Abstract.—Determination of stock structure for striped dolphins (*Stenella coeruleoalba*) in the eastern Pacific has been problematic, because very few specimens have been available for study. We compared length data obtained from vertical aerial photographs of 28 schools of striped dolphins from the northern and southern regions of the eastern tropical Pacific and found no significant differences in average length for adult animals (≥180cm) or for adult females, defined here as dolphins closely accompanied by a calf. Analyses of back-projected birth dates for dolphins ≥155cm revealed a broad pulse in reproduction extending from the fall through the spring; however, sample size was inadequate to compare timing of reproduction between the two areas. Striped dolphins measured from aerial photographs were longer on average than those killed incidentally in fishing operations. We found a pattern of segregation by size between schools that is analogous to the separate schools of juveniles and adults that are found in the western Pacific. We hypothesized that the specimen data base may be biased because tuna purse-seine fishermen in the eastern tropical Pacific may selectively set on schools composed of younger, smaller dolphins.

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Examination of stock and school structure of striped dolphin (*Stenella coeruleoalba*) in the eastern Pacific from aerial photogrammetry

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Because striped dolphins, *Stenella coeruleoalba*, are killed incidentally in purse-seine fishing for yellowfin tuna in the eastern tropical Pacific (ETP), the National Marine Fisheries Service (NMFS) is required by the Marine Mammal Protection Act (as amended in 1988) to monitor trends in their abundance (Holt and Sexton, 1989; Wade and Gerrodette, in press). To satisfy this congressional mandate, information on stock structure is required. The determination of stock structure for striped dolphins in the ETP has been particularly difficult because of the small number of animals killed in the tuna fishery and, therefore, small number of specimens available for study (DeMaster et al., 1992). In the absence of morphological, life history, or genetic data to provide evidence of reproductive isolation, stocks of striped dolphins have been identified provisionally based on discontinuities in distribution. With more sighting data from observers aboard fishing vessels and research cruises, the number of proposed stocks has decreased from five or six (Smith, 1979[1]; Holt and Powers, 1982) to one (Dizon et al., in press) pending availability of additional data.

For this report, we examined length data to help clarify the issue of stock structure. These data were extracted from vertical aerial photographs collected during line transect surveys and are thus presumably free of any "sampling" biases associated with the fishery. Here, we compare length samples from aerial photographs of animals from the northern and southern stock regions proposed by Perrin et al. (1985) for evidence of differences in average length or timing of reproduction. Data were then compared with measurements available from specimens killed incidentally in purse-seine fishing. We also examined the frequency distribution of lengths within individual schools. These data were used to test for size-age segregation, as reported for dolphins taken in the drive fishery on the Pacific coast of Japan (Miyazaki, 1977; Miyazaki and Nishiwaki, 1978).

Methods

Length measurements were made on vertical aerial photographs of 28 schools of striped dolphins (Fig. 1). We photographed the schools with a KA-45A military reconnaissance

[1] Smith, T. D. (ed). 1979. Report of the status of porpoise stocks workshop; 27–31 August, La Jolla, California. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038. Admin. Rep., LJ-79-41, 120 p.

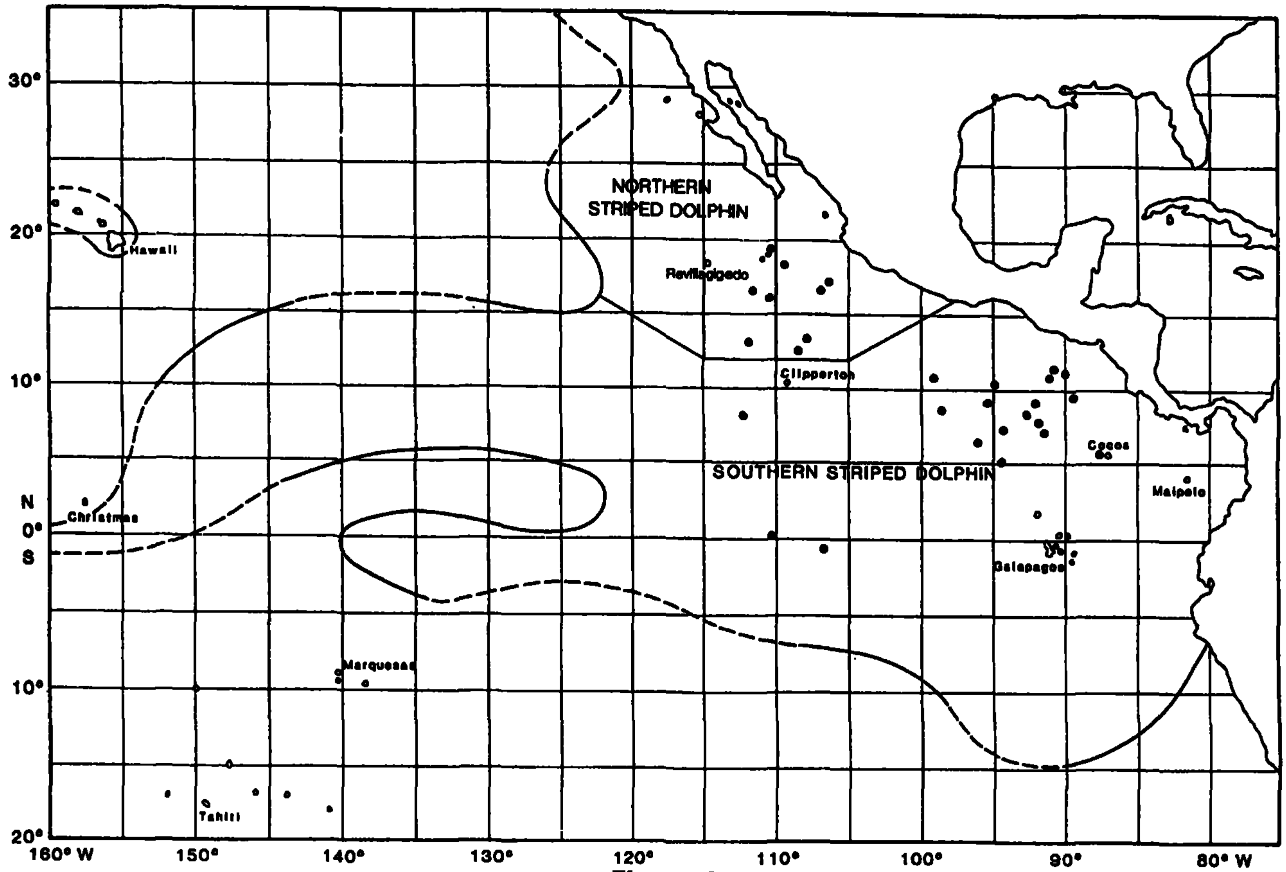

Figure 1

Distribution of schools of striped dolphin, *Stenella coeruleoalba*, (dark circles), from which data were taken for this report. Boundaries for northern and southern stocks were taken from Perrin et al. 1985.

camera mounted below the fuselage of a Hughes 500D helicopter that was launched from the NOAA Ship *David Starr Jordan*. This photographic sampling was part of a long-term research effort conducted by NMFS to monitor trends in abundance of dolphin populations in the ETP (Holt and Sexton, 1989; Wade and Gerrodette, in press).

The reconnaissance camera was equipped with a very fast, medium focal length lens (152 mm) and a forward image motion compensation system that eliminated the blur normally found in images taken from a low altitude, high-speed platform. We used Kodak Plus-X Aerecon II (thin-base) film, exposed through a medium yellow filter, throughout the experiment. This filter significantly reduced the amount of blue light reaching the film, thus enhancing both the contrast and resolution of our photographs.

The observer sitting in the right front seat of the helicopter triggered the camera, controlled cycle rate and shutter speed, and adjusted the forward motion compensation system. As each firing pulse was sent to the camera, a data acquisition system recorded the time that the image was captured and an altitude reading from the helicopter's radar altimeter. To check for accuracy in our recorded altitude data (A_r), we photographed calibration target arrays and compared altitude calculated from measurements of these known distances with recorded altitude (see Perryman and Lynn, 1993).

We found a consistent bias in A_r and used the linear regression equation shown below to calculate a corrected altitude (A_c) for each photograph used in this report.

$$A_c = (A_r)\,1.013 - 33.755\ (r^2 = 0.993).$$

Length determination

We reviewed the images of 88 schools of striped dolphins photographed from 1987 through 1990 and selected the images of 28 schools that provided the best combination of image clarity and water penetration. From this sample, we selected the photographic pass over each school that captured the largest number of dolphins swimming parallel to and very near the surface. Dolphins were not measured if either the rostrum or tail flukes were not clearly visible or if they were surfacing, diving, or jumping, which would make them appear shorter when viewed from above. Because there was from 80 to 90% overlap between adjacent photographs, the same dolphin could often be measured in two to four photographs. If more than one length was available for a dolphin, the largest length was selected, assuming it was the best determination of true length. This helped to minimize the reduction in apparent length caused by the normal swimming movements of the dolphins (Scott and Perryman, 1991; Perryman and Lynn, 1993).

We measured each dolphin from the tip of the rostrum to the trailing edge of the tail flukes (Fig. 2). These points were selected because the fluke notch that is used to determine standard length (Norris, 1961) was very difficult to see in most of the images. For adult specimens, this measurement should exceed standard length by 2–2.5 cm (Chivers, 1993[2]). The measurements were made on sections of the original black and white negatives that we captured with a high-resolution video camera and transferred to a Macintosh IIci computer. Image enhancement and length measurements were made with the aid of the digital image processing and analysis program, Image (version 1.37), which was developed by the National Institute of Health (W. Rasband, Research Services, Bethesda, Maryland). The length of each dolphin was determined by multiplying its length on the image by the scale of the photograph (scale= A_c/lens focal length).

Data analysis

Perrin et al. (1985) compared the mean lengths of physiologically adult male and female dolphins from putative geographic stocks of several species to provide supporting morphological evidence for reproductive isolation. For our analyses, we used length as the criteria for eliminating the youngest dolphins from our sample. Based on the length data for adult striped dolphins in Perrin et al. (1985) and a review of our length sample, we estimated that the minimum length for adult female striped dolphins in the eastern Pacific is about 180 cm. We used this length as our first cut-off point, and tested for differences (t-test) between the means of our length samples (≤180 cm) from the northern and southern regions (Fig. 1). Since the selection of this value was somewhat arbitrary, we repeated the tests on data sets with minimum values of 185 and 190 cm.

Based on behavioral arguments reviewed in Perryman and Lynn (1993), we assumed that the larger dolphin swimming closely alongside a calf was an adult female. Since this determination was based on behavior and not on examination of sexual characters, we qualify the term in quotation marks, "adult female," whenever we are referring to a length sample based on this assumption. A t-test was used to compare the mean lengths of "adult females" from the northern and southern regions. We also performed a power analysis to determine what range of differences between means we could expect to detect (probability of type II error ≤ 0.10) for this analysis and the ones described in the paragraph above.

Calf birth dates

We examined the length data from striped dolphins estimated to be one year old or less for evidence of pulses in reproduction (see Barlow [1984], for spotted and spinner dolphins; Perryman and Lynn [1993], for common dolphins). Ninety centimeters was used as the best estimate of average length at birth and 155 cm for average length at one year for striped dolphins in the eastern Pacific (Gurevich and Stewart, 1979[3]). We assumed postnatal growth was linear during the first year and back-projected the birth dates for all dolphins ≤155 cm in length. Our goal here was not to determine the ex-

[2] S. Chivers. 1993. Southwest Fisheries Science Center, La Jolla, California 92037, unpubl. data.

[3] Gurevich, V. S., and B. S. Stewart. 1979. A study of growth and reproduction of the striped dolphin (*Stenella coeruleoalba*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038. Final Rep to NOAA, SWFC Contract 03-78-D27-1079, 29 p.

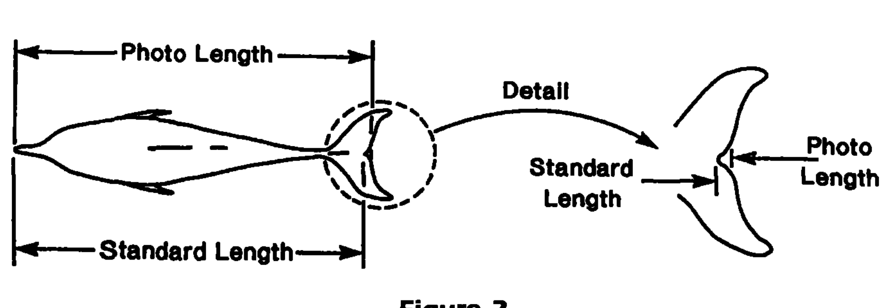

Figure 2
Illustration of the difference between points used to determine standard length and length as measured from our vertical photographs.

act date of birth for each dolphin but rather to examine the distribution of birth dates, based on the same assumptions, from the two regions. We used Kupier's modification of Kolmogorov's test for comparisons of circular distributions (Batschelet, 1965) to compare the calculated distribution of birth dates with a uniform distribution.

Comparisons with specimen data

We conducted four tests to compare the sample of photogrammetric lengths with data collected from striped dolphins killed incidentally in purse-seine fishing in the ETP (Perrin et al., 1976). The data from specimens included the information published by Perrin et al. (1985) and a small set of data from dolphins killed since 1985. *T*-tests were used to compare the mean length of "adult females" with the mean length of adult female specimens and with the mean length of lactating adult female specimens. We also compared the mean (*t*-test) and shape (Kolmogorov-Smirnov test) of the photogrammetrically determined length distribution of striped dolphins ≥ 180 cm with data from specimens ≥ 180 cm in length.

School structure

Examination of the structure of schools of striped dolphins captured in the drive fishery in Japan has revealed a distinct pattern of segregation based on sex, maturity, and length (Miyazaki, 1977, 1984; Miyazaki and Nishiwaki, 1978). Researchers have categorized these schools as adult, juvenile, or mixed depending on the proportion of juvenile dolphins (excluding calves) captured. In these studies, length (<174 cm) or age (<1.5 years) was used as the criterion for eliminating nursing calves from the sample; the remainder of the dolphins was determined to be juvenile or adult by direct examination of the gonads.

We examined the length distributions for the photographed schools to see if an analogous pattern of segregation in schools from the eastern Pacific was detectable. We divided our samples into two length categories which we labeled juvenile or adult. The minimum length for the juvenile category was set at 165 cm to eliminate nursing calves as described above. We selected this minimum value because 1) length at birth for striped dolphins from the ETP is apparently about 10 cm shorter than that reported from the western Pacific (Miyazaki, 1977; Gurevich and Stewart, 1979[3]), and we assumed that the difference in the average length at weaning was approximately the same; 2) dolphins larger than 165–170 cm in length were very rarely found swimming in the characteristic cow/calf configuration we see in our photographs.

We selected 195 cm as the upper bound for the juvenile category because this appears to be about the minimum size for adult male striped dolphins that have been killed in the ETP tuna purse-seine fishery (Perrin et al., 1985). This value was keyed to male length data because the studies of school structure from Japan indicated that a disproportionate number of the dolphins captured in juvenile schools were males (Miyazaki and Nishiwaki, 1978). Thus dolphins in each school were categorized as juvenile if they were between 165 and 195 cm in length and as adult if they were > 195 cm in length. The goal in this classification scheme was to create one category that would be composed of mostly juvenile and young adult dolphins and another that would include mostly adult animals.

We used chi-square analysis to test the hypothesis that the number of dolphins in the two categories in our schools was independent of school. For this analysis, we eliminated schools from which we had measured less than 20% of the school or fewer than 17 dolphins. The second criterion was established to minimize the number of predicted values in the chi-square analysis that were less than five. Application of these criteria reduced our sample to 21 schools for this test. Because the selection of 195 cm for the cut-off between the two size categories probably includes more adult females in the juvenile category than males, we decreased the limit to 190 cm and repeated the chi-square test. We also conducted a regression analysis to determine whether the proportion of the measured sample in the juvenile category was related to school size.

With the exception of the power analyses and birth date comparison which were done by hand, all tests presented in this report were performed with the program StatView developed by Abacus Concepts (Berkeley, CA). Unless noted otherwise, tests were considered significant for P values < 0.05.

Results

Regional comparisons

We compared the average length of striped dolphins from the northern and southern regions and found no significant differences between the samples (Table 1; Fig. 3). In tests for differences in mean lengths of "adult females" (Fig. 4), no differences were found between the regions. Although none of the differences was significant, means of the samples from the northern region were generally a few centimeters smaller than those from the south, a pattern reported by Perrin et al. (1985). This level of difference was less than we could detect given the available sample and the variability of our data (Table 2). With this length sample, it appears that we can expect to detect differences between means that differ by at least 4 cm.

Table 1

Results of t-tests for differences between means of length samples from striped dolhin, *Stenella coerueoalba*, from the northern (Nor) and southern (So) regions.

Sub-sample (cm)	n Nor/So	mean (cm) Nor/So	P (2-tailed)
>180	160/251	205.1/205.9	0.476
>185	154/484	206.0./207.7	0.138
>190	140/450	207.9/209.2	0.230
"Adult females"	19/63	200.2/204.0	0.201

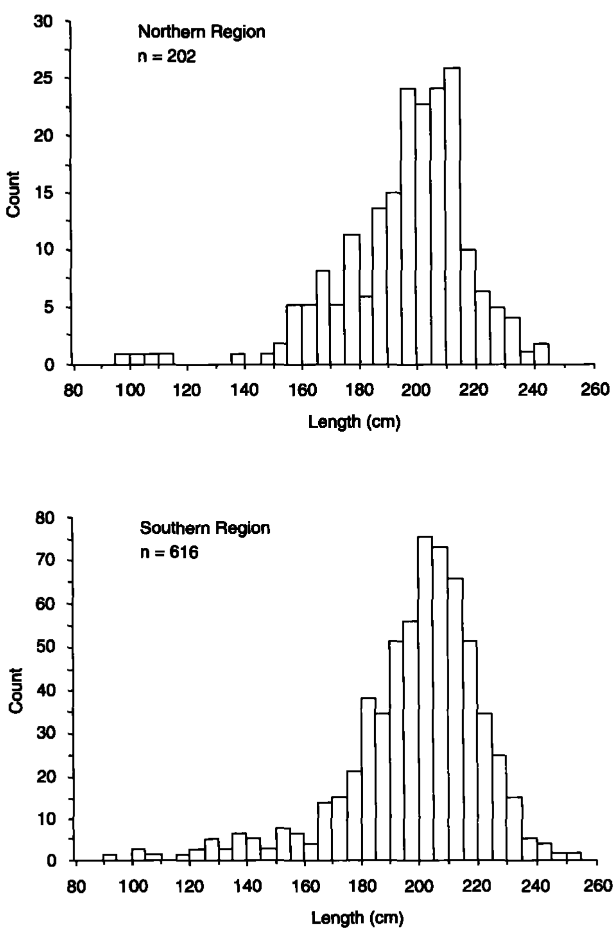

Figure 3

Distribution of lengths of striped dolphins, *Stella coeruleoalba*, measured from the northern and southern regions.

Table 2

Minimum detectable differences between means for t-tests for samples from striped dolphins, *Stenella coerureoalba*, from the northern (Nor) and Southern (So) regions. Beta error set at 0.10.

Sub-sample (cm)	Variance Nor/So	t-value	Minimum detectable difference (cm)
>180	164.99 190.11	1.963	4.01
>185	148.23 162.59	1.964	3.82
>190	122.21 141.94	1.964	3.72
"Adult females"	53.61 147.57	1.292	9.63

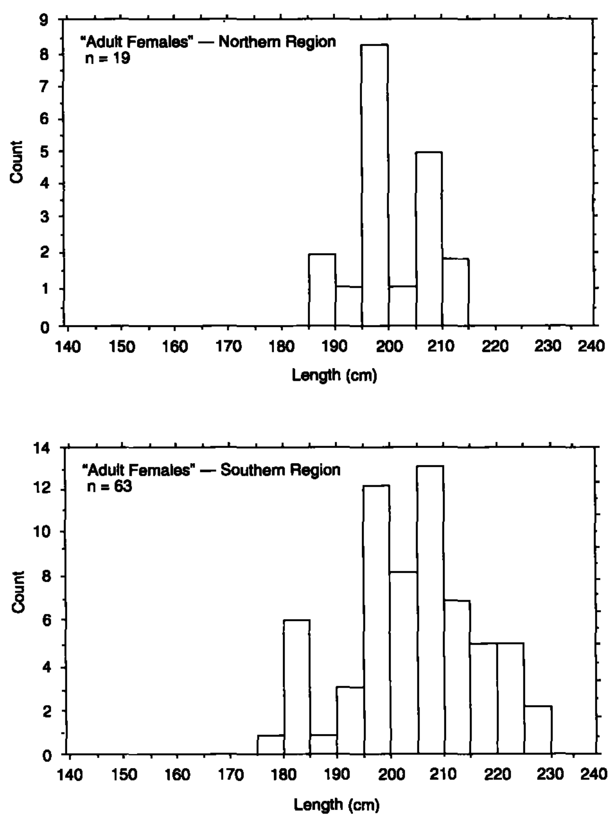

Figure 4

Distribution of lengths of "adult females", defined here as stroped dolphins, *Stenella coeruleoalba*, closely associated with a calf, measured from the northern and southern regions.

The sample from the northern region was too small to test for a seasonal pattern in reproduction, but the distribution of back-projected births from the southern region differed significantly from the uniform distribution (P<0.01; Figs. 5 and 6). Reproduction for striped dolphins from the southern region appears to be broadly pulsed in the fall through spring period.

Photogrammetric and specimen data

Since significant differences between length samples from the northern and southern regions could not be detected, we pooled length data from the two regions in the tests that follow. We found that "adult females" were significantly longer (4.8 cm) on average than adult females from the specimen data base. When the test was repeated by using length data for lactating females from the specimen data base, the two samples no longer differed significantly (Table 3). Striped dolphins ≥ 180 cm in length from the photogrammetric sample were significantly longer on average than the sample based on the same length criteria from specimen data. We also performed a Kolmogorov-Smironov test to compare the two distributions (Fig. 7) and found that they differed significantly (P<0.01).

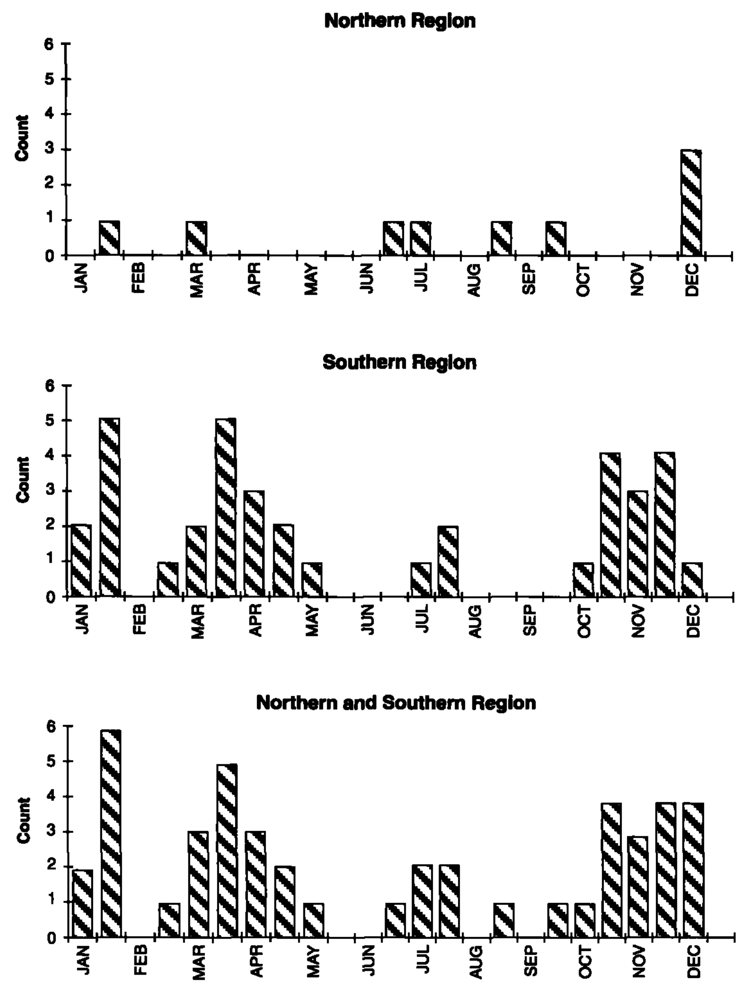

Figure 5

Distribution of back-projected birth dates for striped dolphins, *Stenella coeruleoalba,* from the northern and southern regions and for the two regions combined.

Table 3

Results of comparisons between means of length data for striped dolphins, *Stenella coerueoalba,* taken from specimens (spec) and aerial photographs (photo) (t-tests), and the distribution of lengths ≥180cm (Kolmogorov-Smirnov {k and s} test) from these two sources.

Comparison	n spec/photo	Mean (cm) spec/photo	P (2-tailed)
Adult females			
specimen/photo	50/82	198.2/203.0	0.007
Lactating specimens/ "adult females"	23/82	199.8.203.0	0.202
>180cm t-test	256/681	199.19/205.73	0.0001
>180cm k and s	256/681	Z=3.378	0.0007

School size and structure

We performed a chi-square test to determine whether the number of dolphins in our two size categories were distributed randomly between schools (Fig. 8) and the hypothesis was significantly rejected when the maximum length for the juvenile category was 195 or 190 cm (P<0.001). With a maximum value of 190 cm, four expected values generated by the test were lower than five. When these schools were deleted from the test or lumped with adjacent schools to eliminate these low expected values, the test results remained highly significant.

When school size was regressed against proportion in the juvenile category, the slope of the regression was not significantly different from zero. Thus, in our sample, the proportion of small dolphins in a school was not related to school size.

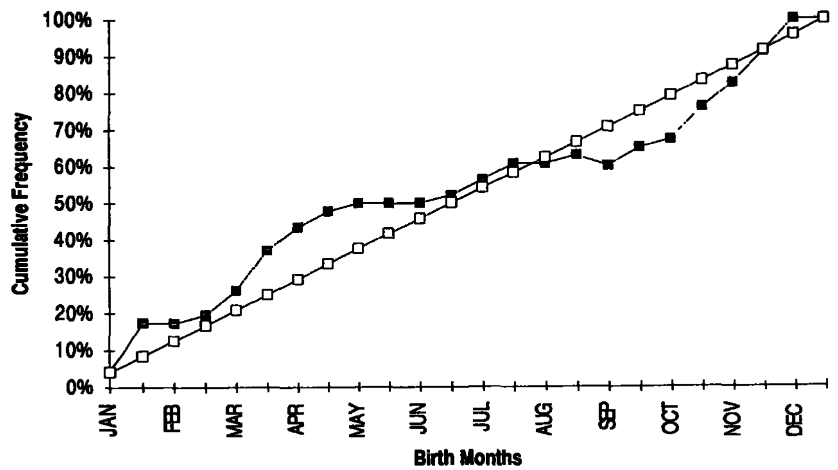

Figure 6

Cumulative distribution of back-projected striped dolphin, *Stenella coeruleoalba*, birth dates (solid squares) and those predicted by a uniform distribution of births (open squares).

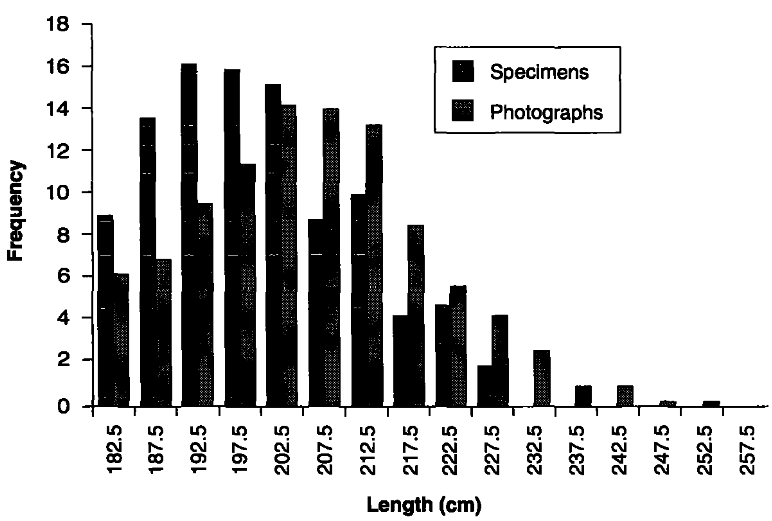

Figure 7

Length-frequency distributions for specimens of striped dolphin *Stenuella coeruleoalba*, (≥ 180 cm) taken incidentally in purse-seine fishing in the eastern tropical Pacific and striped dolphins sampled photogrammetrically that are ≥ 180 cm. Samples from northern and southern regions are combined in this figure.

Discussion

We found no significant differences in our length samples of striped dolphins from the northern and southern regions to support a recommendation that they be managed as separate stocks. This must be tempered by the fact that length differences of a scale not detectable in our sample, i.e. < 4 cm, could exist. The case for two stocks is also weakened by the distribution of sightings of this species from recent research vessel surveys (Wade and Gerrodette, in press). These data indicate that, although a hiatus in striped dolphin distribution exists in the typically tropical (high temperature, low salinity) inshore habitat centered around lat. 15° N, there appears to be a broad avenue for movement between the northern and southern regions in the upwelling modified habitat east of long. 110° West (Au and Perryman, 1985; Reilly, 1990).

When we compared our sample of lengths for "adult females" and dolphins ≥ 180 cm with data from specimens killed incidentally in purse-seine fishing, we found that the means from the photogrammetric sample were significantly larger (by about 3–6 cm). This does not seem unreasonable at first glance because our measurements to the trailing edge of the flukes rather than to the fluke notch introduces a positive bias in the photogrammetric data of about 2–2.5 cm. Also, the "adult female" category probably includes only those females who have carried and given birth to a live calf, thus eliminating the younger, presumably smaller, females who are physiologically adult but have not yet had a successful pregnancy. However, these results for adult females are contrary to previous comparisons of photographic and specimen data for northern and central common dolphins (Perryman and Lynn, 1993) and eastern spinner dolphins (Perryman, unpubl. data). Since the photogrammetric data for all of these taxa were collected in the same manner, it seems likely that the difference between the two striped dolphin samples reflects some form of selectivity in either or both sampling systems.

The schools of striped dolphins that we photographed showed a pattern of segregation by length

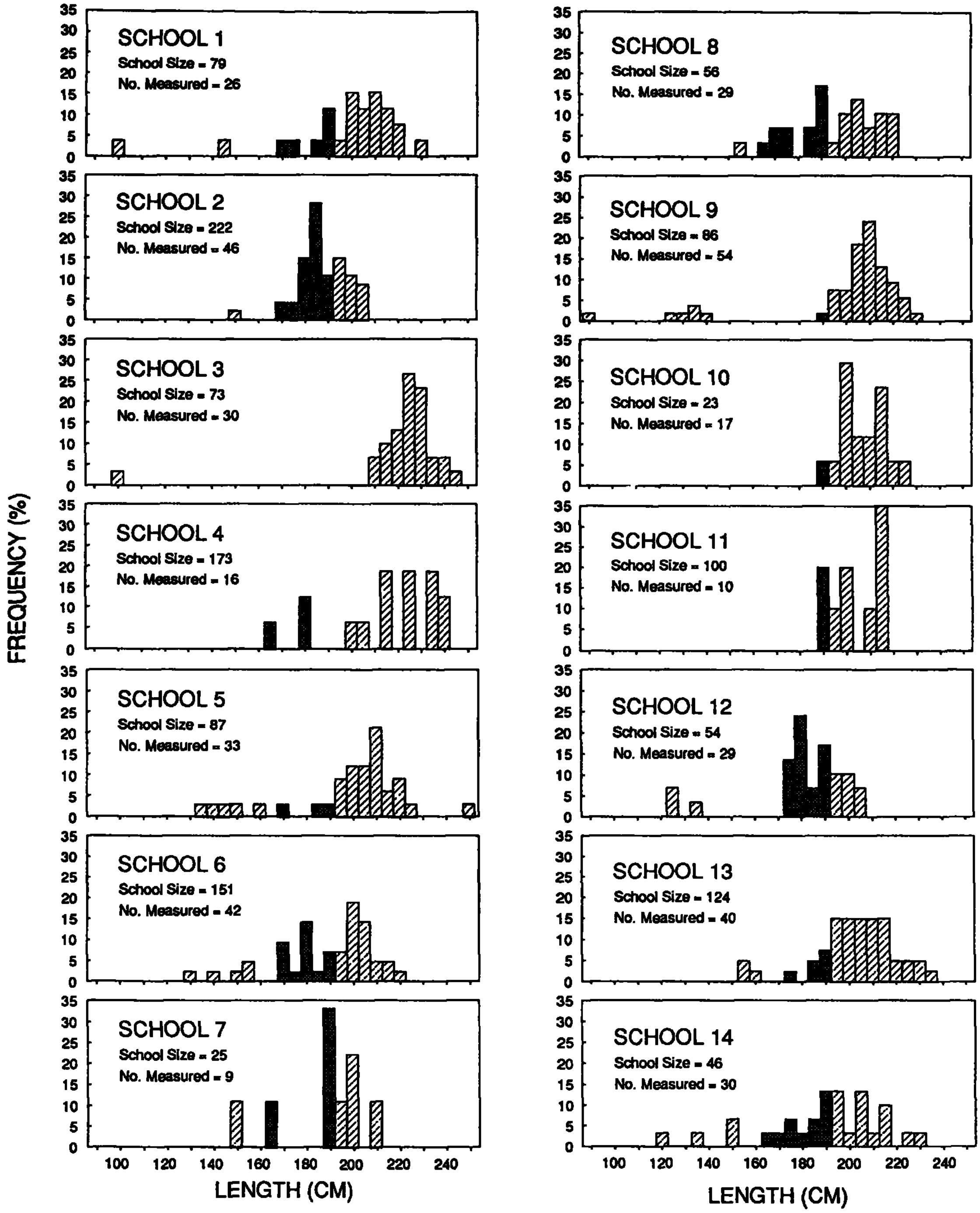

Figure 8

Length frequencies for each school of striped dolphins, *Stenella coeruleoalba*. Shaded bars indicated lengths of dolphins that were included in the juvenile categeory.

that is very similar to that reported from the western Pacific (Miyazaki, 1977; Miyazaki and Nishiwaki, 1978). It also appears that the proportion of smaller dolphins in our sample of schools is not related to school size. Possibly this segregation is the explanation for differences between specimen and photogrammetric data sets.

Tuna fishermen select dolphin schools for encirclement based mainly on the amount of tuna associated with the school. Schools of younger/smaller

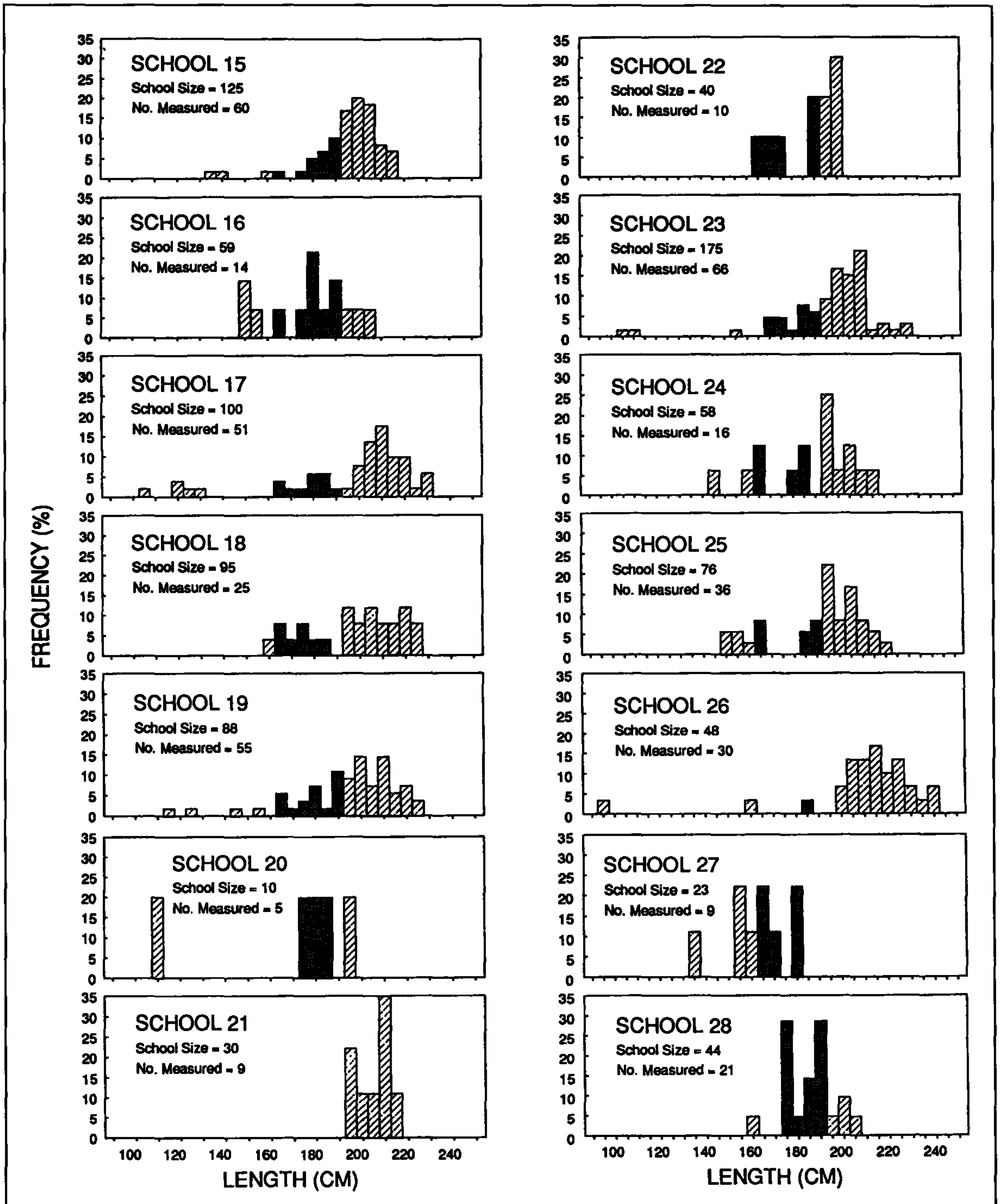

Figure 8 (Continued)

striped dolphins might carry more tuna and be captured more frequently than schools composed of adult animals. If the bond between yellowfin tuna and dolphins is related to size and hydrodynamics as suggested by Edwards (1992) then it may be that the smaller striped dolphins are hydrodynamically more suitable for this association. Juvenile schools of striped dolphins are made up of animals that are about the same length as schools of spotted or spinner dolphins for which the tuna-dolphin association appears to be the strongest.

Acknowledgments

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