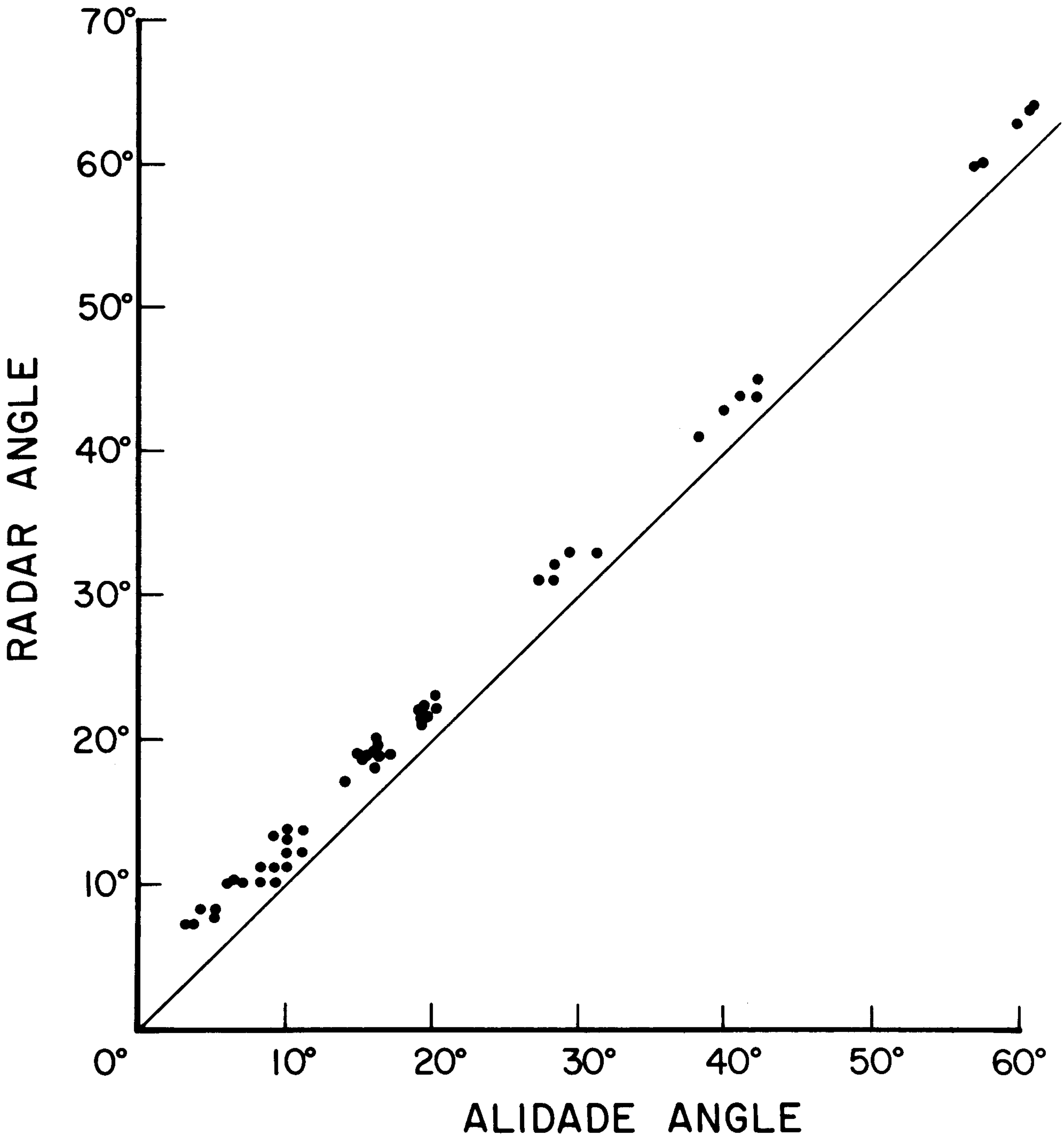

Figure 6. Relationship between radar angle and alidade angle.

effectively been corrected for this error.

The wire angles agree very closely with the radar angles, as shown in Figure 7. Fitting a linear relationship yields an intercept of 0.247 and a slope of 0.968, with standard deviations of 0.292 and 0.006 respectively. The fit is reasonable, with one apparent outlier at 100 degrees. The intercept is not significantly different from zero, (>.05), suggesting a regression though the origin may be appropriate. The slope estimate then is 0.972 with a standard error of 0.004, and is significantly different from unity (P<.01).

Application of Methods

During Experiment 2 the radar angle, wire angle and alidade angle were measured as a ship approached (Table 4). The wire angles were replicated in order to explore the precision of this method of measuring angles. During the time needed to complete the replicate wire angle measurements there was detectable change in the angle to the approaching ship's bow, as reflected in the general tendency for the replicate angles to increase. Thus the replicates do not yield information on the precision of the measurement. The relation between the first of the replicate wire angles and the radar angle is quite good (Figure 8).

The tendency for the radar angles to be greater than the alidade angles, noted above, is detectable in these data also. Greater variability is reflected in these observations, which is consistent with the general difficulty of obtaining alidade angles consistently during the experiment.

Also during Experiment 2 the distances to the approaching ships were measured using the radar and using the binocular reticles (Table 5). Measurements were difficult to make using the reticles due to the vessel motion and the rate of changes of distances as the two vessels passed. The mean reticle counts show the same general relationship to actual distances obtained from the radar as seen in Figure 2. The predicted distances from these mean reticle counts using equation 7, with standard deviations from equation 8 where multiple reticle readings allowed estimating the variance of the mean reticle, are also shown in Table 5.

During Experiment 3 visual estimates of both range and angle, and wire measurements of angle were obtained for five sightings of cetaceans (Table 6). The sightings were of a few to many animals of 4 different species, and were made at ranges visually estimated to be 2 to 5.7 nm. The wire angles were replicated 2 to 6 times. The replicate angles tend to increase consistently, suggesting a change in the angle due to the ship's motion, and perhaps, in part, due to the cetacean's motion. The two *Tursiops* schools eventually approached the ship, and no information is available on the possible movement of the *Grampus* school.

There is general agreement among the visual estimates of the bearing to the cetaceans, except for the *Grampus* sighting (Figure 9). The field notes suggest that this group of animals was only observed briefly, then lost to sight. Another sighting was made very soon afterward, so it is possible that the estimated and measured angles are for two different sightings.

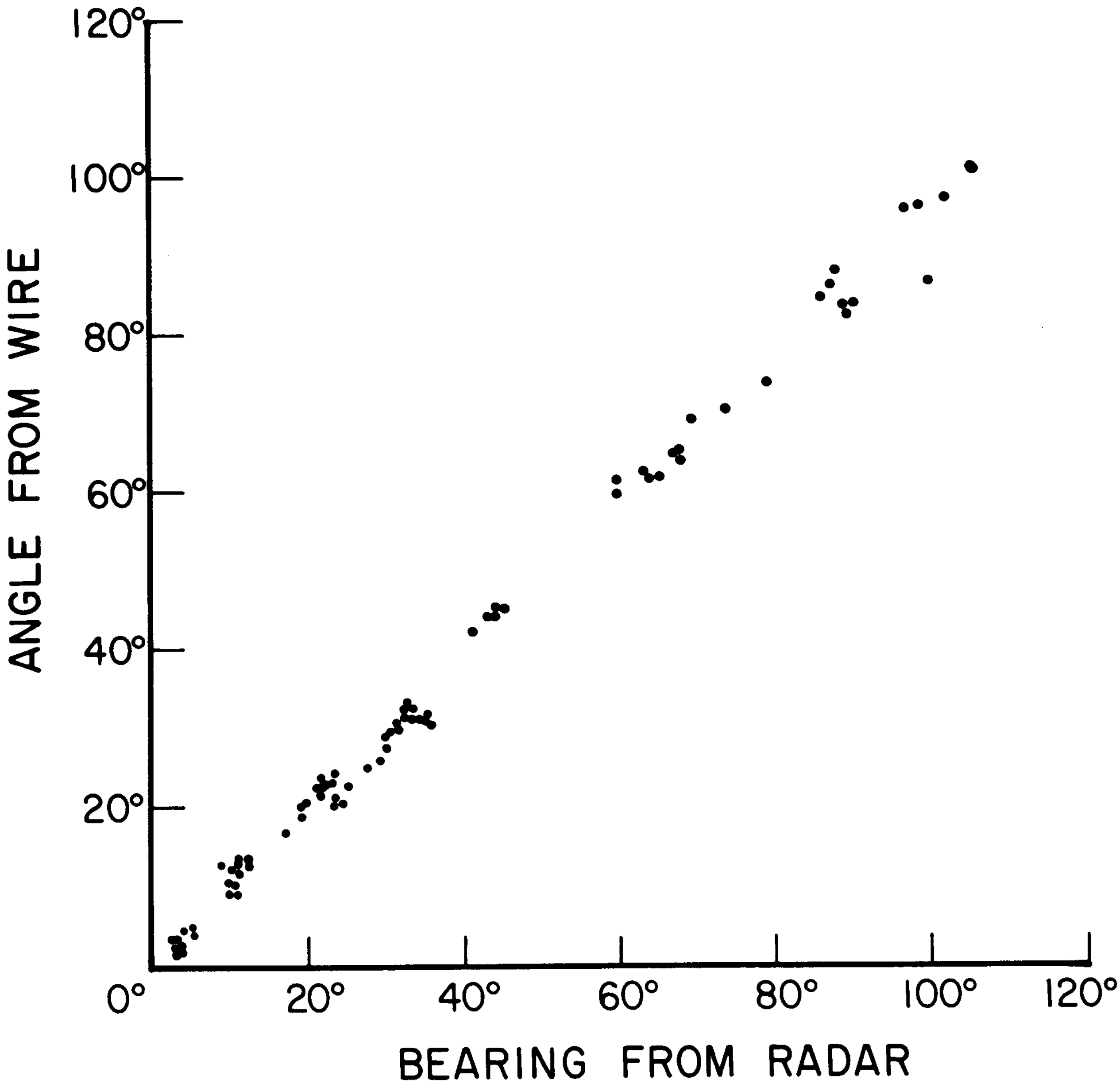

Figure 7. Relationship between angle measured from wire attached to 25x binoculars and bearing to buoy measured on radar.

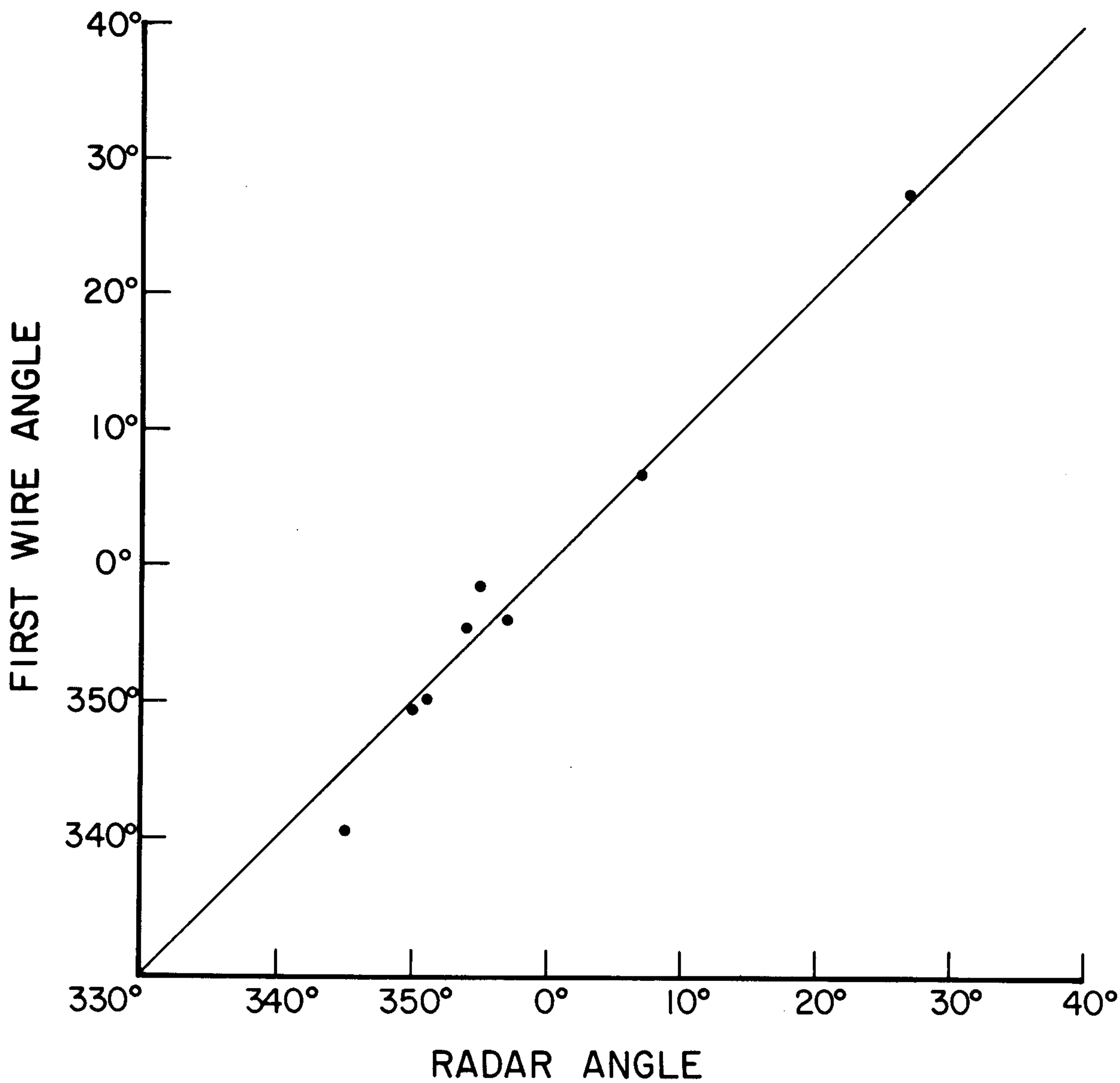

Figure 8. Relationship between the estimated angle to the bow of approaching ships using a wire attached to the 25x binoculars and the angle as measured by radar. The equality line is shown.

Table 4. Angular measurements (degrees) to bow of passing ships, with multiple replicates of the wire angles.

Radar	Alidade	Wire Angle 1	2	3	4	5	6	7
351	346	349.9	350.4	350.4	350.7	351.1	351.4	352.4
354	353	355.5	356.4	356.6	356.9	357.3	357.5	357.9
357	352	355.9	355.9	356.6	356.9	357.9	358.6	358.9
27	24	27.5	28.4	29.2	29.7			
7	---	6.8	7.4	8.4	8.9	9.5		
350	---	349.4	349.4	349.4	349.9	349.1	350.4	
345	340	340.5	341.1	341.1	341.4	341.9	342.6	343.1
355	---	358.4	358.9	358.9	359.1	359.5		
338	---	328.9	330.2	330.4	330.9	330.9	331.4	333.4
35	35	38.9	39.3	39.6	40.4	40.8	41.4	41.9

Table 5. Reticle measurements (number below horizon) to bow of approaching ships with radar measurements of distance. Means, standard deviations (SD) and predicted distances (D) with standard deviation (SD(D)) are given.

Distance (nm)	Reticle Measurement 1	2	3	Mean	SD	D	SD(D)
4.5	0.25	0.20	0.20	0.22	0.03	5.0	0.18
3.4	0.50	0.60		0.55	0.07	3.6	0.22
2.3	0.90	0.80		0.85	0.07	2.8	0.14
1.8	1.80	1.60		1.70	0.14	1.8	0.11
1.3	3.30			3.30	---	1.1	---
1.1	3.50			3.50	---	1.0	---
0.9	4.20			4.20	---	0.9	---

Table 6. Visually estimated and measured angles from bow to sighted cetacean schools.

Sighting number	Species	Visual angle (°)	Visual distance (nm)	Measured Angles, (°), in order 1	2	3	4	5	6	Mean (°)	SD
177	Tursiops	5	5.7	2.5	3.0	3.5	4.0			3.3	0.65
179	Delphinus	50	2.5	44.5	45.2	45.7	46.2	47.5	49.5	46.3	1.81
180	Globicephala	30	2.0	24.5	25.5	26.0	27.0			25.8	1.04
181	Grampus	5	3.0	23.0	24.0					23.5	0.71
185	Delphinus	10	3.0	7.5	8.0	8.5	8.5	9.5		8.4	0.74

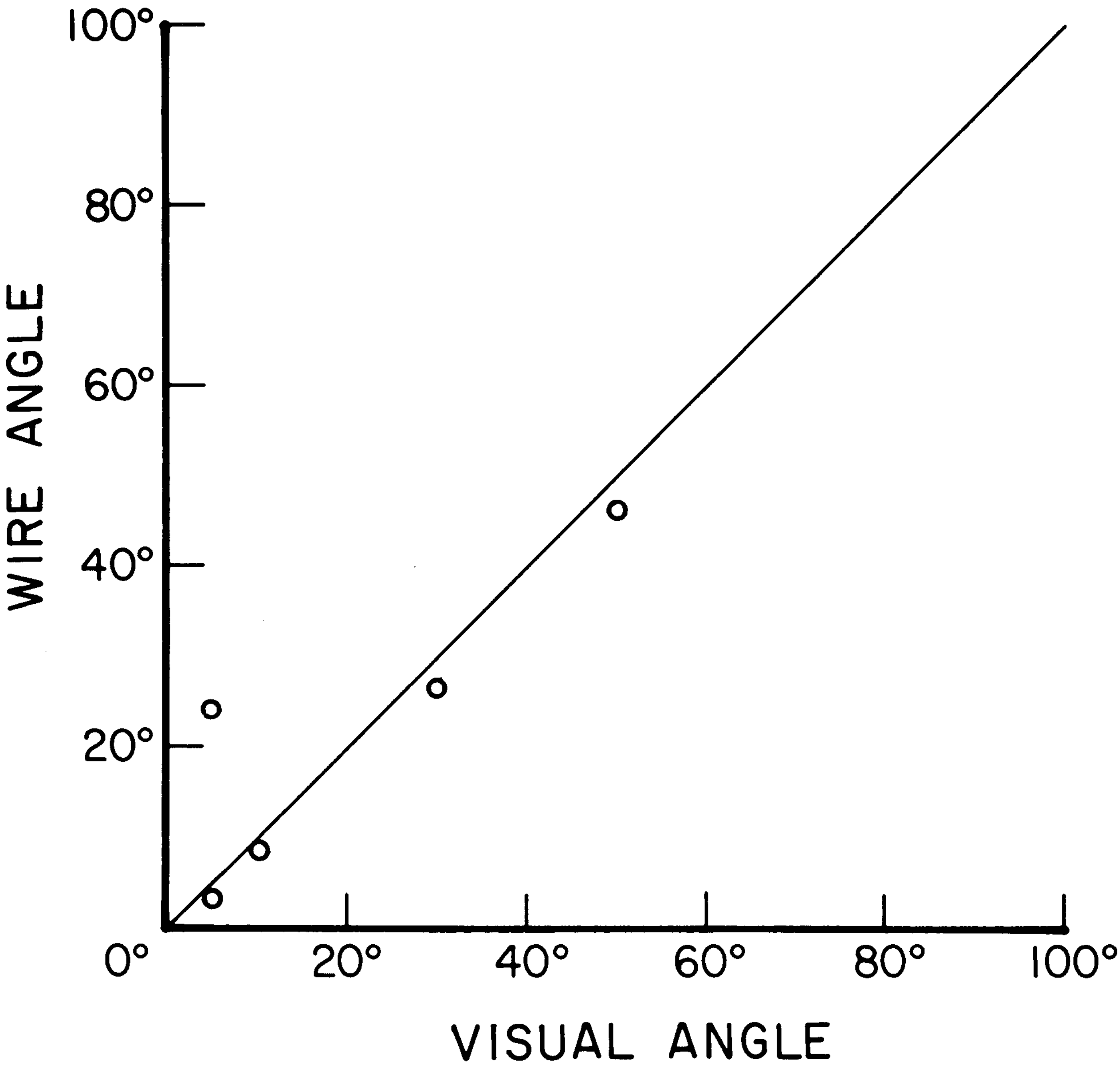

Figure 9. Angle to sighting measured by wire on binoculars versus visual estimated angle.

DISCUSSION

The experiments on the R/V D. S. Jordan suggest that improvements in estimating range and bearing of cetaceans sighted during surveys are possible with new measuring devices. It is not clear, however, what the limits of precision are which can be obtained by technique and equipment refinement, but at the very least one could expect some improvement with estimates and some information on the variability of the estimates. This would be a substantial aid in evaluating the precision and bias in absolute or relative abundance estimates which may be derived from shipboard sighting survey data.

The ultimate limitation in reducing the variance of the estimates of distance to sighted cetaceans is the variability of the reticle readings themselves. The coefficient of variation was around 28% on sightings under ideal conditions, and can be anticipated to be higher under less than ideal conditions, especially where the sighted object may be visible for only brief periods and where the horizon may be difficult to determine due to vessel motion and surface swell. Some improvement can be anticipated by having the reticle scales rearranged for easier use. For instance, for the closer objects many reticle marks must be counted; so sequential numbering or otherwise distinguishing the successive marks may make counting easier. Also, some observers had difficulty seeing the reticles because they are to the side of the field of view. The possibility of placing the marks in the center of the eyepiece should be explored.

The precision of the estimated bearing to sighted cetaceans can be improved by using a measuring device. This has already been explored in a preliminary fashion on a subsequent sighting cruise aboard the R/V D. S. Jordan. The binoculars were mounted on stands with an etched angular scale attached. The angles to the sighted cetaceans were read from these scales rather than visually estimated. Unfortunately the scales were etched to only five degree increments, but the results are encouraging. The frequency distribution of the actual recorded values for this latter cruise and for a comparable earlier cruise are shown in Figure 10, where it is clear that there is a reduced tendency for estimates to clump at favored values.

It is possible to use larger and more finely calibrated angular scales to further reduce the clumping aspect of these observations. However the ability of the scientist making a sighting actually to read an angular scale is limited due to the necessity to maintain visual contact on the animals and due to the motion of the ship. Repetition of angular measurements over several seconds, at least, would reduce variability.

There are some possibilities for equipment improvement which may help reduce the variability of the measurements of bearings and ranges. For angular measurements the most obvious is to determine mechanically the angle of the binoculars and enter this into the ship's computer. Additional information such as the compass heading, the engine revolutions, the time and the ship's position from satellite fixes and extrapolations could also be entered for assistance in computing exact sighting geometry. It would be important for the scientist to be able to trigger such recording, and also to have such information recorded automatically at intervals to study searching patterns.

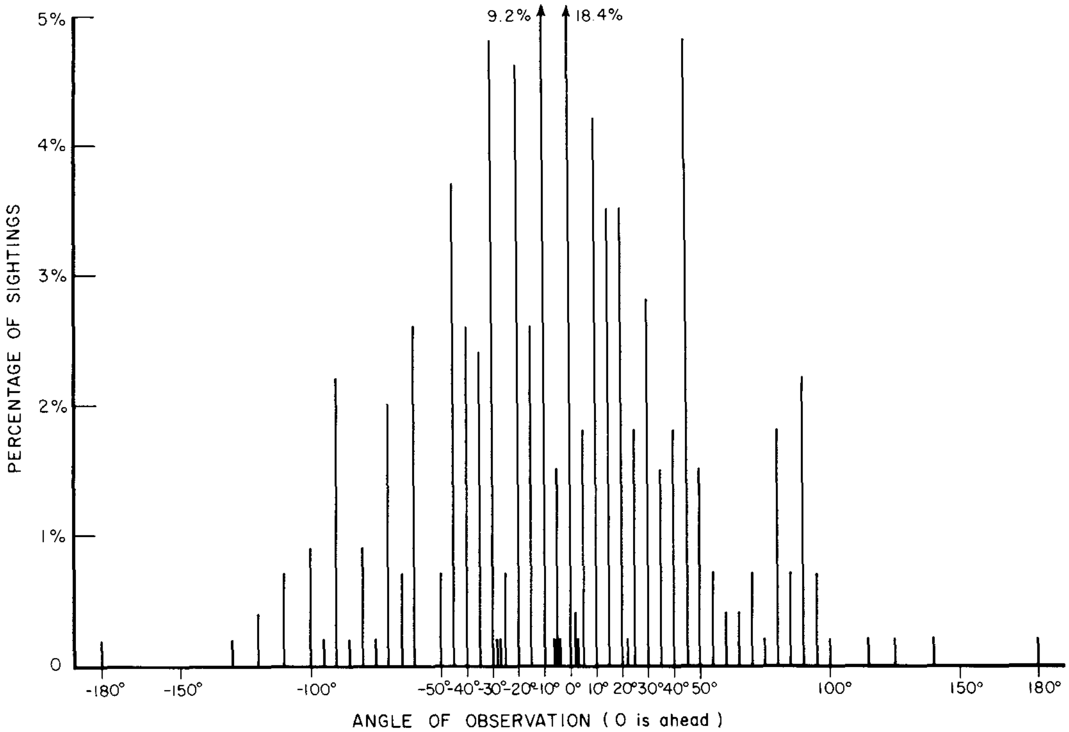

Figure 10a. Frequency of specific angles recorded without a measuring device as estimates of angle to sighted cetaceans.

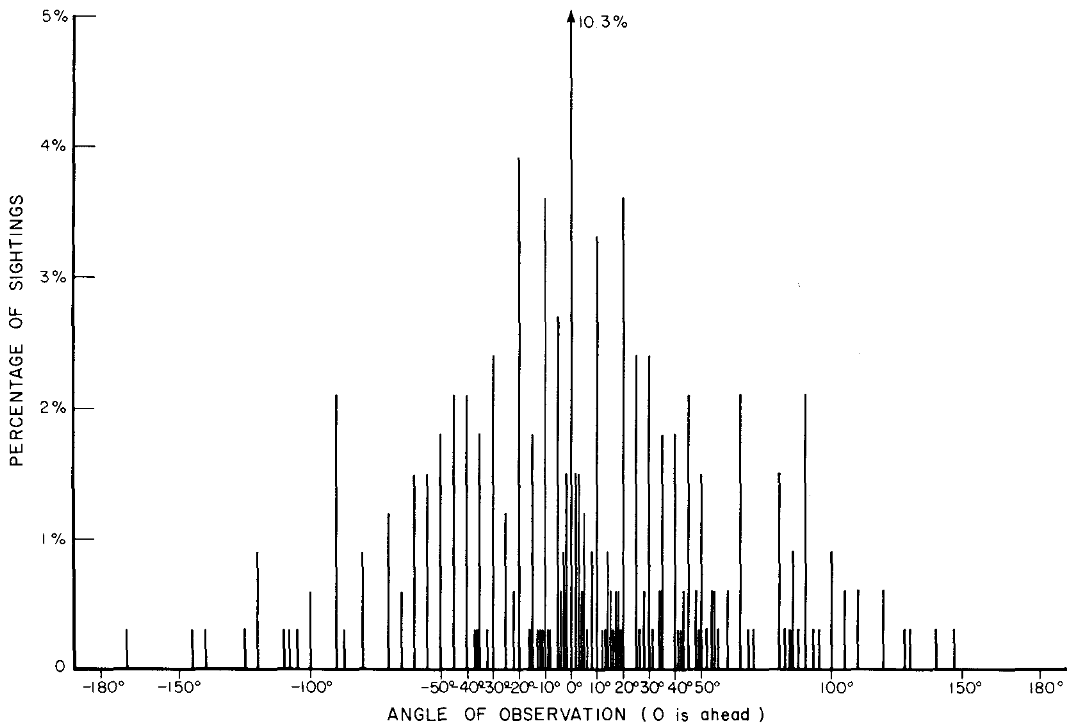

Figure 10b. Frequency of specific angles recorded with a calibrated ring as estimates of angle to sighted cetaceans.

One approach for improving the reticle measurements would be to mount a camera into the binocular optics to record photographically what the scientist is seeing. It may be possible to measure the angle below the horizon from the photographic image. An alternate approach would be to mount a camera with a separate optical system on the binoculars to accomplish the same end. The feasibility of this would, of course, depend on the visibility of the sighting cue which is being observed. The human eye is capable of focusing on a particular portion of the image in the binoculars and detect cetaceans which may not be detectable in the photographic image. One possible approach might be to mount a camera external to the binocular optics with an even higher power lens, although this may result in aiming problems.

An alternate approach to improving the reticle measurements is to gyrostabilize the binoculars themselves, thereby establishing a horizon reference point. It would then be possible to input the vertical angle of the binoculars relative to this horizon directly into the computer. The feasibility of this is unknown, but would depend in part on the response times of a gyrostabilizer of size sufficient for the 50 to 70 kg weight of the 25x binoculars.

Improved equipment of these types would probably result in greatly improved estimates of range and bearing to sighted cetaceans. In addition, such equipment could allow other questions to be approached. Automatic recording of the bearing of the binoculars could be used to examine the search pattern employed by the scientists. Doi (1974) demonstrated the need to understand this process. Best and Butterworth (1980) discuss the possibilities at some length, without being able to determine the relative searching effort expended by the fishermen at different points of the compass from the sighting data. Additional information was collected aboard Japanese sighting vessels in 1980, suggesting that most searching occurs forward of 45^{o} (Doi, Kasamatsu and Nakano, in press).

The trend in the replicate measurements of the angle to approaching ships and to sighted cetaceans by the wire device, suggests the possibility of using the ship itself as a range finder, as it progresses along its trackline for a short period after sighting. Using the vessel for this purpose would be greatly enhanced with the automatic recording of the angle of the binoculars.

One problem with using the ship as a range finder is the possible movement of the sighted cetaceans. This has been identified as a possible problem in general with application of line transect theory, especially if such movement is directional with respect to the ship. Au and Perryman (in press) initiated work on this problem from a helicopter associated with a research vessel. Using equipment as described above, it may be possible to continue such investigations, at least in terms of movement after sighting, from ships alone.

CONCLUSIONS

1. Visual estimates of the range to a buoy at sea averaged over several individuals are reasonable, but the range of estimates among individuals is large. There is a slight tendency to overestimate, as measured by the mean estimates, at distances less than 3 nm.

2. Range to sighted objects can be estimated from measurement of the angle below the horizon through 25x binoculars over a range of 0.3 to 5.0 nm. Actually making these measurements is difficult in practice, especially in less than ideal visibility conditions.

3. The relationship between reticle marks in the optics of Fuji 25x binoculars and the distance to the object is given in equation 7. The equation does not fit the available data very well, and needs additional study. It was validated while the ship was underway by estimating distances to the bow of approaching ships.

4. Prediction of the distance to an object from the reticle measurement is given by equation 9. It was tested using reticle measurement and radar measurements to the bow of approaching ships. An expression for the variance of the predicted distance is given (equation 10) in terms of the variances of the estimates of the parameters f and g, the covariance of these two estimates, and the variance of the actual measurement of the reticle. The statistical properties of this estimator need to be examined further.

5. The binocular wire angle can measure the bearing to a buoy with high precision. The variability is independent of the actual bearing and the distance to the object.

6. The radar on the R/V D. S. Jordan has an approximate 3 degree angle measurement error, independent of angle.

7. The binocular wire angles underestimate the radar angles, after correction, slightly, especially at angles greater than 60 degrees. A simple multiplicative constant is sufficient to correct for this.

8. Development of new equipment to improve the precision and reliability of angle and distance measurements, including possible automation, should improve the possibilities of aplication of line transect theory to ship sighting data.

ACKNOWLEDGEMENTS

This work was the result of collaboration among several individuals. The most important were the sighting survey team, consisting of Tom Duffy, field party chief, Bob Pitman, Mike Graybill, Scott Sinclair, Mike Newcomer, and Gary Friedrichsen. The crew and the captain of the R/V D. S. Jordan assisted us greatly in the extended maneuvering of the ship which was required. This study was largely exploratory, and benefited greatly from at sea discussions with and data collection by Drs. Lee Eberhardt, Robert Clarke, Phil Hammond, Nancy Lo and Rennie Holt. It is to be hoped that similar interactions will continue as work on sighting methodology is pursued.

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