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TESTING THE VALIDITY OF LINE TRANSECT THEORY TO ESTIMATE DENSITY OF DOLPHIN SCHOOLS

by

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ABSTRACT

An experimental aerial survey of dolphins in a localized area was conducted to investigate the effects of sea state, sun glare and observer performance upon the estimates of school densities employing line transect theory. Sea state and observer performance effects were not significant but the presence of sun glare adversely affected estimates of density.

INTRODUCTION

Line transect theory has been used to estimate density of cetaceans (Smith 1981, Holt and Powers 1982, Holt 1983a, Leatherwood 1978, Leatherwood and Show 1980 ,Scott and Winn 1980, Hammond 1981). The valid use of line transect (LT) theory depends on several assumptions being met (Seber 1982, Burnham, Anderson and Laake 1980). The validity of the assumptions has only infrequently been examined (Leatherwood and Show 1982, Holt and Powers 1982).

One critical assumption is that all schools on the trackline are detected under all sighting conditions encountered during the survey. This assumption has been investigated for surveys of terrestrial animals (Laake 1978) but not for marine animals.

The ability of observers to detect all schools on the trackline may be affected by environmental factors such as sea conditions or sun glare and by operational features such as speed of the observation platform or abilities of the observers. These factors are often confounded with each other or with other variables, such as heterogeneity of animal density in the survey area. For example, surveys which traverse nearshore and off-shore tracklines may encounter rougher seas offshore but animal density may decrease offshore resulting in confounding of sea state effects with actual density.

In this document, I present results of an experimental aerial survey for dolphins which investigated in a localized area off Costa Rica the effects of various sea state and sun glare conditions and observer performance on detecting dolphins and the effects of detection conditions on density estimates determined using LT methods.

MATERIALS AND METHODS

Data collection procedures used and data collected during the survey were described by Holt (1983b). Only details specifically relevant to my analyses are reiterated here.

A Beech AT11 aircraft, equipped with a plexiglass nose cone, was operated along the Pacific coast near Liberia, Costa Rica during March 7-April 5, 1981. Although flights were conducted over a larger area, the "study area" was defined as the area offshore within 9° 30' to 11° 00' N and 85° 20' to 86° 35' W (Figure 1).

During each flight, the plane traveled along predetermined tracklines. Searching effort was recorded by effort legs during which environmental conditions, such as sea and sun glare conditions, and operational conditions, such as observer positions, were constant. A new effort leg was initiated at each change in environmental or operational condition.

Observers searched for dolphin schools from 3 observation positions: a bow station located in the nose cone and left and right waist stations located on either side of the plane in the extreme aft of the cabin. A "bow" observer searched, from the bow station, the area directly underneath the plane (the trackline) while "left" and "right" observers searched, from the respective positions, areas from the edge of either side of the plane outboard to a varied distance set primarily by environmental conditions. A bow monitor station was also located in the nose cone adjacent the bow observer, from which a "bow monitor" searched the trackline to provide a direct visual check of the bow observer's performance. Schools detected by the bow monitor were not included in the analyses since the bow monitor was not a member of the "on duty" searching team.

Variables measured were sea state conditions using the Beaufort scale, sun glare recorded by the position of the sun relative to the airplane (Holt 1983b), and observer performance measured for teams of observers. The association of aircraft speed and the rates of detecting dolphin schools, although not an objective of this study, was briefly examined (Appendix 1).

Sea state data were recorded by each sea state but grouped into (1) "calm" sea state (Beaufort numbers 1-2), which included seas without whitecaps, and (2) "rough" sea state (Beaufort numbers 3-5) conditions, which included seas with whitecaps. The presence of whitecaps was important because animal splashes were used as sighting cues during calm seas but could not be used during rough seas.

Sun glare effects were investigated by recording the horizontal and vertical position of the sun relative to the plane (Figure 2). During the experiment, the presence of sun glare on the trackline at various sun positions was periodically noted by the bow observer. These observations were used to develop "good" and "poor" sun glare strata (Table 1). All effort recorded at sun positions where sun glare was noted on the trackline was allocated to the poor sun category. All other effort was classified as good sun conditions. Since light penetration in the coastal waters during cloudy conditions is reduced, cloudy conditions were classified as poor viewing conditions. Other criteria to stratify sun glare condition are possible and a more detailed discussion of my criteria and an alternate classification are presented in Appendix 2.

Two experiments were designed to collect data on the observer's abilities to detect schools: (1) The bow monitor provided a direct visual check of the bow observer's ability to detect trackline schools. The bow monitor was instructed to refrain from indicating the presence of a sighting until the bow observer had clearly failed to detect the school, i.e., the plane had overflown the school without it being detected by the bow observer. (2) The effect of observer experience was tested using one team consisting of 3 people which lacked experience in detecting marine mammals from the aircraft (Inexperienced) and a second team of 3 observers with such experience (Experienced). The two teams alternated watch assignments, conducting approximate 40-minute search watches.

The species of dolphins included in the data analyses are: spotted dolphin, Stenella attenuata; spinner dolphin, S. longirostris; striped dolphin, S. coeruleoalba; rough-toothed dolphin, Steno bredanensis; Risso's dolphin, Grampus griseus; Frazier's dolphin, Lagenodelphis hosei; common dolphin, Delphinus delphis; bottlenosed dolphin, Tursiops truncatus and an "unidentified dolphin" category. Dolphin schools with less than 15 animals were omitted because the probability that all animals of such schools being submerged at the same time and hence unavailable for detection seems to be greater than for larger schools (Holt and Powers 1982). Data on other marine mammal species, i.e., large whales, were omitted because they differ from dolphins in swimming behavior and generally occur in smaller schools. In addition, schools detected at perpendicular distances greater than 1.94 km (1.05 nm) were not used in the analyses (i.e., data were truncated at 1.94 km).

Model Definitions

Burnham et al. (1980) provide a thorough review of LT theory, including its inherent assumptions. If all assumptions are met, then the density of the dolphin schools can be estimated as

$$\hat{D} = \frac{n\ \hat{f}(0)}{2L} \qquad (1)$$

where n is the number of sightings, L is length of trackline searched and f(0) is an estimate of the probability density function (pdf) with perpendicular distance (distance from sighting to trackline) equal 0. The sampling variance of $\hat{D}$ was estimated for each variable tested using the Taylor expansion (Seber 1973),

$$\hat{V}ar\ (\hat{D}) = D^2 \left[\frac{\hat{v}ar\ (n)}{n^2} + \frac{\hat{v}ar\ f(0)}{(\hat{f}(0))^2} \right] \qquad (2)$$

and the estimated variance of n, $\hat{v}ar(n)$, was determined empirically as

$$\hat{V}ar\,(n) = \frac{R \sum_{i=1}^{R} (n_i - \bar{n})^2}{R-1} \qquad (3)$$

where

$$\bar{n} = \frac{\sum_{i=1}^{R} n_i}{R}$$

with n_i=number of schools observed on the ith trackline segment and R = total number of equal trackline segments. I used trackline segments of 28.64 km which was the average length of all effort legs. Equal line segments were formed by either partitioning effort legs or by summing parts or whole legs until 28.64 km was searched. Use of Equation 3 is appropriate (Burnham et al. 1980) because the detection rates of trackline dolphin schools among the segments were not serially correlated (r=0.085).

Several models have been used to estimate f(0) (Burnham et al. 1980). The Fourier series model (FS) first applied to line transect theory by Crain et al. (1978) was used in this study. Theoretically, the model could fit perpendicular sighting distributions of a wide variety of shapes including distributions with large numbers of sightings detected on or near the origin (trackline), i.e., "spiked" distributions.

The pdf for the FS model is

$$f(x) = 1/w + \sum_{k=1}^{m} a_k \cos\,(\,k\pi x/w). \qquad (4)$$

where w is the data truncation point equal 1.94 km. For grouped data, no simple explicit formula exist to estimate the a_k. Instead iterative numerical methods were used to calculate maximum likelihood estimates $\hat{a}_1,\ldots,\hat{a}_m$ and their sampling variances and covariances for any number of terms m.

Upon evaluating f(x) at x=0, equation (4) becomes

$$\hat{f}(0) = 1/w + \sum_{k=1}^{m} \hat{a}_k \qquad k=1,2,3,\ldots \qquad (5)$$

The number of terms selected for the FS model was determined independently for each data stratum. Because the experimental objectives included determining if schools were missed on the trackline during the various conditions and to investigate these effects upon the density estimates, the number of terms used in the FS model was selected to provide the best fit of the data near the origin. Some perpendicular distance distributions had a prominent mode or spike at the origin; therefore, models with several terms (8-9 terms) which may have "over-fit" the data were often selected. This was required to obtain a consist fit of data among the strata. A computer program of the FS model (Laake, Burnham and Anderson 1979) was used to calculate the density estimates.

Data Analyses

Descriptive statistics were computed, where possible, for the effects of calm and rough sea conditions, good and poor sun conditions and observer teams. Statistical differences among variables were investigated by comparing (1) rates of detecting all (combined on and off the trackline) schools, d_a (schools/1000 km searched), (2) rates of detecting trackline schools, d_t (schools/1000 km of trackline searched), and (3) estimates of the density of schools, $\hat{D}$ (schools/1000 km^2). Because of a sparsity of data, density estimates were not tested when the interactions of sun, sea state and observer performance are accounted for. Instead, the effects of sea state and sun glare were simultaneously tested and then sun glare and observer team effects were simultaneously tested.

Statistical differences among density estimates and among detection rates were investigated using modified analysis of variance (modified-ANOVA) comparisons. Modified-ANOVA were used because insufficient sample sizes prevented computing independent, replicate densities for each level of interaction of the variables. A mean density and its variance could be estimated for each level of each variable (Equations 1 and 2).

The modified-ANOVA method uses the estimated sample variances as approximations of the ANOVA sum of squares since the sample variance of a random variable is a function of the sum of squared deviations from the mean. This sum comprises the residual or error variance in a standard ANOVA model. The relationship is shown as follows.

If true replicates exist, the empirical estimate of the variance of an estimated density is

$$\mathrm{Var}\,(\hat{D}.) = \frac{\sum_{r=1}^{R} l_r\,(\hat{D}_r - \hat{D}.)^2}{L(R-1)} \qquad (6)$$

where $\hat{D}.$ is the average density over all r (r=1,...,R). If line lengths are equal ($l_1=l_2=...=l_R=l$), then

$$\mathrm{Var}\,(\hat{D}.) = \frac{l\sum_{r=1}^{R} (\hat{D}_r - \hat{D}.)^2}{L(R-1)}$$

and

$$\mathrm{Var}\,(\hat{D}.) = \frac{\sum_{r=1}^{R} (\hat{D}_r - \hat{D}.)^2}{R(R-1)} \qquad (7)$$

since R = L/l. Equation 7 is the square of the standard error of $\hat{D}.$. Since the sum of squares within a single cell of an ANOVA table is the sum of squared deviations of the individual replicates about the cell mean, or

$$SS_{error} = \sum_{r=1}^{R} (\hat{D}_r - \hat{D}.)^2$$

It follows that the error sum of squares within a cell may be obtained from the variance of $\hat{D}.$ as

$$SS_{error} = R(R-1)\ (Var(\hat{D}.))$$

where R is the number of replicates in the cell of the ANOVA table and $\hat{D}.$ is the cell mean. Therefore in the absence of replicate densities for each cell, ANOVA were performed on cell means, variances and number of replicates.

The error (or residual) degrees of freedom were determined using the number of equal length line segments searched in each cell. If a shorter segment length had been chosen, the error degrees of freedom would have been larger but the critical F value required to indicate significance would not have been affected since the F test already used infinite error degrees of freedom. Line segments must be more than 3 times the average length chosen before the critical F value would be affected. Many cells of the ANOVA model then would contain very few segments.

To investigate the effects of our apriori calm and rough sea classification, statistical comparisons of individual sea state trackline detection rates were investigated using two methods. (1) Modified-ANOVA compared trackline detection rates of individual Beaufort data (only Beaufort 1-4 data were used since sea state 5 data represented only 2% of the effort during which no sightings were detected). (2) Because ANOVA models are based upon assumptions that the data have a Gaussian distribution and have approximately equal cell sizes and variances, a nonparametric contingency table analysis compared the number of equal length line segments with dolphin sightings versus those without sightings. Segments with one or more sightings were pooled since relatively few segments had more than one sighting (Table 4). This is equivalent to analyzing detection rates since a change in the distribution of number of sightings between the two sighting categories will correspond to a change in detection rates. Because of the small amount of data available for Beaufort 5, analyses were performed with Beaufort 4 and 5 combined and with Beaufort 5 data omitted.

In addition, the effect of Beaufort state by latitudinal on detection rates was investigated by partitioning the data into North and South of 10^0 N (see Appendix 5). Contingency table analyses were then completed to investigate the proportion of approximately equal line segments (all segments of at least 25.00 km) with and without sightings during different Beaufort states in the two different areas.

RESULTS

Within the study area (Figure 1), 263 dolphin schools were detected within 1.94 km of the trackline and 11,781 km were searched. Over 22% (58) of all schools detected in the study area were on the trackline (Table 2). The detection rates of all schools (d_a) and those recorded on the trackline (d_t) were 22.32 and 4.92 schools per 1000 km searched, respectively.

As indicated by the probability density distribution (Figure 3), the distribution of perpendicular distances for all data had a "sharp" spike at the origin. Fitting a density function to these data gives an estimate of 25.00 schools/1000 km^2 (Table 3).

Sea State Effects

The rates of detecting trackline schools in calm and rough seas were not significantly different (P>0.05, Table A3-1). The trackline detection rate (d_t) was 4.97 schools per 1000 km searched during calm seas and 4.90 schools per 1000 km searched during rough seas. The detection rate of all schools during calm seas (d_a= 26.65 schools/1000 km) was significantly larger than the rate during rough seas (d_a= 19.72 schools/1000 km) (P<0.05, Table A3-2).

The estimate of school density with calm seas was only slightly larger than the estimate with rough seas (Table 3) and the difference between the two estimates was not significant (Table A3-3). The spike in the sighting distribution at the origin, noted previously, is more prominent in the distribution for rough sea conditions than for calm conditions and the distribution for calm conditions contain a prominent mode at 1.11 km (Figure 3).

The modified-ANOVA did not indicate consistent or significant differences among trackline detection rates of observers during individual Beaufort sea states (Figure 7 and Table A3-5). The association between Beaufort state and proportion of segments with and without sightings was not significant (p>0.05) for trackline sightings but was highly significant (p<0.001) for all sightings (Table A3-6).

Comparisons of the occurrence of individual Beaufort state data in the North and South areas were significant (P<0.001); however, comparisons of the proportion of segments with and without sightings between the two areas were not significant. The three-way association between Beaufort state, area, and number of sightings was not significant (0.05<p<0.10). Similar results were obtained whether Beaufort 5 data were combined with Beaufort 4 data or were omitted from the analyses.

Sun Glare Effects

The detection rate for trackline schools during good sun conditions was larger (d_t= 6.97 schools/1000 km), but not statistically different (0.05<p<0.10) (Table A3-1), than during poor sun conditions (d_t= 4.13 schools/1000 km) (Table 2). The rates of detecting all schools (d_a) during good and poor sun conditions were 23.94 and 21.70 schools per 1000 km searched, respectively, which also were not statistically different (Table A3-2).

The density estimates of dolphin schools observed during good and poor sun glare conditions were 34.83 and 21.15 schools per 1000 km^2, respectively (Table 3) and were statistically different (P < 0.05) (Table A3-3). The good sun pdf had a much larger spike at the origin than did the poor sun distribution (Figure 4).

The interaction effects of sun and weather on detection rates of trackline schools or all schools were not significant (Tables A3-1 and A3-2). The highest rates of detecting trackline schools were for the two good sun categories (Table 2) while the highest rates of detecting all schools were for the two calm sea categories.

No significant interaction of sun and weather effects on the density estimates was demonstrated (Table A3-3). The spike at the origin for the sighting distributions was largest for the rough sea-good sun category (Figure 4). The estimate of school density, therefore, was largest for this category (Table 3). In general, good sun conditions had a larger effect than poor sun conditions on the density estimates at each corresponding sea state condition, but good sun conditons with rough seas had a larger effect than good sun conditions with calm seas.

Observer Performance Comparisons

Bow Monitor Detections

Bow monitors saw 8 marine mammal schools missed by the bow observer but these schools either had fewer than 15 animals, were detected off the trackline or were non-dolphin species. Four of these schools were detected on the trackline but only one was a large school and it was a non-dolphin school (25 False killer whales, *Pseudorca crassidens*). Four were seen off the trackline, one of which consisted of 20 unidentified dolphins detected 185 m from the trackline. The eight sightings were detected by different bow monitors and when different observers were in the bow observer position.

The only direct evidence that bow observers missed large dolphin schools on the trackline was the detection of 20 unidentified dolphins by the left waist observer. This school was positioned on the left boundary of the trackline in an area surveyed by both bow and left waist observers. For sightings near the boundary, observers rounded the perpendicular distance to the nearest perpendicular distance interval. The left waist observer's assessment for this school was that it was located within the 1.85 km trackline path width.

Observer Team Comparisons

Neither detection rates nor estimates of school densities were statistically different between the inexperienced and experienced observer teams (Tables A3-1, A3-2 and A3-4). The inexperienced team's detection rate of all schools was larger than the experienced team's rate (24.14 versus 20.61 schools/1000 km) but their trackline detection rate was smaller (4.37 and 5.44 schools/1000 km, respectively) (Table 2). The experienced team density estimate was larger than the inexperienced team estimate (30.50 versus 20.52 schools/1000 km^2, Table 3).

The detection rates during calm and rough sea conditions for the inexperienced team were slightly lower for trackline schools but were higher for all schools than were the experienced team's rates (Table 2). The inexperienced team detected 4.16 and 2.71 more schools per 1000 km searched during calm seas and rough seas, respectively, than did the experienced team. The inexperienced team, however, detected 1.14 and 1.03

fewer trackline schools per 1000 km searched during calm seas and rough seas, respectively, than did the experienced team. Density estimates for the experienced team were larger than for the inexperienced team with calm sea conditions (30.66 versus 23.09 schools per 1000 km^2) and with rough sea conditions (31.18 versus 20.10 schools per 1000 km^2, Table 3).

The true difference between the two team's density estimates was probably less than indicated since the FS model underestimated $\hat{f}(0)$ for the inexperienced team and slightly overestimated $\hat{f}(0)$ for the experienced team (Figure 5). A mode in the perpendicular distance frequency distribution appears at 1.11 km only for the inexperienced team's sightings.

Detection rates of trackline schools (d_t), all schools (d_a), or estimates of school densities (D) were not statistically different for the two teams' data for good and poor sun conditions (Tables A3-1, A3-2, and A3-4, respectively). The inexperienced team had a slightly higher detection rate of trackline schools during poor sun conditions (0.21 more schools/1000 km surveyed) but a much lower rate during good sun conditions (3.90 fewer schools/1000 km surveyed) than did the experienced team (Table 2). The detection rate of all schools (d_a) for the inexperienced team was larger than for the experienced team during poor sun conditions (5.03 more schools/1000 km surveyed) but the two teams' rates were approximately equal during poor sun conditions (inexperienced team's estimate was only 0.06 schools/1000 km larger than the experienced team's estimate) (Table 2). Estimates of school density for the experienced team were larger than for the inexperienced team during good sun conditions (43.28 versus 24.09 schools per 1000 km^2) and were slightly larger during poor sun conditions (24.06 versus 20.08 schools per 1000 km^2, Table 3).

No consistent patterns were evident relating observer team detection rates, either trackline or all schools, for different sun and sea conditions. Differences in detection rates among teams and sun and sea conditions were not significant (Tables A3-1 and A3-2). The detection rates of all schools for both teams were lower during rough seas than during calm seas during either sun condition (Figure 6). Trackline rates ranged among all categories and teams from 1.56 schools per 1000 km to 9.04 schools per 1000 km (Figure 6)- over a five-fold difference. However, these results are based on small sample sizes and hence the rates may not be representative.

DISCUSSION

Sea state effects were not shown to significantly affect either the rate at which schools on the trackline was detected or the estimate of school density. Calm and rough sea conditions or Beaufort information was found to have no statistically significant effect on trackline detection rates. However, trackline detection rates for Beaufort 4 data were lower than for Beaufort 1-3 data but no consistent trend was present among all Beaufort states. Little data were available for Beaufort state 5 and above so these results might not be directly extrapolated for extreme rough sea states. In Appendix 4, density estimates are given from computations that omit Beaufort 5 data and omit both Beaufort 4 and 5 data.

Sun glare adversely affected the observers' abilities to detect dolphin schools both on and off the trackline. Detection rates of all schools and trackline schools were higher during good sun conditions than during poor sun conditions. The density estimate was 39% lower during poor sun conditions than during good sun conditions.

The experimental design required that observers continue searching for marine mammal cues when severe glare on the trackline was experienced. Bow observers frequently looked under and to the rear of the plane to avoid glare forward of the plane. Results of this experiment indicate that "acceptable" survey conditions must be rigorously defined prior to conducting the survey.

The bow monitors' detection of four schools on the trackline, although the schools were either small or non-dolphin species, illustrated that bow observers missed some trackline schools. The small number of schools detected by the bow monitors did not account for differences in the density estimates noted among the variables tested but bow monitors were subject to the same limitations as the bow observers.

There was no statistical evidence that either detection rates or density estimates differed between the experienced or inexperienced teams. The inexperienced team detected more schools but the experienced team observed more trackline sightings and their density estimate was larger. In fact, the difference between the two team's estimates was due to a relatively large estimate for the experienced team with good sun condition data (Table 3) and possibly due to the relatively poor fit of the FS models to both teams' data. The experienced team's poor sun condition and the inexperienced team's good and poor sun conditions data yielded very similar estimates of density.

The relatively large estimate of density for the experienced team's good sun condition data may be due to (1) incorrect recording of sightings near the trackline by the experienced team during good sun conditions so that an inordinate number of the sightings were noted on the trackline, (2) trackline schools were missed by the experienced team during poor sun conditions and by the inexperienced team during both good and poor sun conditions, or (3) sampling variability because of small sample sizes.

If incorrect recording occurred for the experienced team during good sun conditions, the rate at which schools in that stratum were detected off the trackline should be correspondingly lower. However, the experienced team's good sun and poor sun off-track detection rates were approximately equal and were only slightly less than the inexperienced team's off-track detection rates during both sun conditions (Figure 8). It is possible (2) above occurred but the estimate for the experienced team's good sun condition was based upon a relatively small data sample. Only 16% (1840 km) of the total searching effort and 17% of the total sightings were completed by the experienced team during good sun conditions. In either case, differences in detection rates or density estimates for the teams with different sun conditions were not statistically different; therefore, experience of observers in detecting dolphins in aerial surveys is not a significant factor.

Observer performance has been found to have a significant effect in other census studies (LeResche and Rausch 1974 and Leatherwood et al. 1978). Dirschl et al. (1981) designed an elaborate 2-month training program to insure selection of competent observers. These studies utilized strip or quadrant studies where observers were required to detect all schools in a defined area, whereas, I required all schools be detected only on the trackline.

Erroneous differences among density estimates for variables being tested may result if the estimation models fit poorly or are applied inconsistently among data strata. I attempted to avoid these problems by ensuring that the models closely fit the sighting distributions near the origin. One indication of a model's performance is the degree in which the model's density estimates for the various strata meet the "pooling robustness" criteria (Burnham et al. 1980).

A model is pooling robust if its use provides density estimates of the total data set equal to the sum of the density estimates of data in each stratum (such as good and poor sun strata). For r strata of l_r km in length such that $l_1 + \ldots + l_r = L$ the total length of line searched, an estimate of density $\hat{D}_j$ can be calculated for each stratum such that

$$\hat{D}_j = \frac{n_j \hat{f}_j(0)}{2 l_j}$$

A combined estimate of density for all strata ($\hat{D}_s$) can be calculated by weighting each $\hat{D}_j$ by its respective line length searched and summing over strata as

$$\hat{D}_s = \frac{\sum_{j=1}^{r} l_j \hat{D}_j}{\sum_{j=1}^{r} l_j}$$

An estimate can also be calculated for all data pooled over all strata ($\hat{D}_p$) and the estimator is said to be pooling robust if

$$\hat{D}_s = \hat{D}_p$$

Combined density estimates ($\hat{D}_s$) of data stratified into the various categories were very similar to the pooled estimate ($\hat{D}_p$) (Table 5). The stratified estimates were only slightly larger than the respective pooled estimates and were within 5.1% or less of the pooled estimate.

There was concern during the survey that the rates of detecting schools for the left and right observers might be adversely affected because their field of vision forward of the plane was restricted by the airplane's wings which were attached to the plane near the ventral portion of the fuselage (Holt 1983b). The spike in the perpendicular distance distribution at the origin for pooled data indicated this may have occurred (Figure 3). The spike was present predominantly for data collected during rough sea conditions. The off-track detection rate, as expected, was lower during rough seas than during calm seas. The obstructed view may have contributed to the low off-track detection rate during rough seas.

The cause for the mode in the perpendicular sighting distributions at 1.11 km is unclear. The mode was present for the inexperienced team's calm sea data. It was not due to visual estimation errors of the perpendicular distances since the majority (89%) of the distances were measured electronically and were provided to the data recorder by the pilots at the time of the sightings. This mode, unlike the one at the origin, should have minimal affect on the density estimates but the LT models poorly account for the mode.

The study area was defined to encompass a region that was surveyed proportionally uniformly under all experimental conditions without spatial stratification. This attempted to ensure a balanced experimental design by preventing confounding of the variables tested with possible density gradients in the area surveyed. Inclusion of some survey effort in the extreme northern, southern and offshore regions was questionable because the proportion of rough weather encountered was substantially greater than encountered in the study area and because the number of dolphin schools detected per km searched differed from those in the study area. This data represented a very small proportion of the total data (7.4%) and Appendix 5 includes the effect of including this data.

CONCLUSIONS

Sea state conditions were not found to significantly affect trackline detection rates or density estimates. Estimates of rates of detecting trackline schools and school density during calm and rough seas were similar.

Sun glare conditions significantly affected density estimates. Density estimates during poor sun conditions were 39% smaller than during good conditions.

Use of a bow monitor to independently search the trackline for dolphin schools indicated some schools were missed by the bow observer. The schools were small in size or non-dolphins. Although the density estimate for the experienced team's data was larger than for the inexperienced team's data, the difference was not statistically significant. Experience was not shown to be a critical factor in ability to detect dolphin schools on aerial surveys.

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Table 1. Vertical and horizontal sun positions used to classify sun glare into good and poor sun conditions.

Vertical Sun	Horizontal Sun
Good Sun	
1	4-8[1]
2	4-8
3	1-12
Poor Sun	
1	1-3,9-12
2	1-3,9-12
12	1-12
0[2]	0

[1]4-8 denotes positions 4 through 8 inclusive.

[2]Cloudy weather denoted by 0 vertical and 0 horizontal position.

Table 2. Rates of detecting dolphin schools under different conditions. Estimates are for data separated into calm (Csea) and rough (Rsea) sea conditions, good (Gsun) and poor (Psun) sun conditions, and experienced (Exp) and inexperienced (Ixp) observers.

Variable	Distance Searched (km)	Percent km Searched	Number Schools Detected	Percent All Schools Detected	Overall Detection Rate (Schools/ 1000 km)	S.E. Overall Detection Rate	Number Trackline Schools Detected	Percent Trackline Schools Detected	Trackline Detection Rate (Schools/ 1000 km)	S.E. Trackline Detection Rate
All Data	11781	100.0	263	100.0	22.32	1.67	58	100.0	4.92	0.66
Csea	4428	37.6	118	44.9	26.65	2.63	22	37.9	4.97	1.11
Rsea	7354	62.4	145	55.1	19.72	2.14	36	62.1	4.90	0.83
Gsun	3300	28.0	79	30.0	23.94	3.17	23	39.7	6.97	1.50
Psun	8481	72.0	184	70.0	21.70	1.96	35	60.3	4.13	0.71
Csea-Gsun	1414	12.0	37	14.1	26.17	4.13	8	13.8	5.66	1.80
Csea-Psun	3014	25.6	81	30.8	26.87	3.37	14	24.1	4.65	1.39
Rsea-Gsun	1886	16.0	42	16.0	22.26	4.63	15	25.9	7.95	2.25
Rsea-Psun	5467	46.4	103	39.2	18.84	2.40	21	36.2	3.84	0.79
Exp. Team	6065	51.5	125	47.5	20.61	2.01	33	56.9	5.44	0.89
Ixp. Team	5717	48.5	138	52.5	24.14	2.70	25	43.1	4.37	0.99
Exp. Csea	2161	35.6	53	42.4	24.52	3.15	12	36.4	5.55	1.45
Exp. Rsea	3903	64.4	72	57.6	18.45	2.57	21	63.6	5.38	1.13
Exp. Gsun	1840	30.3	44	35.2	23.91	3.57	16	48.5	8.69	2.01
Exp. Psun	4225	69.7	81	64.8	19.17	2.42	17	51.5	4.02	0.91
Ixp. Csea	2266	39.6	65	47.1	28.68	4.19	10	40.0	4.41	1.67
Ixp. Rsea	3450	60.4	73	52.9	21.16	3.52	15	60.0	4.35	1.22
Ixp. Gsun	1460	25.5	35	25.4	23.97	5.62	7	28.0	4.79	2.22
Ixp. Psun	4257	74.5	103	74.6	24.20	3.08	18	72.0	4.23	1.09

Table 3. Estimates of parameters used in computing dolphin density ($\hat{D}$) for calm (Csea) and rough (Rsea) sea conditions, during good (Gsun) and poor (Psun) sun conditions, and for experienced (Exp) and inexperienced (Ixp) observer teams.

Variable	Terms in Model	Number Schools Detected (N)	S.E. (N)	$\hat{f}(0)$	S.E. $\hat{f}(0)$	Density ($\hat{D}$) (Schools/ 1000 km^2)	Var ($\hat{D}$)	S.E. ($\hat{D}$)	C.V. ($\hat{D}$)	Number Days Searched
All Data	9	263	19.66	2.24	0.249	25.00	11.218	3.349	0.134	423
Csea	8	118	11.66	1.93	0.322	25.72	24.865	4.986	0.194	161
Rsea	9	145	15.75	2.53	0.336	24.94	18.312	4.279	0.172	262
Gsun	9	79	10.47	2.91	0.452	34.83	50.582	7.112	0.204	120
Psun	9	184	16.66	1.95	0.291	21.15	13.633	3.692	0.175	303
Csea-Gsun	6	37	5.83	2.23	0.439	29.18	54.123	7.357	0.252	52
Csea-Psun	8	81	10.14	1.77	0.378	23.78	34.664	5.888	0.248	109
Rsea-Gsun	9	42	8.73	3.54	0.001	39.42	67.127	8.193	0.208	68
Rsea-Psun	9	103	13.12	2.14	0.394	20.16	20.369	4.513	0.224	194
Exp. Team	9	125	12.17	2.96	0.364	30.50	22.890	4.784	0.157	218
Ixp. Team	8	138	15.45	1.70	0.289	20.52	17.443	4.177	0.204	205
Exp. Csea	9	53	6.81	2.50	0.554	30.66	61.670	7.853	0.256	79
Exp. Rsea	9	72	10.05	3.38	0.001	31.18	18.937	4.352	0.140	139
Ixp. Csea	5	65	9.49	1.61	0.274	23.09	26.809	5.178	0.224	82
Ixp. Rsea	9	73	12.15	1.90	0.452	20.10	34.060	5.836	0.290	123
Exp. Gsun	9	44	6.57	3.62	0.572	43.28	88.544	9.410	0.217	67
Exp. Psun	9	81	10.23	2.51	0.000	24.06	9.234	3.039	0.126	151
Ixp. Gsun	9	35	8.21	2.01	0.668	24.09	96.044	9.800	0.407	53
Ixp. Psun	8	103	13.13	1.66	0.333	20.08	22.782	4.773	0.238	152

Table 4. Number of segments for all schools (A) and trackline schools (B) classified by Beaufort state and numbers of sightings detected per segment. Values in parentheses are percent of column totals.

A. Number Sightings/ Segment	Beaufort 1	2	3	4	5	Total
0	8 (38.1)	65 (50.8)	106 (55.5)	45 (86.5)	7 (100.0)	231 (57.9)
1	9 (42.9)	43 (33.6)	57 (29.8)	6 (11.5)	0 (0.0)	115 (28.8)
2	2 (9.5)	11 (8.6)	17 (8.9)	0 (0.0)	0 (0.0)	30 (7.5)
3	2 (9.5)	6 (4.7)	6 (3.1)	0 (0.0)	0 (0.0)	14 (3.5)
4	0 (0.0)	3 (2.3)	4 (2.1)	1 (1.9)	0 (0.0)	8 (0.0)
5	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
6	0 (0.0)	0 (0.0)	1 (0.5)	0 (0.0)	0 (0.0)	1 (0.3)
Total	21	128	191	52	7	399

B. Number Sightings/ Segment	Beaufort 1	2	3	4	5	Total
0	18 (85.7)	114 (89.1)	160 (83.8)	49 (94.2)	7 (100.0)	348 (87.2)
1	3 (14.3)	12 (9.4)	30 (15.7)	2 (3.8)	0 (0.0)	47 (11.8)
2	0 (0.0)	1 (0.8)	1 (0.5)	1 (1.9)	0 (0.0)	3 (0.8)
3	0 (0.0)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.3)
Total	21	128	191	52	7	399

Table 5. Comparison of stratified density estimates to pooled density estimates for pooling robustness during good (GS) and poor (PS) sun conditions, during calm (CS) and rough (RS) seas, and for experienced (EXP) and inexperienced (IXP) observer teams.

Variables pooled	Stratified estimate ($\hat{D}_s$) (schools/ 1000 km^2)	Pooled estimate ($\hat{D}_p$) (schools/ 1000 km^2)	Percent $\hat{D}_s$ different from $\hat{D}_p$
Gs + Ps	25.24	25.00	1.0
Cs + Rs	25.23	25.00	1.0
Csgs + Csps + Rsgs + Rsps	25.25	25.00	1.0
Exp + Ixp	25.66	25.00	2.6
Expcs + Exprs	30.99	30.50	1.6
Expgs + Expps	29.89	30.50	2.0
Ixpcs + Ixprs	21.29	20.52	3.8
Ixpgs + Ixpps	21.10	20.52	2.8
Expcs + Ixpcs	26.79	25.72	4.2
Exprs + Ixprs	25.98	24.94	4.2
Expgs + Ixpgs	34.79	34.83	0.1
Expps + Ixpps	22.06	21.15	4.3
Expcs + Exprs + Ixpcs + Ixprs	26.28	25.00	5.1
Expgs + Expps + Ixpgs + Ixpps	25.63	25.00	2.5

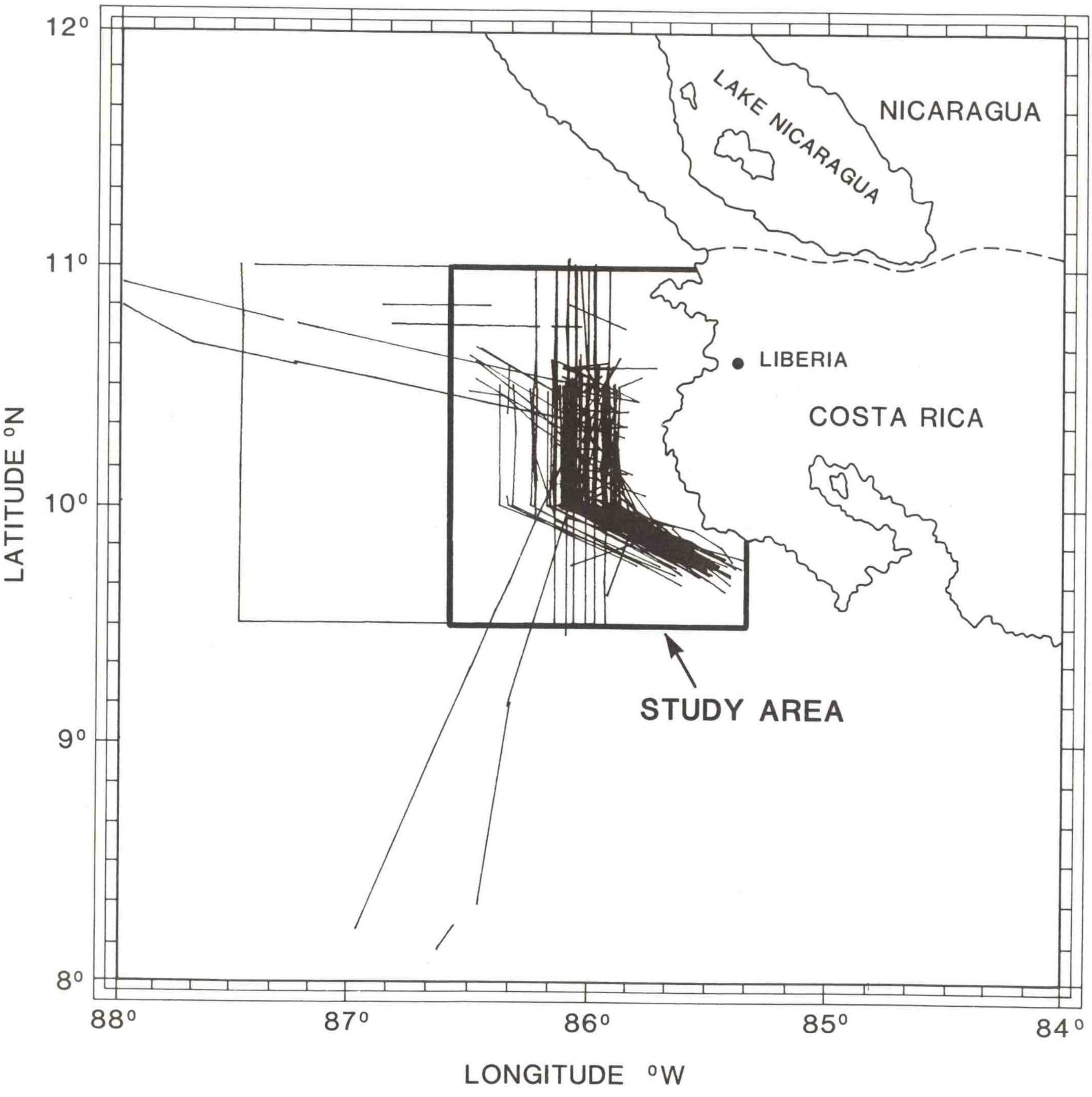

Figure 1. Tracklines flown in survey area. Study area is delineated in bold lines.

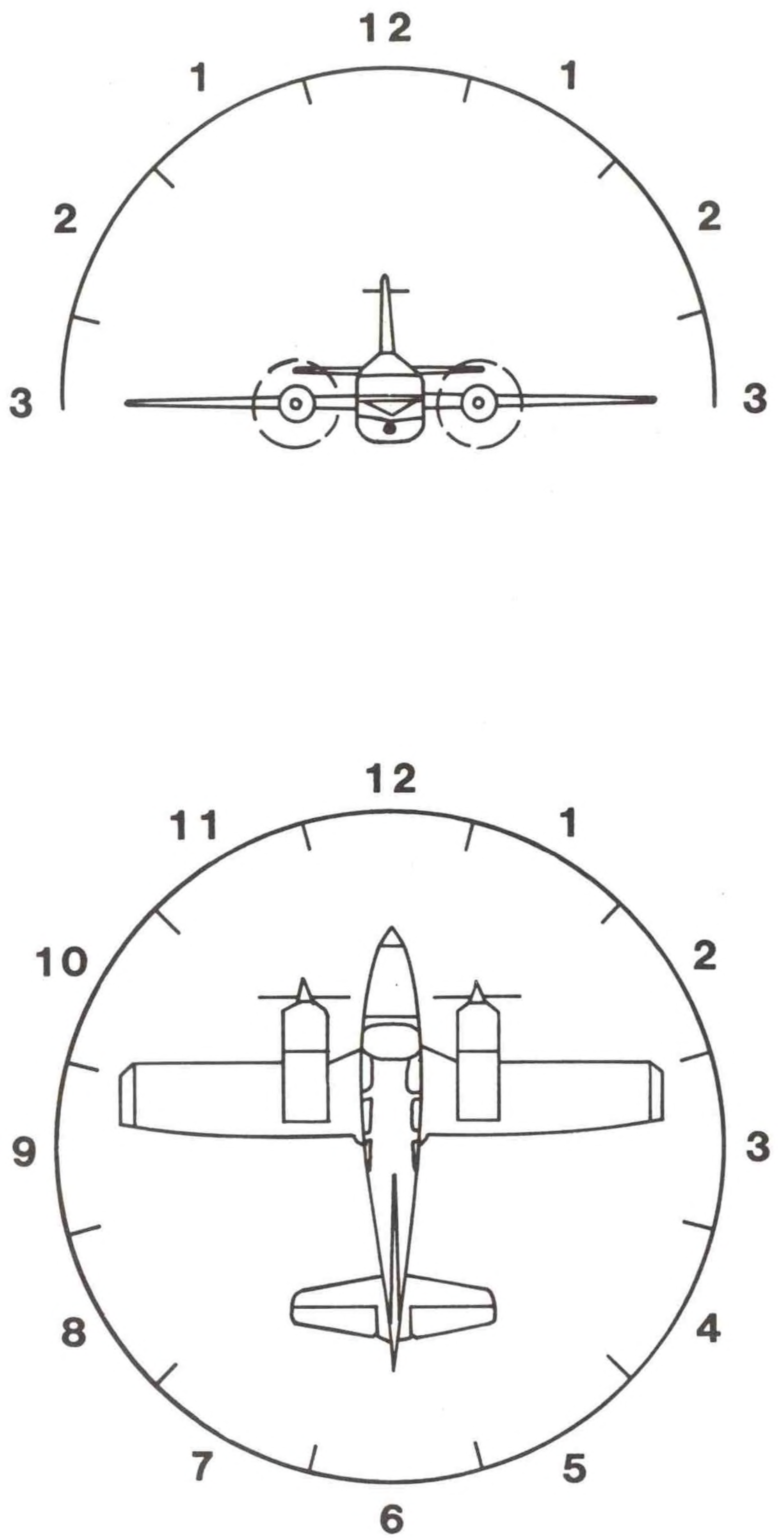

Figure 2. Horizontal and vertical positions used to record orientation of the sun relative to the airplane.

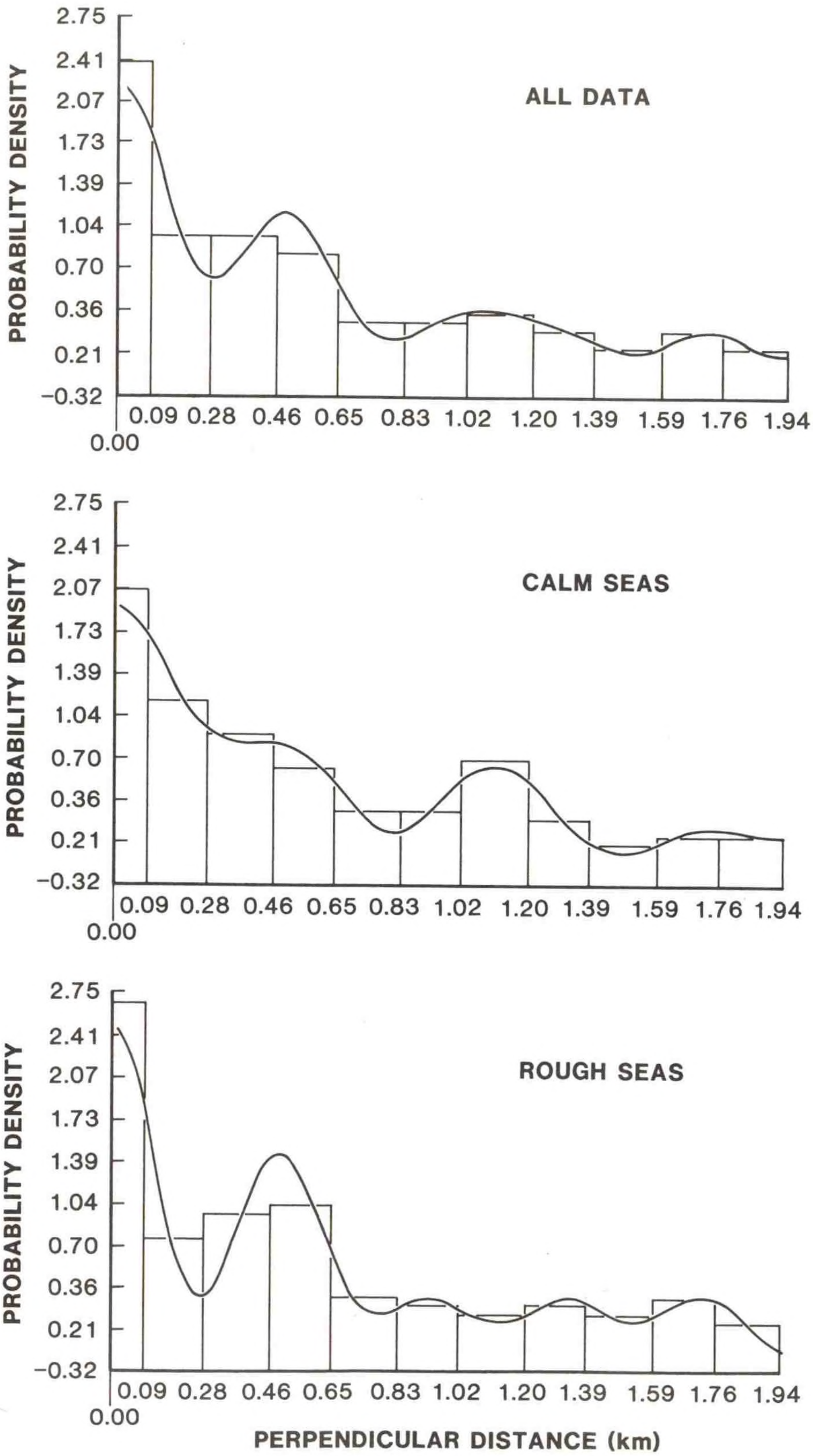

Figure 3. Fit of the Fourier series model to dolphin line transect data. Fits are shown for pooled data, calm sea state data and rough sea state data.

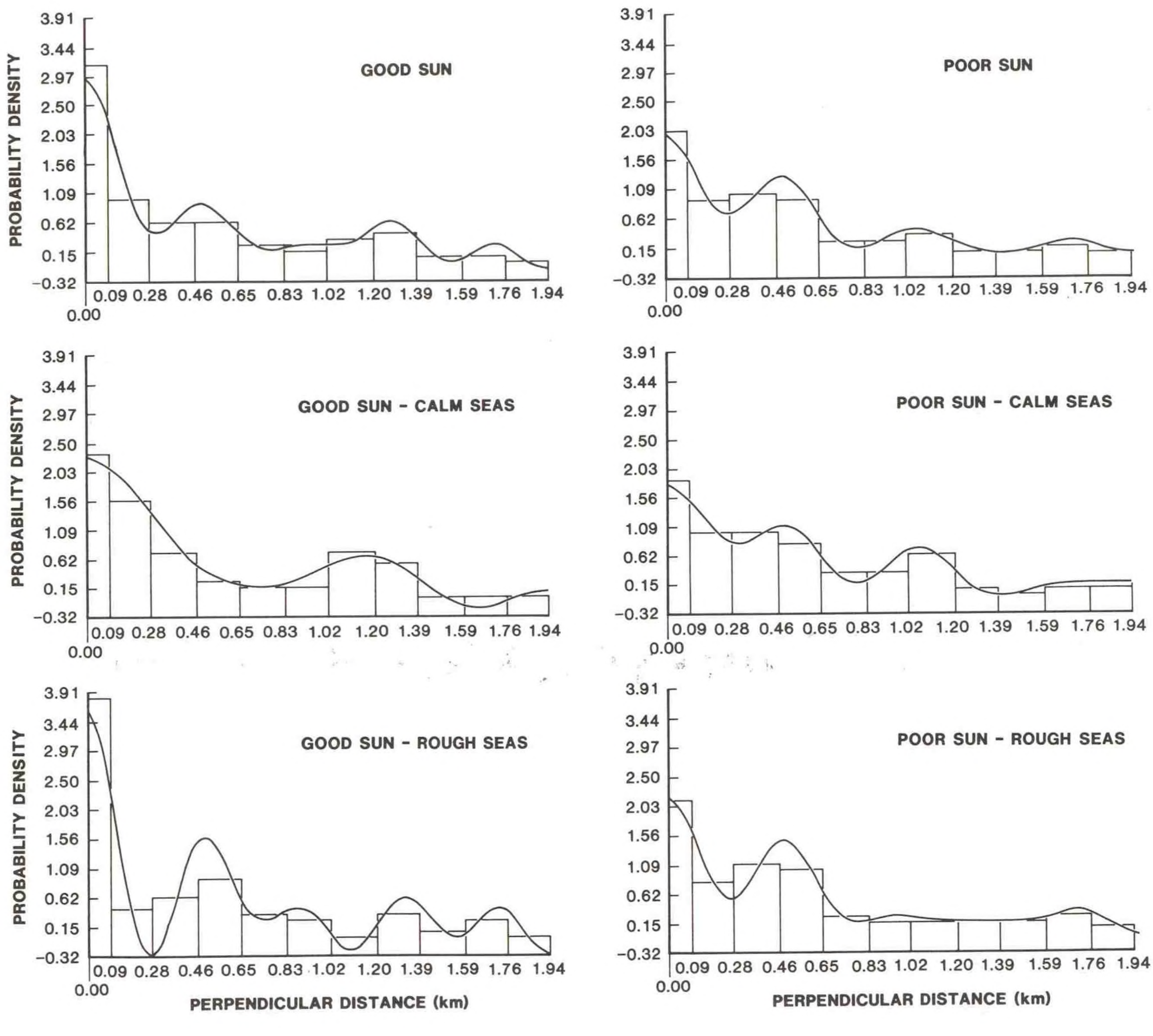

Figure 4. Fit of the Fourier series model to dolphin line transect data. Fits are shown for good sun conditions, poor sun conditions, and combinations of calm and rough sea and good and poor sun conditions.

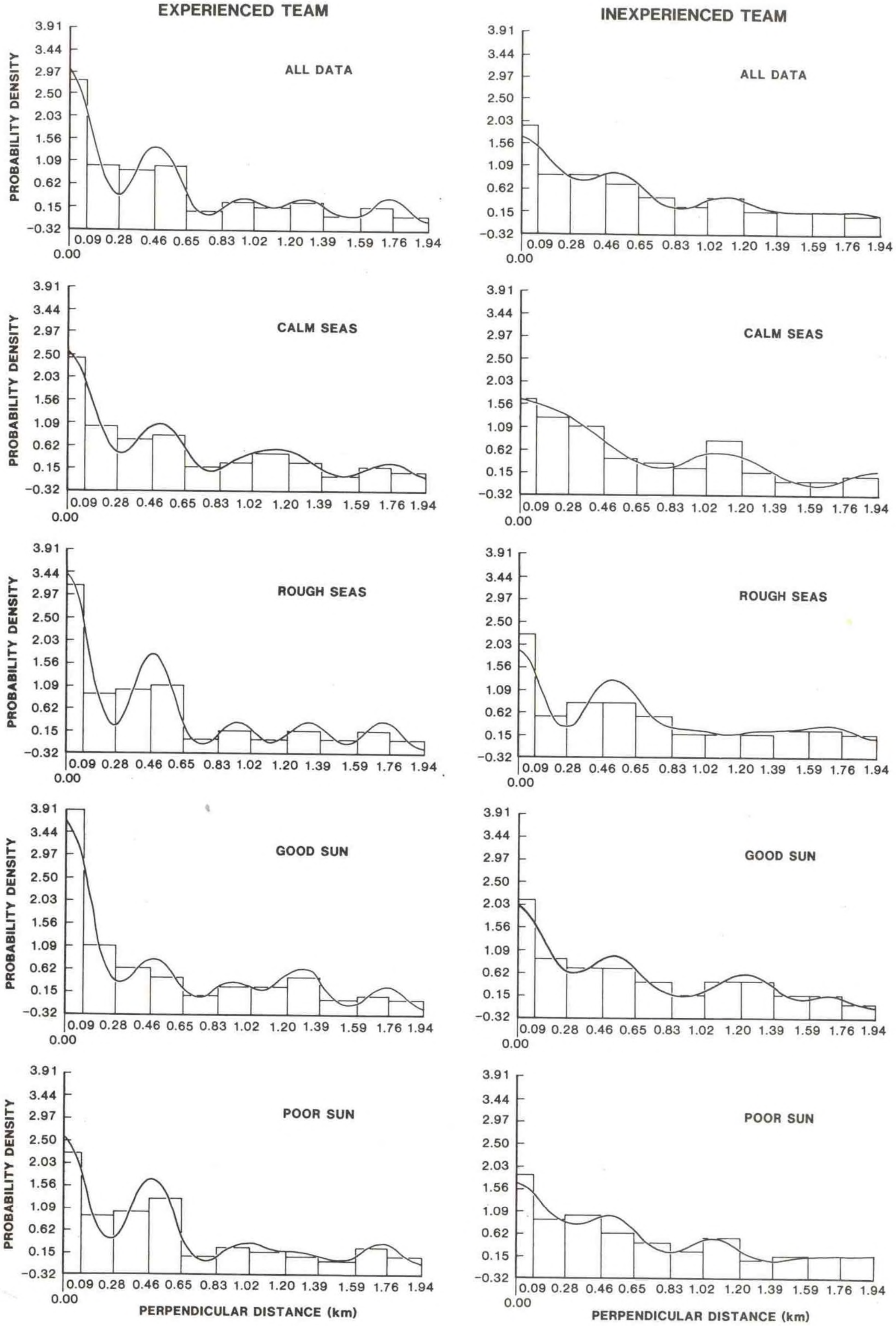

Figure 5. Fit of the Fourier series model to dolphin line transect data. Fits are shown for experienced (Exp) and inexperienced (Ixp) teams' data during calm and rough sea states and during good and poor sun conditions.

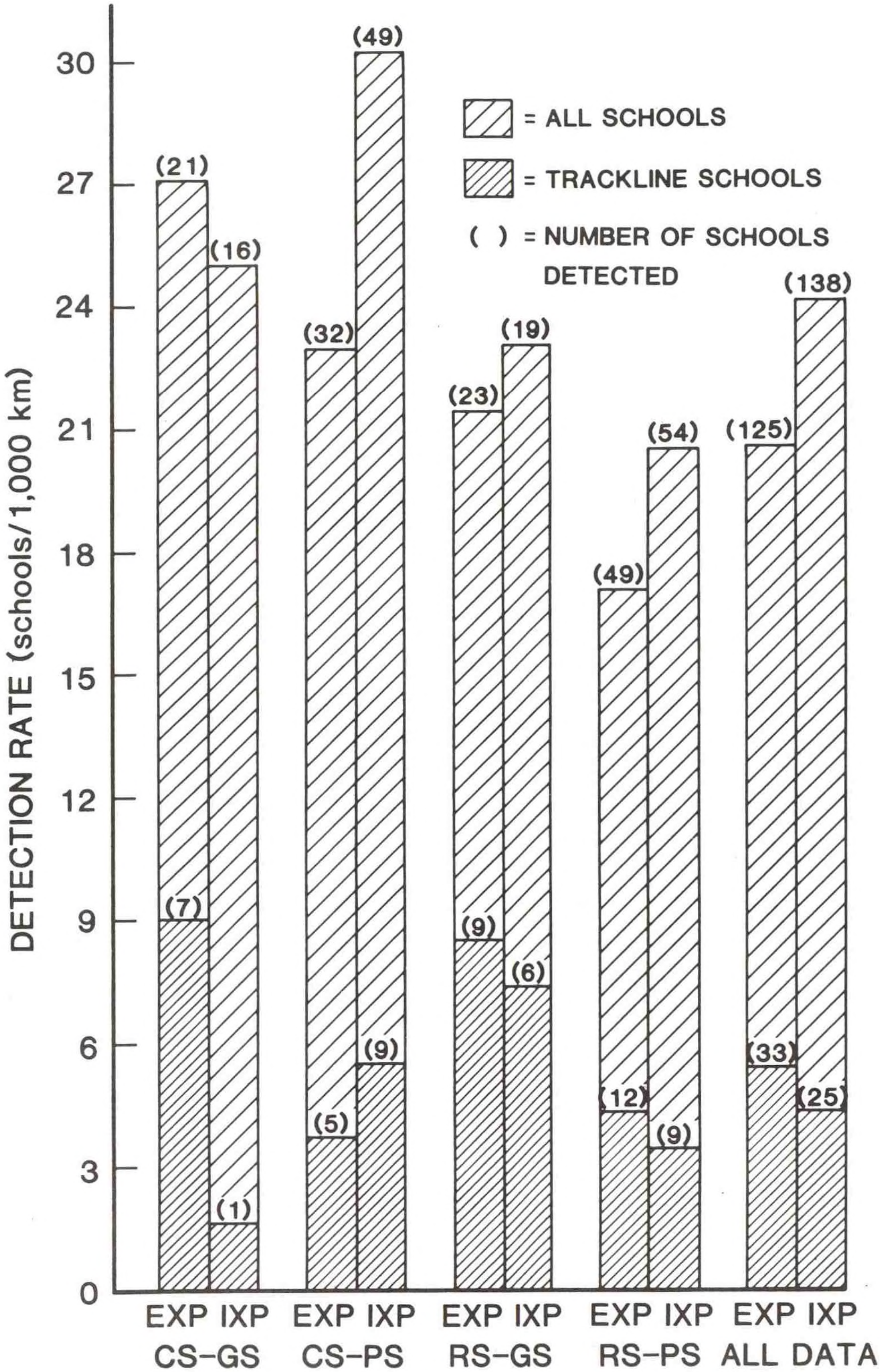

Figure 6. Rate of detecting dolphin schools for perpendicular distance data for the experienced (Exp) and inexperienced (Ixp) teams during calm sea-good sun (Cs-Gs), calm sea-poor sun (Cs-Ps), rough sea-good sun (Rs-Gs) and rough sea-poor sun (Rs-Ps) conditions.

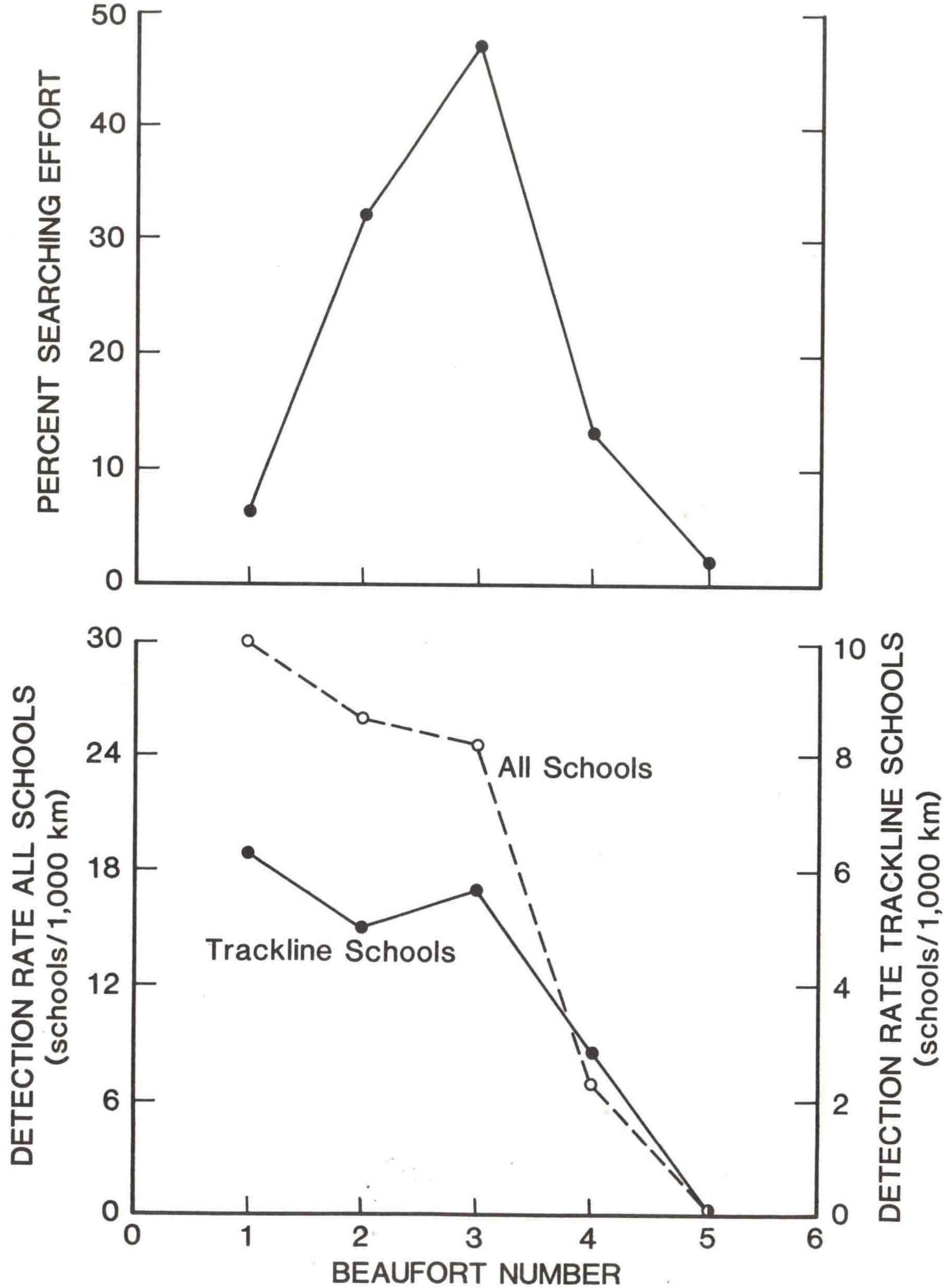

Figure 7. Percent searching effort and detection rates of all schools and trackline schools at each sea state (Beaufort number).

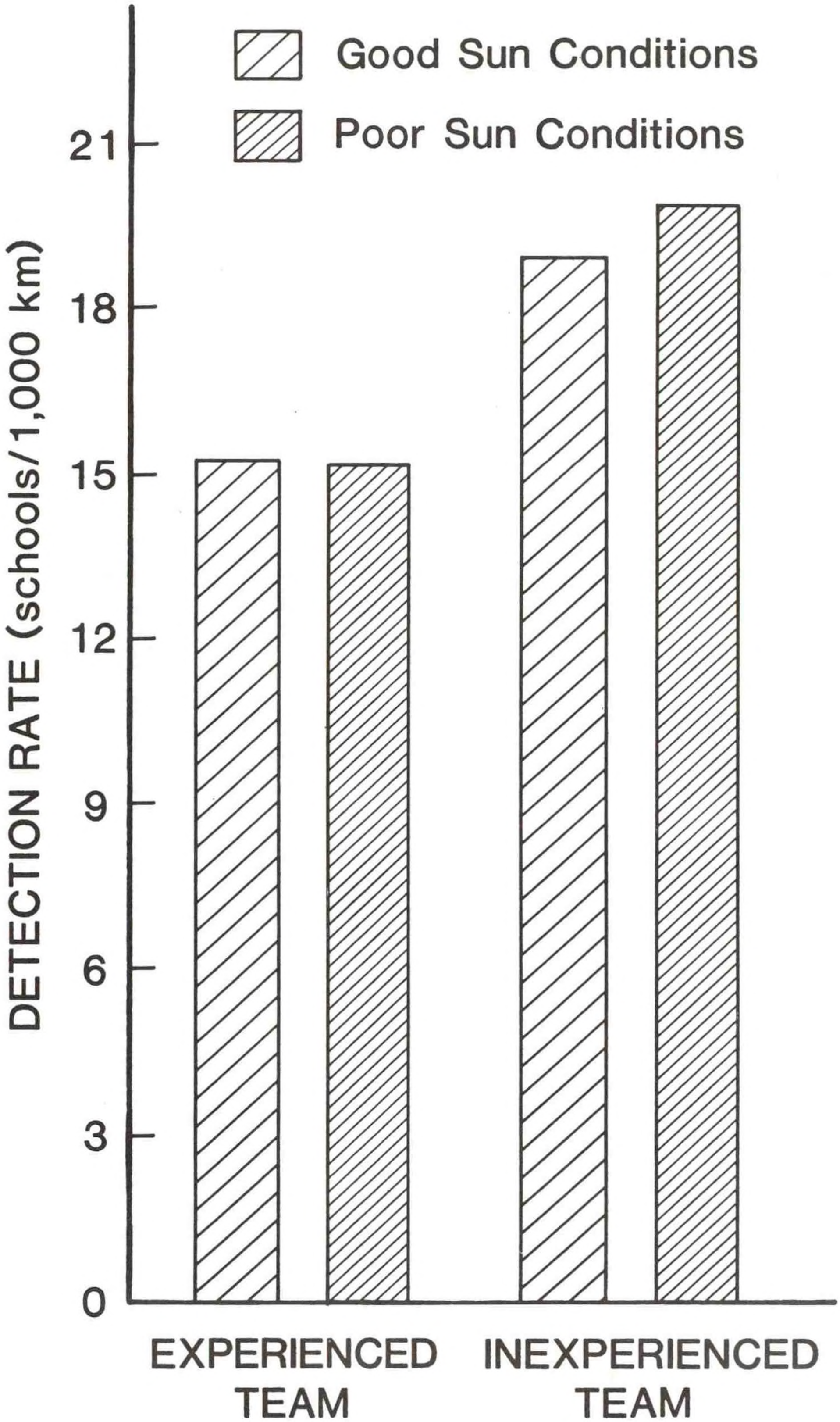

Figure 8. Detection rate of dolphin schools off the trackline for experienced and inexperienced observer teams.

APPENDIX 1

Investigation of Aircraft Speed on Dolphin Detection Rates

The association of the aircraft's speed and the rates of detecting dolphin schools was investigated although it was not an objective included in the experimental design. The speed of the aircraft was measured by recording the plane's "air speed" from the velocity of the wind across the plane's wings and by calculating the "ground speed" from the rate that the aircraft traversed between two fixed points. Air speed was recorded from the planes instruments while ground speed (velocity) was calculated from successive positions recorded during an elapsed time. The pilots were instructed to maintain an air speed of 222 km/hr but varying wind direction and velocity varied ground speed.

Substantial variation in aircraft velocity may have also occurred due to imprecision in recording time and geographic position. Time was not recorded precisely but rather, was measured using a digital clock that displayed time in minutes only. The possible error in elapsed time for each period of continuous searching effort (subleg) was -1 to +1 minute, depending on how much time had elapsed between changes in the clock at the moments beginning and ending times were recorded.

Velocity (km/hr) was calculated as

$$\text{Velocity} = 60 * \text{distance}/\text{time} \qquad (1)$$

where distance was the difference between beginning and ending positions for each subleg and time was elapsed time (minutes) during the subleg.

The potential effect of error in recorded time upon computed velocity was investigated using several representative values of time that were varied by plus or minus 1 minute. If the true elapsed time was 2 minutes but the recorded time was 1 minute, the computed velocity was 2/1 times, or twice, the true velocity. If the recorded time was 3 minutes, then the computed velocity was 2/3 times, or two thirds, the true velocity. If the true time was only 1 minute, but recorded time was 0 because the clock did not change during the subleg, then computed velocity would be infinite. All sublegs with recorded time of 0 were omitted from the analysis. In general, sublegs of few minutes sustained larger relative errors in velocity and accounted for most of the very low or high rates of velocity (Figure A1-1).

Because velocity of sublegs of very few minutes were the most affected by recording errors, the stability of average detection rates over discrete velocity intervals was investigated by successively eliminating sublegs of increasing time from the data set. For velocity intervals of 10 km/hr, average detection rates were computed with 1, 1 and 2, and 1 through 3 minute sublegs removed in succession. It was found from qualitative examination that elimination of these sublegs did not change average detection rates "substantially" over velocities ranging between 160 and 300 km/hr, while detection rates outside this range varied greatly. Because little effort occurred outside this range (5.8% of total effort) and the occurrence of velocities outside this range was unlikely, the initial analysis did not include this data. All sublegs within the range were used. However, even the uncertainty associated with computed velocities for sublegs with lengths of greater than 3 minutes covered a substantial portion of the range.

Multiple regression analyses were used to investigate factors affecting rates of detecting trackline schools. The dependent, or response, variable was trackline detection rate (schools per 1000 km) while variables investigated as possible predictors were velocity, sea state (calm or rough), sun condition (good or poor), team (experienced or inexperienced), velocity squared (to allow for a curvilinear relationship), and cross products of velocity with sea state, sun condition, and team (to allow for possible interaction of velocity with any of these variables). Variable selection was based on three strategies: results of forward and backward stepwise regression, comparison of models by the technique of additional reduction in residual sum of squares, and qualitative inspection of plots to determine extent of relationship with detection rate. Velocity was always the first variable to be included because its contribution to a significant regression was of primary interest.

The need for weighted least squares was investigated by plotting the variance of detection rate for each 10 km/hr interval between 160 and 300 km/hr as a function of velocity or length of effort (km searched). If a relationship was apparent, a weighted regression was used; otherwise, no weights were used. A significant regression was one which had a regression F statistic exceeding the 0.05 level of probability.

Both forward and backwards stepwise linear regressions for trackline detection rates obtained during velocities within the range selected velocity and velocity-sun interaction. The variance of trackline detection rate within 10 km/hr intervals was found to be significantly and inversely related to velocity at the midpoint of the intervals ($p<0.01$), so weighted least squares analysis was performed using velocity as the weighting factor. The results of weighted least squares were compared to those for ordinary least squares. The regression on velocity alone using either ordinary or weighted least squares was significant (Tables A1-1 and A1-2, respectively). The additional reduction in residual sum of squares upon adding the velocity-sun interaction term was not significant for weighted least squares (Table A1-3) but was significant for ordinary least squares method (Table A1-4).

A plot of detection rate versus velocity (Figure A1-2) revealed that two points with high detection rates had excessive influence on the least squares regression line because their computed velocities (189 and 191 km/hr) were near the low end of the 160-300 km/hr range. Therefore, the stepwise unweighted and weighted regressions were repeated with these two points removed. There was no significant regression on velocity when these two segments were removed (Tables A1-5 and A1-6). The addition of the velocity-sun interaction term was not significant using the weighted least squares method (Table A1-7) but was for the ordinary least squares method (Table A1-8).

Because of the extreme influence of only two points out of 526 points, the effect of the relative position of these points along the range was investigated. Both of these points were obtained during sublegs with recorded times of 2 minutes during which 1 school was detected. When 1 minute was subtracted from the recorded time of each of these two points and velocity re-computed, the resulting velocities were 378 and 382 km/hr. The regression was now significant but with opposite slope. Subtracting 0.5 minutes from the 2 minute recorded times of the two points and re-computing velocity resulted in values of 252 and 255 km/hr and the regression was not significant since the values were near the midpoint of the range.

The extreme influence exerted by just two points upon the regression analysis was further investigated by simulation. The simulation studies added uniformly distributed random errors between -1 and +1 minutes to each recorded time, re-computed velocities and then completed simple regression analysis investigating the relationship of detection rate to velocity. The procedure was repeated 10 times for each of three approaches.

First, all data including sublegs with velocities outside the 160-300 km/hr range were randomized and the regression relationship was determined for all points within the range. This allowed points which may have had true velocities within the range to be included in the analysis. The second approach randomized all velocities but regression analysis was performed without any range restriction. The third approach differed from the second only in that one "outlier" point was removed and the analysis repeated. Weighted regressions were not performed during the simulations because of the complexity involved in determining the need for weights at each repeat step of the simulation.

For the first approach, none of the 10 regressions on velocity were significant. In fact, compared to the value of 2.172 obtained for the unweighted regression on the original data, 7 of the 10 simulated F statistics had values less than 1.0, one was less than 2.0, and two were between 2.0 and 2.5. Since a corresponding change should occur in the F statistic for a weighted regression, this suggest that a significant result might be expected only 2 out of every 10 times if the study was repeated many times.

All 10 regressions were significant using the second approach. This was due to the occurrence of a single subleg which had a detection rate of 5460 schools/1000 km. This subleg had one sighting but only 0.18 km searched. The subleg was terminated directly after it began. Our methods of recording time or position were too imprecise to accurately determine either velocity or distance for these short sublegs. The third approach, which removed this point, resulted in only 1 significant regression on velocity.

In summary, there was large uncertainty in velocity due to imprecision in recording time and possibly distance. Potential errors in recorded time could account for computed velocities that could fall along a substantial portion of the range of velocities encountered during the survey. A few points, determined from sublegs of very few minutes, greatly affected the least squares fit. Changing the velocities by adding to recorded time random errors within limits of reasonably expected potential error altered the regression results drastically. The results of simulations showed that results like those obtained using the linear regression analysis were unlikely over a large number of simulated samples. It is therefore concluded that the data available are inadequate to either demonstrate or disprove that any relationship exists between dolphin trackline detection rate and aircraft velocity.

A detailed investigation of the rates of detecting all schools (on and off the trackline) was not conducted since the same errors in recording times were also present for this data. Forward and backwards stepwise linear regression for all sightings were completed with velocity squared and seastate selected as the best predictive variables. The curvilinear relationship indicated that higher detection rates were present for sublegs with low and high computed velocities (Figure A1-3). Sublegs of few minutes duration, which were most affected by data recording errors, tended to have both low and high computed velocities (Figure A1-1). Since searching was frequently terminated to inspect a sighting, short sublegs may have resulted when a sighting was detected shortly after the subleg began. This would result in short sublegs having high detection rates with potentially large errors in recorded time and, hence, with relatively low or high computed velocities.

Table A1-1. Weighted regression comparing dolphin trackline detection rates and aircraft ground speed.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	1	280555	280555	5.129	<0.05
Residual	524	28664672	54704		
Total	525	28945226			

Table A1-2. Ordinary regression comparing dolphin trackline detection rates and aircraft ground speed.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	1	1247.9	1247.9	4.686	<0.05
Residual	524	139522.0	266.3		
Total	525	140769.9			

Table A1-3. Weighted regression comparing dolphin trackline detection rates and aircraft ground speed plus speed and sun interaction effects.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	2	455742	227871	4.183	
Velocity	1	280555	280555	5.150	
Velocity*Sun	1	175187	175187	3.216	>.05
Residual	523	28489494	54473		
Total	525	28945239			

Table A1-4. Ordinary regression comparing dolphin trackline detection rates and aircraft ground speed plus speed and sun interaction effects.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	2	2445.6	1222.8	4.623	
Velocity	1	1247.9	1247.9	4.718	
Velocity*Sun	1	1197.7	1197.7	4.528	<0.05
Residual	523	138324.4	264.5		
Total	525	140770.0			

Table A1-5. Weighted regression comparing detection rates of all dolphin schools and aircraft ground speed.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	1	95921	95921	2.523	>0.05
Residual	522	19843340	38014		
Total	523	19939263			

Table A1-6. Ordinary regression comparing detection rates of all dolphin schools and aircraft ground speed.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	1	387.3	387.3	2.172	>0.10
Residual	522	93056.7	178.3		
Total	523	93444.0			

Table A1-7. Weighted regression comparing detection rates of all dolphin schools and aircraft ground speed plus speed and sun interaction effects.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	2	211987	105994	2.799	
Velocity	1	95921	95921		
Velocity*Sun	1	116066	116066	2.533	>0.05
Residual	521	19727276	37864		
Total	523	19939268			

Table A1-8. Ordinary regression comparing detection rates of all dolphin schools and aircraft ground speed plus speed and sun interaction effects.

Source	d.f.	Sum of Squares	Mean Square	F	p
Regression	2	1164.3	582.2	3.287	
Velocity	1	387.3	387.3		
Velocity*Sun	1	777.0	777.0	2.187	<0.05
Residual	521	92279.7	177.1		
Total	523	93444.0			

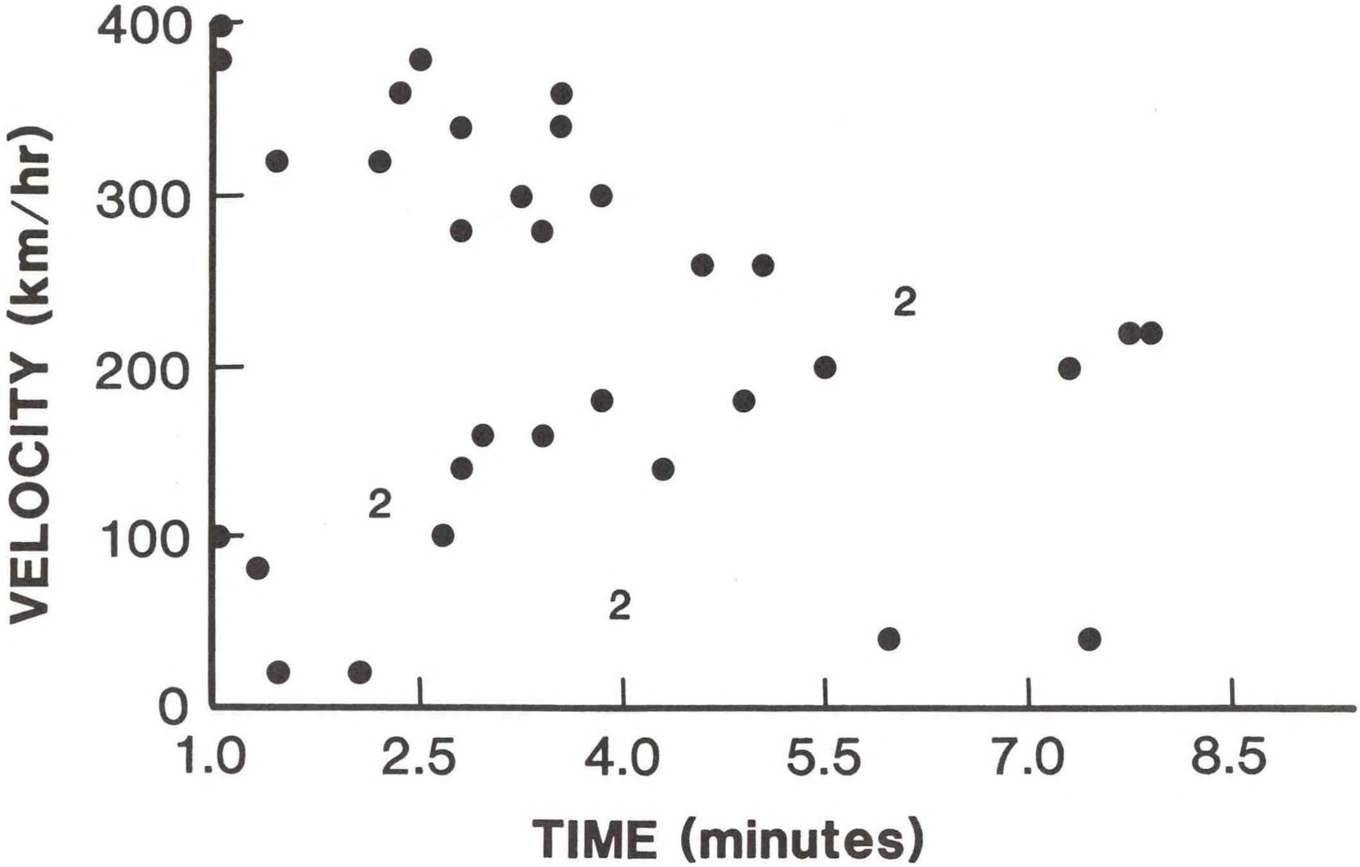

Figure A1-1. Comparison of length (minutes) of effort sublegs and aircraft velocity.

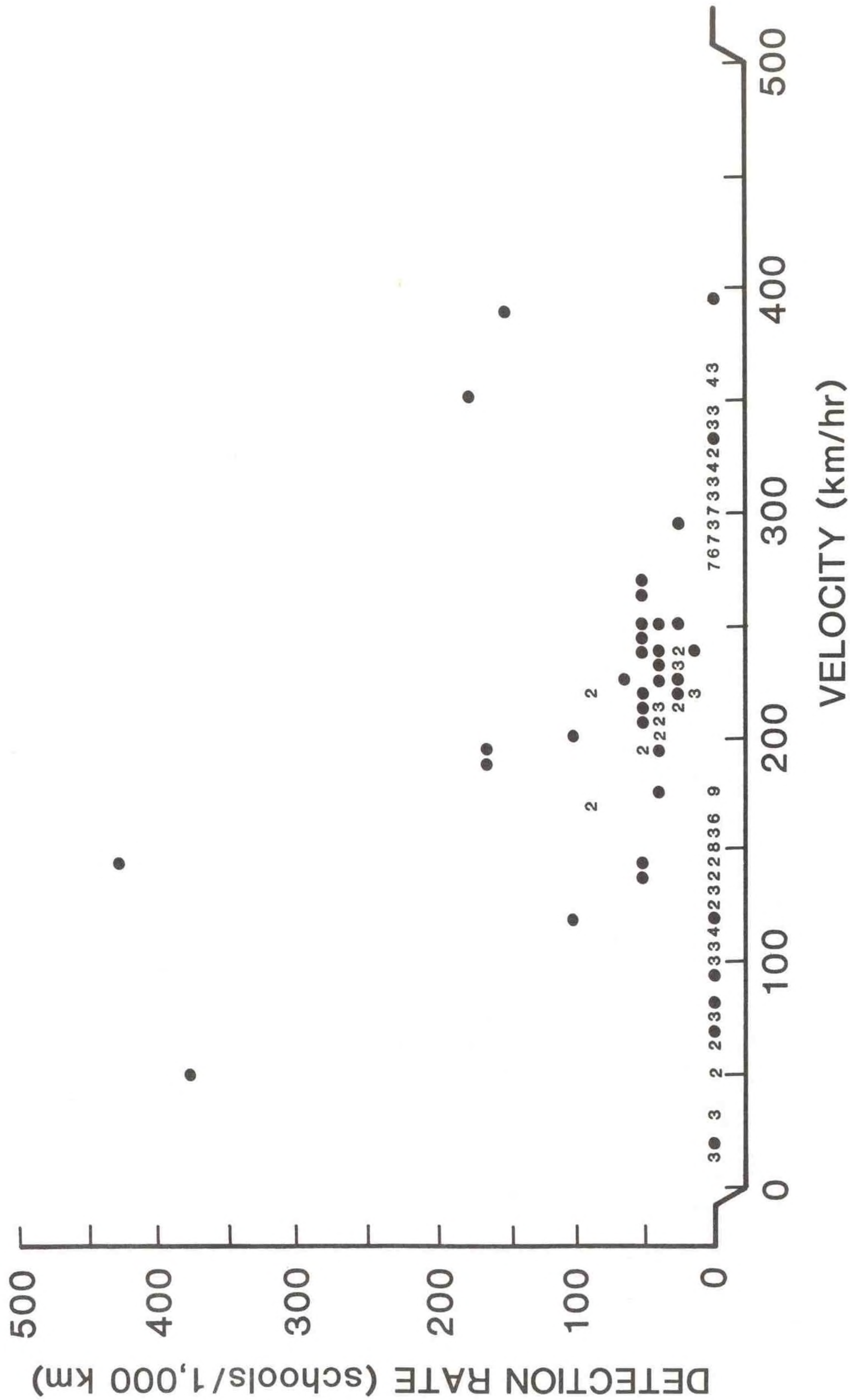

Figure A1-2. Comparison of aircraft velocity and rate of detecting trackline schools.

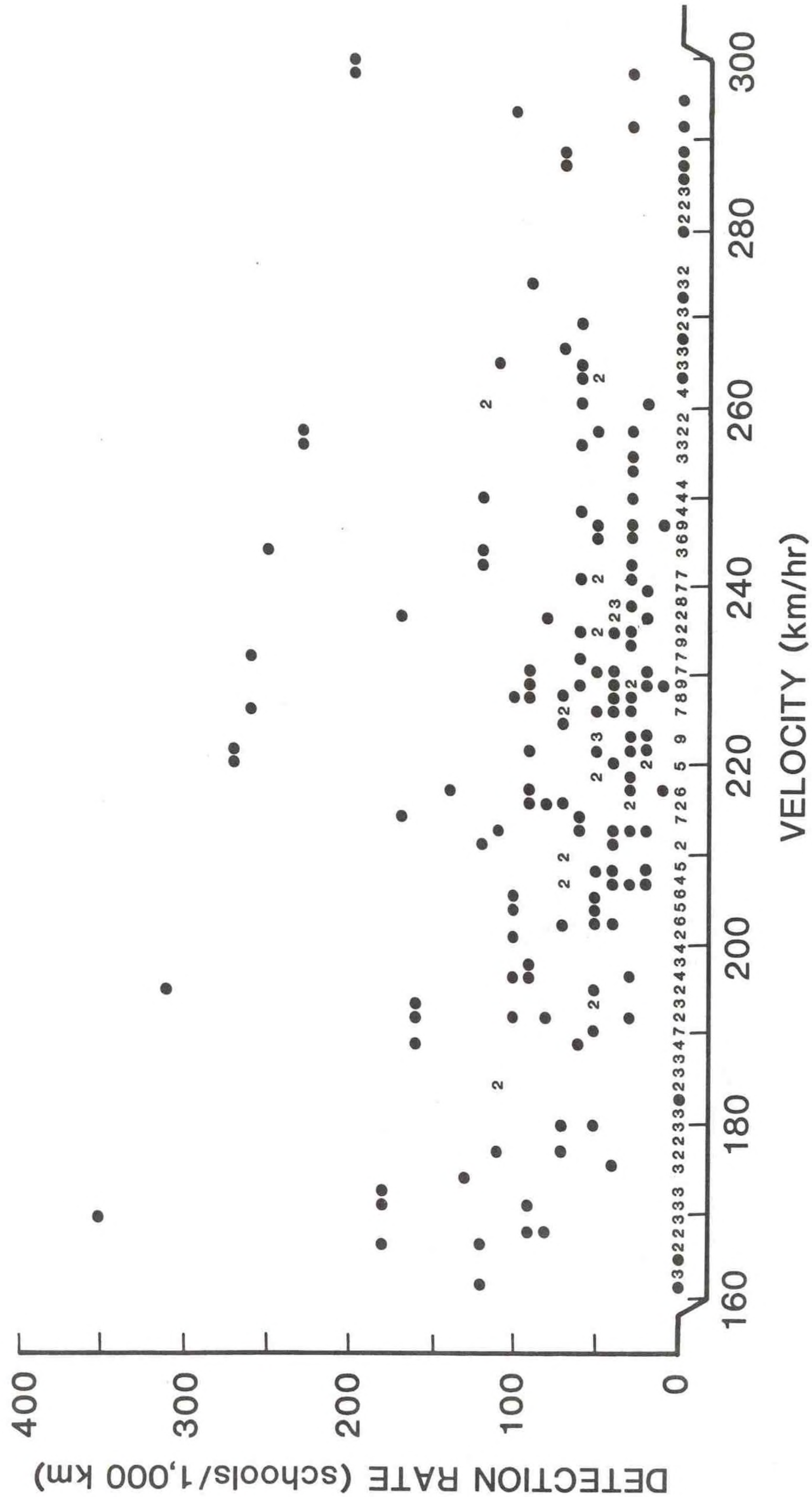

Figure A1-3. Comparison of aircraft velocity and rate of detecting all schools.

APPENDIX 2

Selection of Good and Poor Sun Glare Strata

Prior to execution of the experiment, criteria allocating survey effort at the various sun positions (Figure 2 of text) to good and poor sun glare conditions were developed primarily using experience gained in a previous aerial survey (Holt and Powers 1982). While conducting the experiment, these strata were observed to be inconsistent with the presence of trackline glare, therefore, observers were periodically questioned or periodically offered observations concerning the presence of glare on the trackline at specific sun positions. The presence of glare was noted on the survey effort form (Holt 1983b) and are descriptive in nature. They are not quantitative since the number of times a specific position was noted with trackline glare was not indicative of the severity of glare on the trackline at that position. In fact, from the beginning of the experiment, it was evident that severe glare existed at some sun positions (i.e., when the sun was directly in front or overhead the bow observer). Therefore, there was little necessity in repeatedly documenting the obvious.

Good and poor sun glare strata (Table A2-1) were developed using the observers comments indicating the presence of trackline glare at specific sun positions by applying the following criteria:

1) Trackline sun glare effects at each vertical sun position were assumed to occur symmetrically on either side of the trackline (i.e., for a given vertical sun position, if sun glare was indicated for horizontal 1 position then the same effects were assumed for horizontal 11 data.

2) Where no observer comment was available, trackline sun glare was assumed to occur at horizontal positions if sunglare was indicated at more lateral (aft) horizontal positions. For example, for a given vertical position, if sun glare was indicated at horizontal positions 3 and 9 then sun glare was assumed to be present for horizontal positions 2 and 10.

3) All vertical position 12 (direct overhead) effort was assigned to the poor sun stratum. When the sun was at vertical position 12, horizontal positions were redundant and were difficult to assign. The observers generally assigned the horizontal component by locating the relative position of the plane's shadow upon the water. Horizontal positions were usually assigned as being directly overhead (horizontal 12), or one of the quarter-hour positions (horizontal 3,6 or 9).

One member of the SWFC Pre-Sops Panel C provided alternate good and poor sun strata based upon the observer's comments. His strata were formed by assuming the frequency of the observer's comments were indicative of the severity of trackline sun glare. His poor sun strata is much more restrictive than the one used in this paper. Specifically, his poor sun strata includes at vertical 12 only horizontal positions 1 and 3 and does not include vertical 1-horizontal 3 and 9 or vertical 2- horizontal 2 and 10 or 3 and 9 positions.

His method does not consistently allocate effort symmetrically about the trackline (Criteria 1 above). For example at vertical 12 sun position, horizontal position 3 was included in the poor sun stratum while horizontal 9 was not. This may have been because observer comments did not indicate the presence of glare at the horizontal 9 position (Table A2-1). However for both vertical sun positions 1 and 2, horizontal 1 effort was included with horizontal 11 effort in the absence of observer comments.

Although his method included in the poor sun stratum data at some positions where trackline glare was not indicated, it omitted from the poor sun stratum some effort with specific comments that intense trackline glare was present. Specific comments were recorded for vertical 12-horizontal 12, vertical 1-horizontal 3 and 9, vertical 2-horizontal 3 and 9 positions (Table A2-1).

His treatment of vertical 12 sun data was inconsistent and differs from the observers field comments. In fact, when the sun position was at vertical 12, intense glare was present on the trackline and observers had to look forward or behind the plane. The plane's direction could be orientated to obtain desired sun conditions except when the sun was directly overhead. For this reason, the amount of flying during mid-day, when the sun was directly overhead, was curtailed to more evenly allocate effort among the sun strata.

In summary, his criteria for establishing sun strata appear to be based upon a quantitative treatment of the number of times each sun position was noted with trackline glare. The data was not collected in this manner. His method was inconsistent because some sun positions lacking comments indicating the presence of sun glare were included in the poor sun stratum while some sun positions with specific comments indicating sun glare were not included in the stratum. Finally his strata are not intuitively reasonable for the allocation of effort at vertical sun position 12.

Dolphin encounter rates and density estimates using his sun strata are presented in Tables A2-2 and A2-3, respectively. Differences between his good and poor sun strata for detection rates and density estimates are much larger than those calculated in the text.

Table A2-1. Distance searched, rates of detecting dolphin schools and number of effort legs where observers noted trackline sun glare for each vertical sun position with horizontal positions pooled symmetrically about the trackline. All tracks surveyed during flights 2-16 used.

Sun Position Vertical	Sun Position Horizontal	Number legs with bow glare indicated	Distance searched (km)	All sightings	Detection rate all schools (Schools/ 1000 km)	Trackline sightings	Detection rate trackline schools (Schools/ 1000 km)
12	12	2	395	19	48.10	7	17.72
	1,11	2	105	0	0	0	0
	2,10		32	1	31.25	0	0
	3,9	5	570	15	26.32	3	5.26
	4,8		109	2	18.35	1	9.17
	5,7		45	0	0	0	0
	6		333	9	27.03	0	0
1	12	14	664	11	16.57	0	0
	1,11	10	965	13	13.47	1	1.04
	2,10	8	823	21	25.52	2	2.43
	3,9	3	1440	40	27.78	10	6.94
	4,8	1	664	16	24.10	3	4.52
	5,7		865	19	21.97	8	9.25
	6		622	15	24.12	3	4.82
2	12	3	220	8	36.36	1	4.54
	1,11	5	599	10	16.69	3	5.01
	2,10		294	5	17.01	1	3.40
	3,9	3	1763	23	13.05	5	2.84
	4,8		510	7	13.73	3	5.88
	5,7		777	15	19.31	5	9.80
	6		107	6	56.07	1	9.35
3	1,11		20	0	0	0	0
	2,10		19	1	52.63	0	0
	4,8		15	0	0	0	0
	6		32	0	0	0	0
Cloudy			871	7	8.04	1	1.15
Total		56	12859	263	20.45	58	4.51

Table A2-2. Rates of detecting dolphin schools under different condition using the alternate sun criteria. Estimates are for data seperated into good (Gsun) and poor (Psun) sun conditions and combinations of sun and calm (Csea) and rough (Rsea) sea data with no Beaufort, Beaufort 5 and Beauforts 4 and 5 data deleted.

Variable	Distance Searched (km)	Percent km Searched	Number Schools Detected	Percent All Schools Detected	Overall Detection Rate (Schools/ 1000 km)	S.E. Overall Detection Rate	Number Trackline Schools Detected	Percent Trackline Schools Detected	Trackline Detection Rate (Schools/ 1000 km)	S.E. Trackline Detection Rate
No Beaufort Data Deleted										
Gsun	7586	64.4	185	70.3	24.39	2.09	49	84.5	6.46	0.93
Psun	4195	35.6	78	29.7	18.59	2.37	9	15.5	2.15	0.71
Csea-Gsun	2691	22.8	87	33.1	32.33	3.72	19	32.8	7.06	1.69
Csea-Psun	1737	14.7	31	11.8	17.85	3.19	3	5.2	1.73	1.06
Rsea-Gsun	4895	41.5	98	37.3	20.02	2.45	30	51.7	6.13	1.10
Rsea-Psun	2458	20.9	47	17.9	19.12	3.39	6	10.3	2.44	0.95
Beaufort 5 Data Deleted										
Gsun	7390	64.1	185	70.3	25.03	2.18	49	84.5	6.63	0.96
Psun	4130	35.9	78	29.7	18.89	2.39	9	15.5	2.18	0.72
Csea-Gsun	2691	23.4	87	33.1	32.33	3.72	19	32.8	7.06	1.69
Csea-Psun	1737	15.1	31	11.8	17.85	3.19	3	5.2	1.73	1.06
Rsea-Gsun	4699	40.8	98	37.3	20.86	2.63	30	51.7	6.38	1.15
Rsea-Psun	2393	20.8	47	17.9	19.64	3.44	6	10.3	2.51	0.98
Beauforts 4 and 5 Data Deleted										
Gsun	6327	63.5	177	70.0	27.98	2.53	46	85.2	7.27	1.06
Psun	3642	36.5	76	30.0	20.87	2.66	8	14.8	2.20	0.77
Csea-Gsun	2691	27.0	87	34.4	32.33	3.72	19	35.2	7.06	1.69
Csea-Psun	1737	17.4	31	12.3	17.85	3.19	3	5.6	1.73	1.06
Rsea-Gsun	3636	36.5	90	35.6	24.75	3.43	27	50.0	7.43	1.37
Rsea-Psun	1905	19.1	45	17.8	23.62	4.18	5	9.3	2.62	1.11

Table A2-3. Estimates of parameters used in computing dolphin density using the alternate sun criteria. Estimates are for data separated into good (Gsun) and poor (Psun) sun conditions and combinations of sun and calm (Csea) and rough (Rsea) sea data with no Beaufort, Beaufort 5 and Beauforts 4 and 5 data deleted.

Variable	Terms in Model	Number Schools Detected N	S.E. (N)	$\hat{f}(0)$	S.E. $\hat{f}(0)$	Density ($\hat{D}$) (Schools/ 1000 km^2)	Var ($\hat{D}$)	S.E. ($\hat{D}$)	C.V. ($\hat{D}$)	Number Days Searched
No Beaufort Data Deleted										
Gsun	9	185	15.84	2.65	0.299	32.31	20.947	4.577	0.142	270
Psun	3	78	9.96	1.21	0.170	11.25	4.561	2.136	0.190	152
Csea-Gsun	8	87	10.02	2.25	0.000	36.37	17.547	4.189	0.115	97
Csea-Psun	2	31	5.53	1.07	0.191	9.55	5.806	2.410	0.252	64
Rsea-Gsun	9	98	11.98	2.93	0.407	29.33	29.454	5.427	0.185	173
Rsea-Psun	3	47	8.33	1.33	0.215	12.72	9.305	3.050	0.240	88
Beaufort 5 Data Deleted										
Gsun	9	185	16.08	2.65	0.299	33.17	22.319	4.724	0.142	264
Psun	3	78	9.88	1.21	0.170	11.43	4.672	2.161	0.189	150
Csea-Gsun	8	87	10.02	2.25	0.000	36.37	17.547	4.189	0.115	97
Csea-Psun	2	31	5.53	1.07	0.191	9.55	5.806	2.410	0.252	64
Rsea-Gsun	9	98	12.35	2.93	0.407	30.55	32.837	5.730	0.188	167
Rsea-Psun	3	47	8.23	1.33	0.215	13.06	9.689	3.113	0.238	86
Beauforts 4 and 5 Data Deleted										
Gsun	9	177	16.04	2.64	0.305	36.93	29.399	5.422	0.147	228
Psun	2	76	9.69	1.15	0.117	12.00	3.831	1.957	0.163	134
Csea-Gsun	8	87	10.02	2.25	0.000	36.37	17.547	4.189	0.115	97
Csea-Psun	2	31	5.53	1.07	0.191	9.55	5.806	2.410	0.252	64
Rsea-Gsun	9	90	12.46	2.94	0.422	36.39	52.653	7.256	0.199	131
Rsea-Psun	2	45	7.95	1.23	0.144	14.53	9.480	3.079	0.212	70

APPENDIX 3

Analysis of Variance Comparisons

Results of analysis of variance (ANOVA) comparisons and contingency table analysis are displayed in Tables A3-1 through A3-6.

Table A3-1. Analysis of variance comparisons of rates of detecting trackline schools among sea state, sun glare and observer team sightings.

Source	d.f.	Sum of Squares	Mean Square	F
Observer Team (A)	1	120.915	120.915	0.6506
Sea State (B)	1	0.843	0.843	0.0045
Sun Glare (C)	1	700.311	700.311	3.7682
A-B INT	1	0.922	0.922	0.0050
B-C INT	1	191.621	191.621	1.0311
A-C INT	1	360.361	360.361	1.9390
A-B-C INT	1	424.937	424.937	2.2865
Error	415	77127.000	185.848	

Table A3-2. Analysis of variance comparisons of rates of detecting all schools among sea state, sun glare and observer team sightings.

Source	d.f.	Sum of Square	Mean Squares	F
Observer Team (A)	1	1308.466	1308.466	1.1086
Sea State (B)	1	4794.773	4794.773	4.0622*
Sun Glare (C)	1	431.294	431.294	0.3654
A-B INT	1	57.771	57.771	0.0489
B-C INT	1	377.732	377.732	0.3200
A-C INT	1	554.420	554.420	0.4697
A-B-C INT	1	296.359	296.359	0.2511
Error	415	489837.188	1180.331	

* $p < 0.05$

Table A3-3. Analysis of variance comparisons of estimates of dolphin school density among sea state and sun glare data.

Source	d.f.	Sum of Squares	Mean Squares	F
Sea State (A)	1	13.52325	13.52325	0.003
Sun Glare (B)	1	15703.34082	15703.34082	4.061*
A-B INT	1	4056.92798	4056.92798	1.049
Error	419	1620085.50000	3866.55249	

* $p < 0.05$

Table A3-4. Analysis of variance comparisons of estimates of dolphin school density among sun glare and observer team sightings.

Source	d.f.	Sum of Squares	Mean Squares	F
Observer Team (A)	1	8273.38770	8273.38770	2.497
Sun Glare (B)	1	13957.11914	13957.11914	4.212*
A-B INT	1	4986.56250	4986.56250	1.505
Error	419	1388281.50000	3313.32104	

* $p < 0.05$

Table A3-5. Analysis of variance comparisons for the rates of detecting (A) all schools and (B) trackline schools during Beaufort sea states 1-4.

A. All Schools

Source	d.f.	Sum of Squares	Mean Squares	F
Beaufort State	3	17926.314	5975.438	5.1742
Error	401	463095.125	1154.851	

B. Trackline Schools

Source	d.f.	Sum of Squares	Mean Squares	F
Beaufort State	3	476.585	158.862	0.8686
Error	401	73342.227	182.898	

Table A3-6

All Schools

Simultaneous significance levels for effects

Order	d.f.	Chi-square	p value
0	15	289.95	0.000
1	10	67.43	0.000
2	3	2.75	0.432
3	0	0.	1.000

Significance Levels of Interaction Effects

Effect	d.f.	Chi-square	p value
B - S	3	31.77	0.000
B - A	3	31.56	0.000
S - A	1	0.14	0.709

Trackline Schools

Simultaneous significance levels for effects

Order	d.f.	Chi-square	p value
0	15	505.87	0.000
1	10	45.21	0.000
2	3	6.74	0.081
3	0	0.	1.000

Significance Levels of Interaction Effects

Effect	d.f.	Chi-square	p value
B - S	3	6.30	0.098
B - A	3	32.18	0.000
S - A	1	0.01	0.905

Contingency table analysis of Beaufort state (B), detection rates (S), and area (A) north or south of 10° N for all schools and trackline schools.

APPENDIX 4

Estimates With Beaufort 5 And With Beaufort 4 And 5 Effort Omitted

Detection rates and density estimates were calculated by omitting data collected during 1) Beaufort 5 conditions and 2) Beaufort 4 and 5 conditions. These are presented in Tables A4-1 and A4-2, respectively.

Table A4-1. Rates of detecting dolphin schools under different conditions. Estimates are for data separated into calm (Csea) and rough (Rsea) sea conditions, good (Gsun) and poor (Psun) sun conditions, and experienced (Exp) and inexperienced (Ixp) observers with Beaufort 5 and Beauforts 4 and 5 data deleted.

Variable	Distance Searched (km)	Percent km Searched	Number Schools Detected	Percent All Schools Detected	Overall Detection Rate (Schools/ 1000 km)	S.E. Overall Detection Rate	Number Trackline Schools Detected	Percent Trackline Schools Detected	Trackline Detection Rate (Schools/ 1000 km)	S.E. Trackline Detection Rate
Beaufort 5 Data Deleted										
All Data	11520	100.0	263	100.0	22.83	1.69	58	100.0	5.03	0.69
Csea	4428	38.4	118	44.9	26.65	2.63	22	37.9	4.97	1.11
Rsea	7092	61.6	145	55.1	20.45	2.20	36	62.1	5.08	0.89
Gsun	3233	28.1	79	30.0	24.43	3.21	23	39.7	7.11	1.52
Psun	8286	71.9	184	70.0	22.21	2.00	35	60.3	4.22	0.76
Csea-Gsun	1414	12.3	37	14.1	26.17	4.13	8	13.8	5.66	1.80
Csea-Psun	3014	26.2	81	30.8	26.87	3.37	14	24.1	4.65	1.39
Rsea-Gsun	1820	15.8	42	16.0	23.08	4.76	15	25.9	8.24	2.32
Rsea-Psun	5272	45.8	103	39.2	19.54	2.46	21	36.2	3.98	0.88
Exp. Team	5863	50.9	125	47.5	21.32	2.06	33	56.9	5.63	0.92
Ixp. Team	5657	49.1	138	52.5	24.39	2.71	25	43.1	4.42	1.04
Exp. Csea	2161	36.9	53	42.4	24.52	3.15	12	36.4	5.55	1.45
Exp. Rsea	3701	63.1	72	57.6	19.45	2.69	21	63.6	5.67	1.19
Exp. Gsun	1773	30.2	44	35.2	24.81	3.64	16	48.5	9.02	2.07
Exp. Psun	4089	69.8	81	64.8	19.81	2.49	17	51.5	4.16	0.94
Ixp. Csea	2266	40.1	65	47.1	28.68	4.19	10	40.0	4.41	1.67
Ixp. Rsea	3390	59.9	73	52.9	21.53	3.55	15	60.0	4.42	1.34
Ixp. Gsun	1460	25.8	35	25.4	23.97	5.62	7	28.0	4.79	2.22
Ixp. Psun	4197	74.2	103	74.6	24.54	3.10	18	72.0	4.29	1.18
Beauforts 4 and 5 Data Deleted										
All Data	9969	100.0	253	100.0	25.38	1.88	54	100.0	5.42	0.78
Csea	4428	44.4	118	46.6	26.65	2.63	22	40.7	4.97	1.11
Rsea	5541	55.6	135	53.4	24.36	2.65	32	59.3	5.78	1.10
Gsun	2954	29.6	78	30.8	26.40	3.40	23	42.6	7.79	1.73
Psun	7014	70.4	175	69.2	24.95	2.26	31	57.4	4.42	0.83
Csea-Gsun	1414	14.2	37	14.6	26.17	4.13	8	14.8	5.66	1.80
Csea-Psun	3014	30.2	81	32.0	26.87	3.37	14	25.9	4.65	1.39
Rsea-Gsun	1540	15.4	41	16.2	26.62	5.34	15	27.8	9.74	2.87
Rsea-Psun	4001	40.1	94	37.2	23.50	3.04	17	31.5	4.25	1.02
Exp. Team	5244	52.6	117	46.2	22.31	2.21	31	57.4	5.91	1.02
Ixp. Team	4725	47.4	136	53.8	28.78	3.10	23	42.6	4.87	1.20
Exp. Csea	2161	41.2	53	45.3	24.52	3.15	12	38.7	5.55	1.45
Exp. Rsea	3083	58.8	64	54.7	20.76	3.04	19	61.3	6.16	1.42
Exp. Gsun	1713	32.7	43	36.8	25.10	3.55	16	51.6	9.34	2.12
Exp. Psun	3530	67.3	74	63.2	20.96	2.80	15	48.4	4.25	1.09
Ixp. Csea	2266	48.0	65	47.8	28.68	4.19	10	43.5	4.41	1.67
Ixp. Rsea	2458	52.0	71	52.2	28.88	4.56	13	56.5	5.29	1.73
Ixp. Gsun	1241	26.3	35	25.7	28.21	6.48	7	30.4	5.64	2.89
Ixp. Psun	3484	73.7	101	74.3	28.99	3.53	16	69.6	4.59	1.27

Table A4-2. Estimates of parameters used in computing dolphin density ($\hat{D}$) for calm (Csea) and rough (Rsea) sea conditions, during good (Gsun) and poor (Psun) sun conditions, and for experienced (Exp) and inexperienced (Ixp) observer teams with Beauforts 5 and Beauforts 4 and 5 data deleted.

Variable	Terms in Model	Number Schools Detected (N)	S.E. (N)	$\hat{f}(0)$	S.E. $\hat{f}(0)$	Density ($\hat{D}$) (Schools/ 1000 km^2)	Var ($\hat{D}$)	S.E. ($\hat{D}$)	C.V. ($\hat{D}$)	Number Days Searched
Beaufort 5 Data Deleted										
All Data	9	263	19.52	2.24	0.249	25.57	11.680	3.418	0.134	414
Csea	8	118	11.66	1.93	0.322	25.72	24.865	4.986	0.194	161
Rsea	9	145	15.59	2.53	0.336	25.86	19.532	4.419	0.171	253
Gsun	9	79	10.40	2.91	0.452	35.55	52.405	7.239	0.204	118
Psun	9	184	16.54	1.95	0.291	21.65	14.227	3.772	0.174	296
Csea-Gsun	6	37	5.83	2.23	0.439	29.18	54.123	7.357	0.252	52
Csea-Psun	8	81	10.14	1.77	0.378	23.78	34.664	5.888	0.248	109
Rsea-Gsun	9	42	8.65	3.54	0.001	40.85	70.767	8.412	0.206	66
Rsea-Psun	9	103	12.98	2.14	0.394	20.91	21.754	4.664	0.223	187
Exp. Team	9	125	12.06	2.96	0.364	31.55	24.325	4.932	0.156	211
Ixp. Team	8	138	15.36	1.70	0.289	20.74	17.752	4.213	0.203	203
Exp. Csea	9	53	6.81	2.50	0.554	30.66	61.670	7.853	0.256	79
Exp. Rsea	9	72	9.94	3.38	0.001	32.88	20.603	4.539	0.138	132
Exp. Csea	5	65	9.49	1.61	0.274	23.09	26.809	5.178	0.224	82
Ixp. Rsea	9	73	12.04	1.90	0.452	20.46	35.068	5.922	0.289	121
Ixp. Gsun	9	44	6.46	3.62	0.572	44.92	93.866	9.688	0.216	65
Exp. Psun	9	81	10.17	2.51	0.000	24.86	9.743	3.121	0.126	146
Ixp. Gsun	9	35	8.21	2.01	0.668	24.09	96.044	9.800	0.407	53
Ixp. Psun	8	103	13.02	1.66	0.333	20.37	23.326	4.830	0.237	150
Beauforts 4 and 5 Data Deleted										
All Data	9	253	18.72	2.19	0.253	27.79	14.535	3.812	0.137	361
Csea	8	118	11.66	1.93	0.322	25.72	24.865	4.986	0.194	161
Rsea	9	135	14.67	2.46	0.347	29.97	28.474	5.336	0.178	200
Gsun	9	78	10.05	2.98	0.453	39.34	61.465	7.840	0.199	109
Psun	9	175	15.83	1.83	0.295	22.83	17.807	4.220	0.185	252
Csea-Gsun	6	37	5.83	2.23	0.439	29.18	54.123	7.357	0.252	52
Csea-Psun	8	81	10.14	1.77	0.378	23.78	34.664	5.888	0.248	109
Rsea-Gsun	9	41	8.23	3.68	0.598	48.99	160.060	12.651	0.258	57
Rsea-Psun	9	94	12.17	1.94	0.405	22.79	31.339	5.598	0.246	143
Exp. Team	9	117	11.58	3.01	0.374	33.58	28.452	5.334	0.159	190
Ixp. Team	8	136	14.65	1.62	0.289	23.31	23.605	4.859	0.208	171
Exp. Csea	9	53	6.81	2.50	0.554	30.66	61.670	7.853	0.256	79
Exp. Rsea	9	64	9.38	3.49	0.001	36.22	28.186	5.309	0.147	111
Exp. Csea	5	65	9.49	1.61	0.274	23.09	26.809	5.178	0.224	82
Ixp. Rsea	9	71	11.21	1.72	0.450	24.84	57.621	7.591	0.306	89
Ixp. Gsun	9	43	6.08	3.81	0.563	47.82	95.651	9.780	0.205	63
Exp. Psun	9	74	9.87	2.46	0.000	25.78	11.828	3.439	0.133	127
Ixp. Gsun	9	35	8.05	2.01	0.668	28.34	131.231	11.456	0.404	46
Ixp. Psun	8	101	12.29	1.54	0.332	22.32	30.536	5.526	0.248	125

APPENDIX 5

Selection Of The Study Area

The experimental design required that the study area be surveyed approximately uniformly for all variables. Empirical observations during collection of the data and subsequent examination of the data indicated that effort encountered in the northern, southern and far offshore regions were covered under much rougher sea conditions during which few animals were detected. Holt (1983b) suggested conservative boundaries for including data in the study area (herein called "original" study area). His boundaries excluded approximately 2214 km of search effort during which 12 dolphin schools (2 trackline schools) were detected. Rough sea conditions were encountered during 83% of this effort versus only 62% of the effort inside the original study area. The detection rate of all schools for the omitted data was 5.2 schools/1000 km compared to 23.67 schools/1000 km in the original study area.

Discussions with members of SWFC Pre-SOPS panel C2 indicated that some of the omitted data might be included without seriously biasing the results. Adjusted boundary lines were suggested by one of the panel members. This "adjusted" study area included effort from the coast westward to 86^{o} 35' W and from 11^{o} N to 9^{o} 30' N (Figure 1 of text).

In addition, differences in sea state conditions in the northern areas versus the southern areas were investigated. The survey data was partitioned into that occurring above and below 10^{o} N. This line was chosen because during the survey the airplane frequently was turned from a north/south direction to a south/west direction (vice versa on the return leg) at the 10^{o} N line.

The effects of including the additional data and the geographic variation of the data were examined by partitioning the adjusted study area into 5 regions (Figure A5-1). Region 1 included effort in the original study area north of 10^{o} N while region 2 included effort in the original area south of 10^{o} N. Regions 3, 4 and 5 included effort within the adjusted study area but outside the original area. Region 3 included the northern effort, region 4 included the westward effort north of 10^{o} N, and region 5 included the westward and southern effort south of 10^{o} N. Region 6 included all effort outside the original study area (sum of regions 3, 4 and 5); region 7 included all effort north of 10^{o}N (sum of regions 1, 3 and 4); region 8 included all effort south of 10^{o}N (sum of regions 2 and 5); region 9 included all effort in the original study area (sum of regions 1 and 2); and region 10 included all effort in the adjusted study area (regions 1-5). Table A5-1 presents detection rates of trackline and all schools by each Beaufort state for each of these regions.

The distribution of effort by sea state varied among the "omitted" regions (regions 3-5 of Table A5-1). Approximately 61% of the searching effort in regions 3, 4, and 5 occurred at Beaufort 4, 2 and 3, respectively (Table A5-1). Detection rates of all schools at each Beaufort state for the three regions combined (Table A5-1: region 6) were generally much lower than for rates in the original study area (Table A5-1: region 9). Only the Beaufort 1 rate in the omitted area was higher and it was based upon little data. Comparisons of trackline detection rates were not made since only 2 trackline schools were detected in the omitted areas.

Although the omitted data had lower detection rates, its inclusion in the study area would not bias the analysis if the proportions of searching effort at each sea state were similar in the original and the omitted areas. However, a much larger proportion of the searching effort occurred during Beaufort 4 and 5 conditions in the omitted areas than occurred in the original area (region 6 versus region 9).

Inclusion of the additional data still would not bias the analyses if the rates of detecting schools were similar among all Beaufort states. This was not the case since the rates of detecting all schools were much lower during Beaufort 4 and 5 conditions than during Beaufort 1-3 conditions. The 2 trackline schools were detected during Beaufort 1 and 2 conditions.

Finally the bias introduced by including data in the omitted areas would be small if the relative amount of effort in the areas was small compared to the effort in the original area. In fact, the effect of including the additional area data was small since it comprised only 9.6% of the total effort in the adjusted area. The effects of including the additional data, however, were evident when the data were stratified among the test variables. For example, the additional data increased the amount of rough seas in the study area by 12% during which 5 schools were detected but none of these were on the trackline. The amount of calm seas was only increased 8.5% during which 6 schools were detected and two of these were on the trackline. The additional effort slightly increased the calm seas trackline detection rate and reduced the rough seas trackline detection rate. Consequently, the highest individual Beaufort trackline detection rate in the original study area was for Beaufort 3 data but the additional data reduced the Beaufort 3 rate below Beaufort 1 and 2 rates.

Although the data outside the original study area occurred during rougher sea conditions and had lower detection rates than data in the original study area, the impact of including the data was minimal. As presented in the text, sea state did not significantly affect the rates of detecting trackline schools (Table A3-1) or estimates of school density (Table A3-3), even with the additional data included, therefore, data in the larger adjusted study area were used in the analyses.

Survey effort in the northern adjusted study area (Table A5-1: region 7) was conducted during rougher sea conditions than in the southern area (region 8). Beaufort 4 and 5 conditions were experienced 21.2% of the effort in the northern area but only 5.3% in the southern area (Table A5-1). Comparison of the rates of detecting schools at each Beaufort state between the two areas was difficult due to a sparsity of data in some strata.

Only Beauforts 2 and 3 conditions had large sample sizes in both areas. Comparisons of detection rates of all schools and trackline schools did not yield consistent trends between or within the two areas (Table A5-1). The detection rate of all schools during Beaufort 2 conditions in the northern area was larger than in the southern area but the northern Beaufort 3 detection rate of all schools was smaller than the corresponding southern Beaufort 3 rate. The opposite trend was present for rates of detecting trackline schools in the two areas during Beaufort 2 and 3 conditions; the northern Beaufort 2 trackline rate was smaller than the southern rate and the northern Beaufort 3 rate was larger than the southern rate.

Contingency table analysis (discussed in text and Table A3-6) indicated that the occurrence of Beaufort conditions in the two areas were significantly different ($P>0.001$) but that the rates at which trackline schools or all schools were detected in the two areas were not significantly different. Therefore data in the northern and southern areas were combined in the analysis.

Table A5-1. Rates of detection of dolphin schools during each Beaufort state. Estimates are for data separated into 5 regions and for data combined over various strata.

Variable	Distance Searched (km)	Percent km Searched	Number Schools Detected	Percent All Schools Detected	Overall Detection Rate (Schools/1000 km)	S.E. Overall Detection Rate	Number Trackline Schools Detected	Percent Trackline Schools Detected	Trackline Detection Rate (Schools/1000 km)	S.E. Trackline Detection Rate
Region 1										
All Data	6543	100.0	155	100.0	23.69	2.35	35	100.0	5.35	0.91
Beaufort 1	369	5.6	13	8.4	35.27	10.05	3	8.6	8.14	4.09
Beaufort 2	1595	24.4	50	32.3	31.34	5.28	5	14.3	3.13	1.63
Beaufort 3	3464	52.9	84	54.2	24.25	3.24	23	65.7	6.64	1.31
Beaufort 4	988	15.1	8	5.2	8.10	4.28	4	11.4	4.05	2.36
Beaufort 5	127	1.9	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 2										
All Data	4105	100.0	97	100.0	23.63	2.70	21	100.0	5.12	1.17
Beaufort 1	239	5.8	5	5.2	20.91	8.06	0	0.0	0.00	0.00
Beaufort 2	1879	45.8	44	45.4	23.42	3.62	12	57.1	6.39	2.11
Beaufort 3	1760	42.9	48	49.5	27.28	4.83	9	42.9	5.11	1.57
Beaufort 4	195	4.7	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 5	33	0.8	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 3										
All Data	587	100.0	3	100.0	5.11	2.63	0	0.0	0.00	0.00
Beaufort 1	0	0.0	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 2	11	1.9	0	0.0	0.00	0.00	0	57.1	0.00	0.00
Beaufort 3	195	33.2	1	33.3	5.13	4.67	0	42.9	0.00	0.00
Beaufort 4	359	61.2	2	66.7	5.57	3.69	0	0.0	0.00	0.00
Beaufort 5	22	3.7	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 4										
All Data	353	100.0	6	100.0	17.00	5.31	2	100.0	5.67	4.36
Beaufort 1	44	12.5	2	33.3	45.60	15.34	1	50.0	22.80	24.84
Beaufort 2	216	61.2	4	66.7	18.55	6.59	1	50.0	4.64	4.48
Beaufort 3	4	1.1	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 4	9	2.5	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 5	80	22.7	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 5										
All Data	194	100.0	2	100.0	10.29	26.26	0	50.0	0.00	0.00
Beaufort 1	0	0.0	0	0.0	0.00	0.00	0	50.0	0.00	0.00
Beaufort 2	76	39.0	0	0.0	0.00	0.00	0	50.0	0.00	0.00
Beaufort 3	119	61.0	2	100.0	16.84	44.15	0	0.0	0.00	0.00
Beaufort 4	0	0.0	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 5	0	0.0	0	0.0	0.00	0.00	0	0.0	0.00	0.00

Table A5-1. Continued

Variable	Distance Searched (km)	Percent km Searched	Number Schools Detected	Percent All Schools Detected	Overall Detection Rate (Schools/ 1000 km)	S.E. Overall Detection Rate	Number Trackline Schools Detected	Percent Trackline Schools Detected	Trackline Detection Rate (Schools/ 1000 km)	S.E. Trackline Detection Rate
Region 6 (Regions 3 + 4 + 5)										
All Data	1135	100.0	11	100.0	9.69	2.99	2	100.0	1.76	1.49
Beaufort 1	44	3.9	2	18.2	45.60	15.34	1	50.0	22.80	24.84
Beaufort 2	302	26.6	4	36.4	13.23	5.11	1	50.0	3.31	3.08
Beaufort 3	318	28.0	3	27.3	9.43	7.42	0	0.0	0.00	0.00
Beaufort 4	368	32.5	2	18.2	5.43	3.65	0	0.0	0.00	0.00
Beaufort 5	102	9.0	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 7 (Regions 1 + 3 + 4)										
All Data	7483	100.0	164	100.0	21.92	2.07	37	100.0	4.94	0.79
Beaufort 1	412	5.5	15	9.1	36.37	9.28	4	10.8	9.70	4.18
Beaufort 2	1822	24.3	54	32.9	29.64	4.70	6	16.2	3.29	1.49
Beaufort 3	3664	49.0	85	51.8	23.20	3.08	23	62.2	6.28	1.25
Beaufort 4	1356	18.1	10	6.1	7.37	2.53	4	10.8	2.95	1.40
Beaufort 5	229	3.1	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 8 (Regions 2 + 5)										
All Data	4298	100.0	99	100.0	23.03	2.63	21	100.0	4.89	1.03
Beaufort 1	239	5.6	5	5.1	20.91	8.06	0	0.0	0.00	0.00
Beaufort 2	1954	45.5	44	44.4	22.51	3.34	12	57.1	6.14	1.77
Beaufort 3	1877	43.7	50	50.5	26.64	4.77	9	42.9	4.79	1.48
Beaufort 4	195	4.5	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Beaufort 5	33	0.8	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 9 (Regions 1 + 2)										
All Data	10647	100.0	252	100.0	23.67	1.79	56	100.0	5.26	0.72
Beaufort 1	608	5.7	18	7.1	29.62	8.38	3	5.4	4.94	2.65
Beaufort 2	3474	32.6	94	37.3	27.06	3.00	17	30.4	4.89	1.30
Beaufort 3	5224	49.1	132	52.4	25.27	2.67	32	57.1	6.13	1.04
Beaufort 4	1183	11.1	8	3.2	6.76	3.64	4	7.1	3.38	2.01
Beaufort 5	159	1.5	0	0.0	0.00	0.00	0	0.0	0.00	0.00
Region 10 (Regions 1 + 2 + 3 + 4 + 5)										
All Data	11781	100.0	263	100.0	22.32	1.67	58	100.0	4.92	0.66
Beaufort 1	652	5.5	20	7.6	30.69	7.76	4	6.9	6.14	2.83
Beaufort 2	3776	32.0	98	37.3	25.95	2.91	18	31.0	4.77	1.28
Beaufort 3	5541	47.0	135	51.3	24.36	2.68	32	55.2	5.78	0.98
Beaufort 4	1551	13.2	10	3.8	6.45	2.25	4	6.9	2.58	1.24
Beaufort 5	262	2.2	0	0.0	0.00	0.00	0	0.0	0.00	0.00

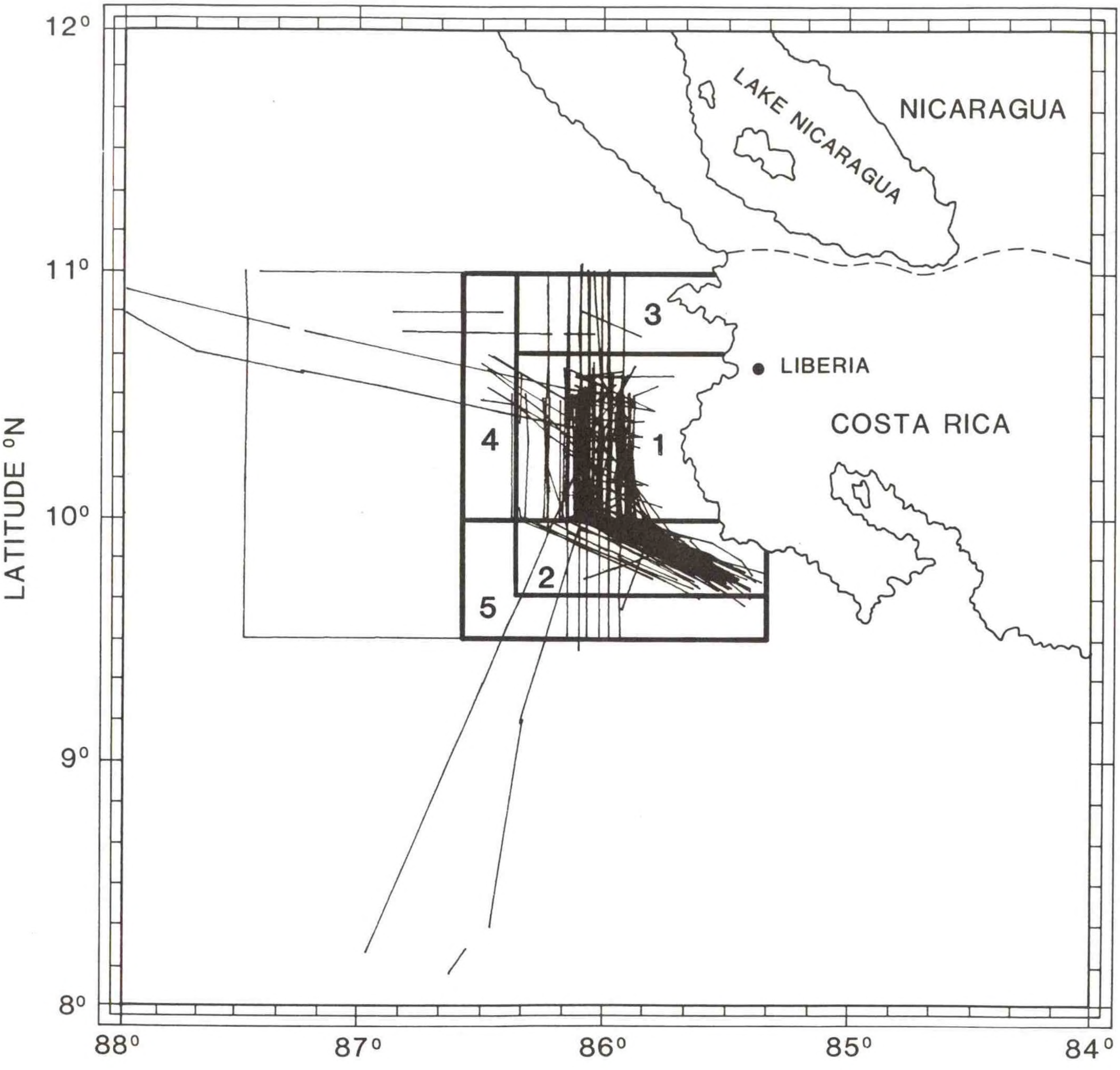

Figure A5-1. Geographic regions used to define the study area.