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LENGTH DISTRIBUTION OF STRIPED DOLPHINS FROM AERIAL PHOTOGRAPHS: ARE STOCKS IDENTIFIABLE?

By

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LENGTH DISTRIBUTIONS OF STRIPED DOLPHINS FROM AERIAL PHOTOGRAPHS: ARE STOCKS IDENTIFIABLE?

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We compared length data obtained from aerial photographs of 28 schools of striped dolphins (*Stenella coeruleoalba*) from the northern and southern stocks (as defined by Perrin et al. 1985) and found no significant differences in average length for adult animals ($\geq$ 180 cm) or for adult females defined as dolphins closely accompanied by a calf. Analyses of back projected birth dates for striped dolphins, $\leq$ 155 cm, revealed a broad pulse in reproduction extending from late October through April. Sample size was inadequate to compare timing of reproduction between the northern and southern regions. The structure of striped dolphin schools in the eastern Pacific demonstrates the same pattern of size segregation that has been reported for schools of this species taken in the drive fishery in Japan.

Introduction

The striped dolphin (*Stenella coeruleoalba*) has a world wide distribution in tropical and temperate waters (Wilson et al. 1987). Most of what has been learned about this species comes from specimens taken in a drive and harpoon fishery that is limited mostly to the Izu Peninsula of Japan (Nishiwaki 1975; Kasuya 1985). Data from this fishery indicate that average size at birth is about 100 cm (Kasuya 1972; Miyazaki 1977) and that length at age one is about 166 cm (Miyazaki 1984). In the western Pacific, striped dolphins appear to be sexually dimorphic, with asymptotic lengths of 238.9 and 225.7 cm for males and females, respectively (Miyazaki 1984). In this area, there appear to be two calving seasons, one in the winter and one in the summer (Miyazaki 1984). Based on samples from schools of which at least 20% of the animals were examined, a ratio of juveniles and subadults to adult dolphins has been used to categorize schools of striped dolphins as juvenile, adult or mixed schools (Kasuya 1976; Miyazaki and Nishiwaki 1978). Adult and mixed schools were further categorized as either breeding or non-breeding schools (Miyazaki and Nishiwaki 1978).

In the eastern Pacific, striped dolphins are found in "upwelling modified" surface waters in the northern winter (Au and Perryman 1985) and then shift partially into warmer tropical surface waters in the summer months (Reilly 1990). Although occasionally found associated with yellowfin tuna, they are rarely set upon by purse seine fishermen and mortalities have consistently been much lower than those for spotted and spinner dolphins (*S. attenuata* and *S. longirostris*) which are two of the three target species for the fishery (DeMaster et al. 1992). Perrin et al. (1985) recommended two distinct management units for this species (Figure 1) based on a low density band between the two high density centers. The very limited sample of adult body-length data available to Perrin and his co-workers did not suggest a modal difference in length between animals from the two regions.

In this report, we present a large new set of length data for striped dolphins from both the northern and southern regions. We examined these data for evidence of differences in size or life history parameters that might support the recommendation that these two populations be managed separately. In addition, we compared our length distributions for schools of striped dolphins from the eastern Pacific with the school structure categories developed from data on schools captured in the drive fishery off Japan.

Methods

The length data used in this report were extracted from aerial photographs taken with a KA45A military reconnaissance camera that was mounted vertically below the fuselage of a Hughes 500D helicopter. This helicopter was carried aboard the NOAA Ship DAVID STARR JORDAN during the dolphin abundance surveys conducted from July through December of 1987-1990 (Holt and Sexton 1989). The main objective of the aerial photographic effort was to collect data for calibration of observer estimates of dolphin school sizes (Gerrodette 1991). Because the camera was mounted vertically and a radar altimeter was provided for accurate altitude determination, the lengths of dolphins swimming close to the surface could be accurately determined from measurements of their images on the photographs.

The length data presented here were collected from aerial photographs of 28 schools of striped dolphins. This sample includes schools from high density centers for northern and southern regions and 3 "outlier schools" from within the southern boundaries proposed by Perrin et al. (1985; Figure 1).

For 22 of the schools, school size was determined by averaging three independent counts taken from aerial photographs. For the remaining six schools, the number of dolphins in the schools was estimated by observers in the helicopter.

Length Determination

We reviewed all the photographs of striped dolphin schools taken during the 4 years of this study and selected a subset of schools that were collected in the best conditions for light penetration through the water (low sea state and clear skies) and with the clearest images. From this sample we selected the photographic passes over the schools which captured the largest percentage of the school swimming parallel to and very near the surface. Dolphins were excluded from the sample if either the rostrum or tail flukes were not clearly visible or if they were performing behaviors (surfacing, diving, or jumping) that would make them appear shorter in the photographs. Because there was from 60 to 80% overlap between adjacent photographs, the same dolphin could occasionally be measured in two to four different photographs. If more than one length was available for a dolphin, we selected the largest length as our best determination of true length. We made this selection to minimize the negative bias in apparent length caused by the normal swimming movements of the dolphins (Perryman and Lynn 1991; Scott and Perryman 1991).

We measured dolphins from the tip of the rostrum to the trailing edge of the tail flukes (Figure 2). We selected these points 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 probably overestimates total length by about 2.5 cm when compared to standard length.

In preparation for measurement, a section of the original black and white negative of the dolphin school was captured with a high resolution video camera and this digitized image was transferred to a Macintosh IIci computer. Image enhancement and length measurements were made with the digital image processing and analysis program Image (version 1.37) which was developed by the US National Institute of Health. The length measurements on the image were converted to true length by multiplying by the scale of the photograph.

In vertical photographs, the relationship between the size of an object and its image on the film is determined by the ratio of the focal length of the lens and the distance from the camera to the object. This ratio is commonly called the scale of the photograph and is defined as

$$scale = A/f = o/i$$

where,

A = altitude

f = lens focal length

o = size of object photographed, and

i = size of the image of the photographed object.

In our study, focal length remained constant and scale varied with altitude. Our computer based data acquisition system recorded an altitude reading from the radar altimeter as each photograph was taken. We checked the scale determined from radar altimeter readings by photographing objects of known size and comparing scale calculated from these objects with scale from altimetry. The results of these calibrations are reported in Perryman and Lynn (1991).

Data Analysis

Our length distributions from the northern and southern regions included a small sample of calfs and young animals and a larger sample mode containing subadult and adult age classes. We eliminated the youngest dolphins from our sample using length as the limiting criteria ($\geq$ 180 cm; for example from southern region see Figure 3) and tested for regional differences in the remaining sample from each region with a t-test (Figure 3). We selected 180 cm as the minimum length for this first comparison because it was a few centimeters smaller than the smallest adult female reported by Perrin et al. (1985). Because the selection of 180 cm as a minimum size was somewhat arbitrary, we repeated the analysis with minimum values of 185 and 190 cm.

Three schools in the southern region were located outside the area of high sighting density. We performed the comparisons between the northern and southern regions with and without these schools to examine their impact on the results.

Based on behavioral arguments described in Perryman and Lynn (1991), we assumed that the larger dolphin swimming closely alongside a calf was an adult female. Because 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. We conducted an additional t-test to compare the mean lengths of "adult females" from the northern and southern regions.

Reproductive Seasonality

Growth in delphinids is typically very rapid and almost linear through the first year. Change in length is large relative to variability in length at age during this period and modes in length distributions of young dolphins have been used to distinguish between age groups and estimate growth rates (Perrin et al. 1976; Barlow 1984; Hohn and Hammond 1985).

We used 90 cm as the best estimate of average length at birth and 155 cm for average length at 1 year for striped dolphins in the eastern Pacific (Gurevich and Stewart 1979). We assumed postnatal growth was linear during the first year and calculated the birth dates for all dolphins $\leq$ 155 cm in length. 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.

Results and Discussion

We compared the average lengths of striped dolphins from the northern and southern regions (with and without schools outside the high density area) and found no significant differences between any of the samples (Table 1; Figure 4). We also tested for differences in mean lengths of "adult females" (Figure 5) and again found no differences between the regions. Although none of the differences were significant, means of the samples from the northern region were consistently a few centimeters smaller than those from the south, a pattern reported by Perrin et al. (1985). Our mean lengths for "adult females" from the northern and southern regions were three to five centimeters larger than those reported by Perrin and his coworkers from specimens killed by the purse seine fishery. We suspect that these differences are the result of the small number of specimens in the fishery sample rather than a bias inherent in the photographic sampling (see Perryman and Lynn 1991).

We calculated the birth dates for all striped dolphins whose lengths were 155 cm or smaller (Figure 6). The sample from the northern region was too small to determine any seasonal pattern in reproduction and, because there was no apparent difference between the samples, we pooled all of the estimated dates of birth. We compared this combined sample with a uniform distribution and found that the birth date distribution differed significantly from the uniform pattern ($p < 0.05$; Figure 7). These data indicate that reproduction in striped dolphins in the eastern tropical Pacific (ETP) is broadly pulsed in the fall through spring period.

School Structure

We found a pattern of size segregation in our schools of striped dolphins (Figure 8) that is analogous to the school structures reported for this species from the coast of Japan (Kasuya 1972; Miyazaki 1977; Miyazaki and Nishiwaki 1978). While most of the schools in our sample include a wide range of size/age classes, a few of the samples are clearly composed almost exclusively of smaller, presumably juvenile dolphins (e.g., schools # 2, 12, and 27) or adult sized dolphins (e.g., schools #3, 9, and 28).

Stock Structure

We found no differences in length or timing in reproduction to support the provisional recommendation that there are two stocks of striped dolphins in the ETP (Perrin et al. 1985).

Acknowledgements

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Literature Cited

Au, D. W. K. and W. L. Perryman. 1985. Dolphin habitats in the eastern tropical Pacific. Fishery Bulletin 83:623-643.

Barlow, J. 1984. Reproductive seasonality in pelagic dolphins (*Stenella* spp.): Implications for measuring rates. In Reproduction in Whales, Dolphins and Porpoises. eds. W. F. Perrin, R. L. Brownell, Jr. and D. P. DeMaster, Reports of the International Whaling Commission (Spec. Issue 6), pp. 191-198.

Batschelet, E. 1965. Statistical Methods for the Analysis of Problems in Animal Orientation and Certain Biological Rhythms. American Institute of Biological Science, Monograph, 57 pp.

DeMaster, D. P., E. F. Edwards, P. Wade and J. E. Sisson. 1992. Status of dolphin stocks in the eastern tropical Pacific. In McCullough, D. and R. Barrett (eds.), Wildlife 2001: Populations. Elsevier. in press.

Gerrodette, T. 1991. Calibration of shipboard estimates of dolphin school size from aerial photographs. NMFS SWFSC Administrative Report LJ-91-36, 31 pp.

Gurevich, V. S. and B. S. Stewart. 1979. A study of growth and reproduction of the striped dolphin (*Stenella coeruleoalba*). Unpublished Contract Report # 03-78-D27-1079, 19 pp.

Hohn, A. A. and P. S. Hammond. 1985. Early postnatal growth of the spotted dolphin, *Stenella attenuata*, in the offshore eastern tropical Pacific. Fishery Bulletin 83:553-566.

Holt, R. S. and S. N. Sexton. 1989. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1986 data, the first year. Fishery Bulletin 88:105-111.

Kasuya, T. 1972. Growth and reproduction of *Stenella coeruleoalba* based on the age determination by means of dentinal growth layers. Scientific Reports of the Whales Research Institute 24:57-79.

Kasuya, T. 1976. Reconsideration of life history parameters of the spotted and striped dolphins based on cemental layers. Scientific Reports of the Whales Research Institute 28:73-106.

Kasuya, T. 1985. Effect of exploitation on reproductive parameters of the spotted and striped dolphins off the Pacific Coast of Japan. Scientific Reports of the Whales Research Institute 36:107-138.

Miyazaki, N. 1977. School structure of *Stenella coeruleoalba*. Report of the International Whaling Commission 27:498-499.

Miyazaki, N. and M. Nishiwaki. 1978. School structure of the striped dolphin off the Pacific Coast of Japan. Scientific Reports of the Whales Research Institute 30:65-115.

Miyazaki, N. 1984. Further analysis of reproduction in the striped dolphin, *Stenella coeruleoalba*, off the Pacific Coast of Japan. In Reproduction in Whales, Dolphins and Porpoises. eds. W. F. Perrin, R. L. Brownell, Jr. and D. P. DeMaster, Reports of the International Whaling Commission (Spec. Issue 6), pp. 343-353.

Nishiwaki, M. 1975. Ecological aspects of smaller cetaceans, with emphasis on the striped dolphin (*Stenella coeruleoalba*). Journal of the Fisheries Research Board of Canada 32:1069-1073.

Norris, K. S. (ed) 1961. Standardized methods for measuring and recording data on smaller cetaceans. Journal of Mammalogy

42:471-476.

Perrin, W. F., J. M. Coe and J. R. Zweifel. 1976. Growth and reproduction of the spotted dolphin, *Stenella attenuata*, in the offshore eastern tropical Pacific. Fishery Bulletin 74:229-269.

Perrin, W. F., M. D. Scott, G. J. Walker, and V. L. Cass. 1985. Review of geographical stocks of tropical dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern Pacific. NOAA Technical Report NMFS-28. iv + 28 pp.

Perryman, W. L. and M. S. Lynn. 1991. Identification of common dolphin (*Delphinus delphis*) stocks from aerial photographs. NMFS SWFSC Administrative Report LJ-91-40, 36 pp.

Reilly, S. B. 1990. Seasonal changes in distributions and habitat differences among dolphins in the eastern tropical Pacific. Marine Ecology Progress Series 66:1-11.

Scott, M. D. and W. L. Perryman. 1991. Using aerial photogrammetry to study dolphin school structure. In Dolphin Societies-Discoveries and Puzzles. eds K. Pryor and K. S. Norris, University of California Press, Berkeley, p. 227-241.

Wilson, C. E., W. F. Perrin, J. W. Gilpatrick, Jr. and S.

Leatherwood. 1987. Summary of worldwide locality records of the striped dolphin, *Stenella coeruleoalba*. NOAA Technical Memorandum NMFS-SWFC-90, 65 pp.

Table 1. Results of t-tests for differences between mean lengths for northern (Nor) schools and southern (So) schools from the high density area and for all southern (All So) schools.

Sub Sample	Nor/So	p (2-tail)	Nor/All So	p (2-tail)
<180 cm	205.1/206.4	0.287	205.1/205.9	0.476
<185 cm	206.0/208.3	0.056	206.0/207.7	0.138
<190 cm	207.9/209.4	0.188	207.9/209.2	0.230
"Adult Females"	200.2/203.7	0.262	200.2/204.0	0.201

Figures

Fig. 1. Recommended management units for striped dolphins from Perrin et al. (1985). Locations of schools used in this report are plotted on this figure.

Fig. 2. Illustration of the difference between standard length and lengths measured from aerial photographs.

Fig. 3. Length distributions for all striped dolphins photographed from the southern region.

Fig. 4. Length frequency distributions for striped dolphins ≥ 180 cm from the northern region, southern region (high density area only) and the entire southern region. Sample size, mean and standard deviation included for each sample.

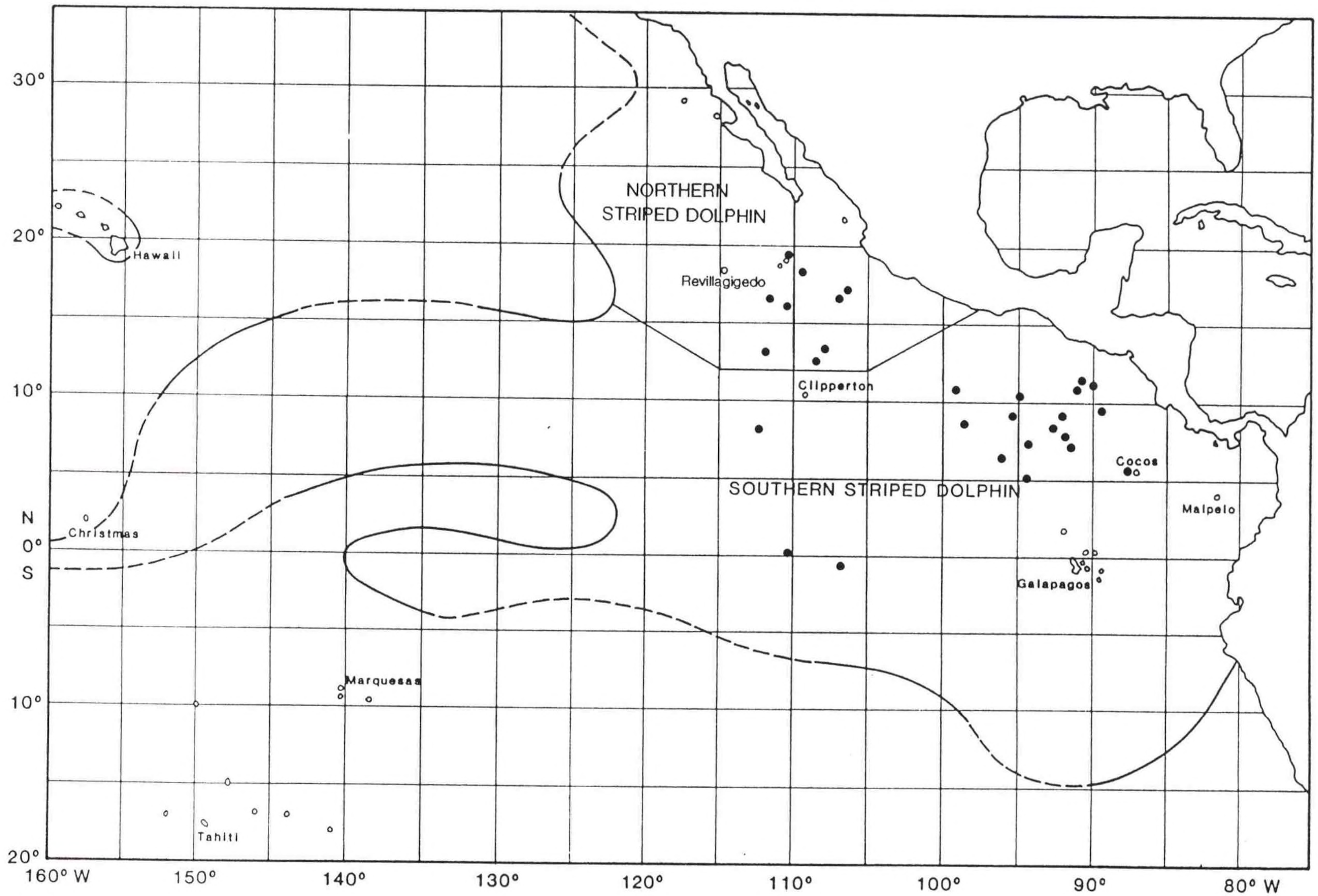
Fig. 5. Length frequency distributions for "adult female" striped dolphins from the northern, southern (high density area) and entire southern regions. Sample size, mean and standard deviation included for each sample.

Fig. 6. Distribution of calculated birth dates for the three regions described for figures four and five.

Fig. 7. Cumulative distribution of calculated birth dates for striped dolphins from all regions. Plot of open boxes represents cumulative distribution of births if births were uniform throughout the year; closed boxes represent estimated cumulative distribution of births.

Fig. 8. School size, sample size and length distribution for

each school of striped dolphin.



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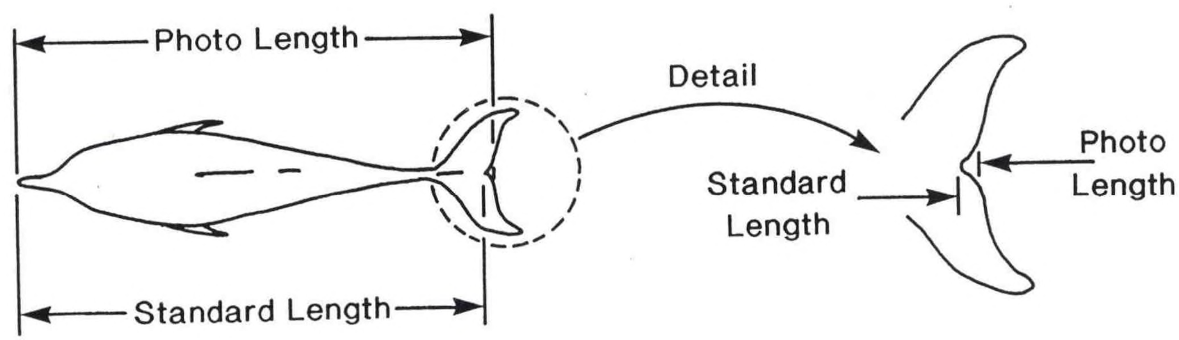


Figure 2 - Illustration of the difference between standard length and lengths measured from aerial photographs.

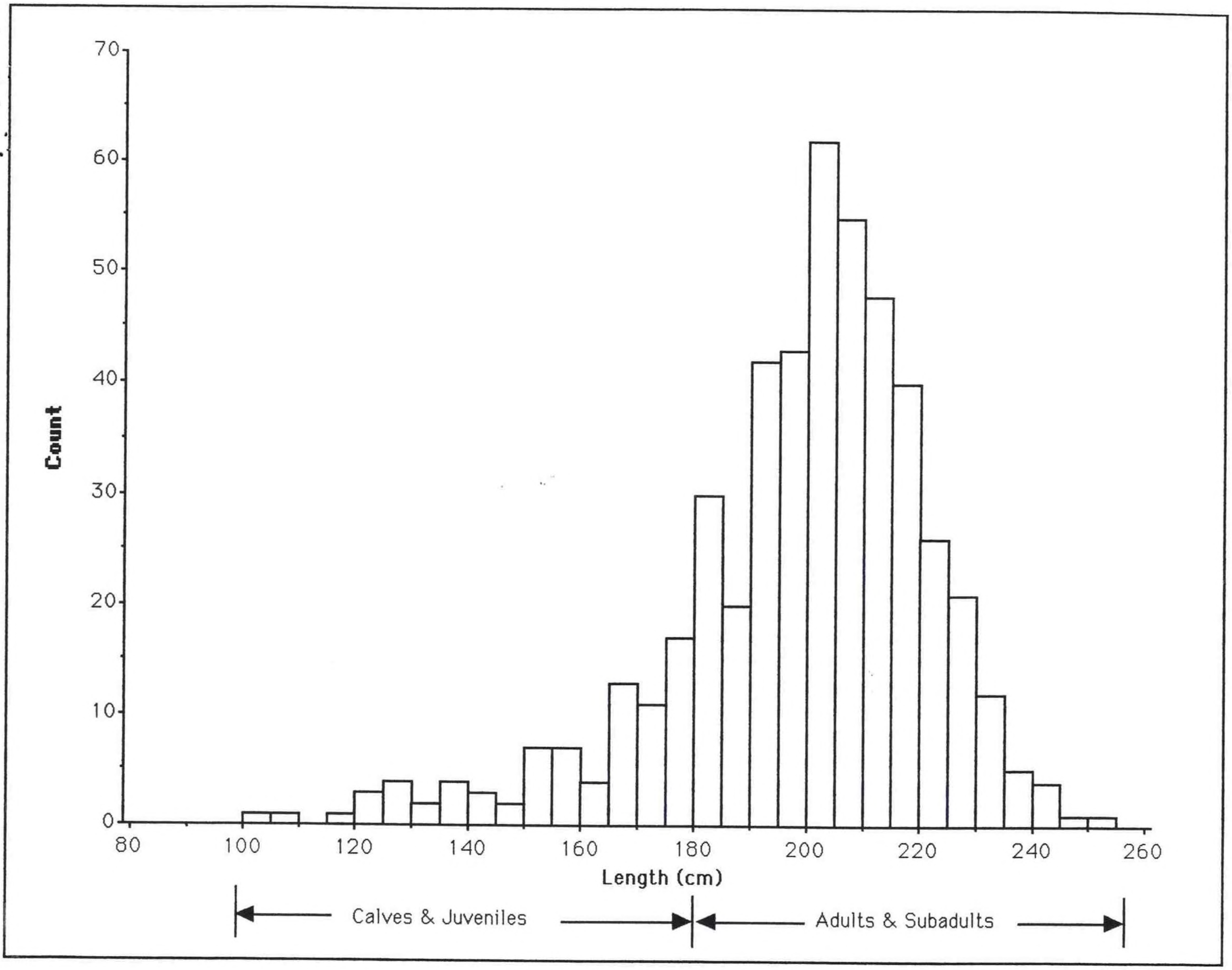


Figure 3 - Length distribution for all striped dolphins photographed from the southern region.

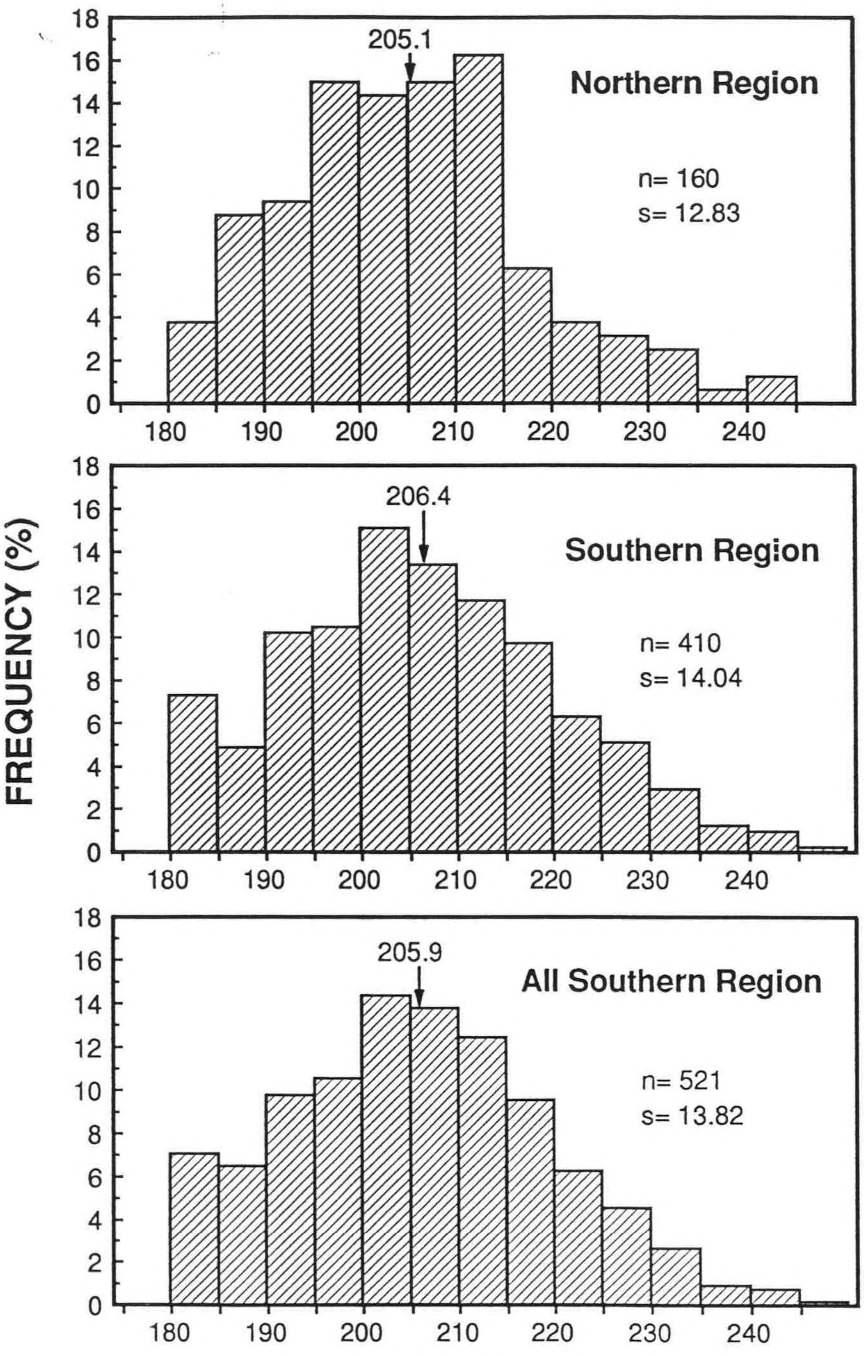


Figure 4 - Length frequency distributions for striped dolphins ≥ 180 cm from the northern region, southern region (high density), and the entire southern region. Sample size, mean and standard deviation included for each sample.

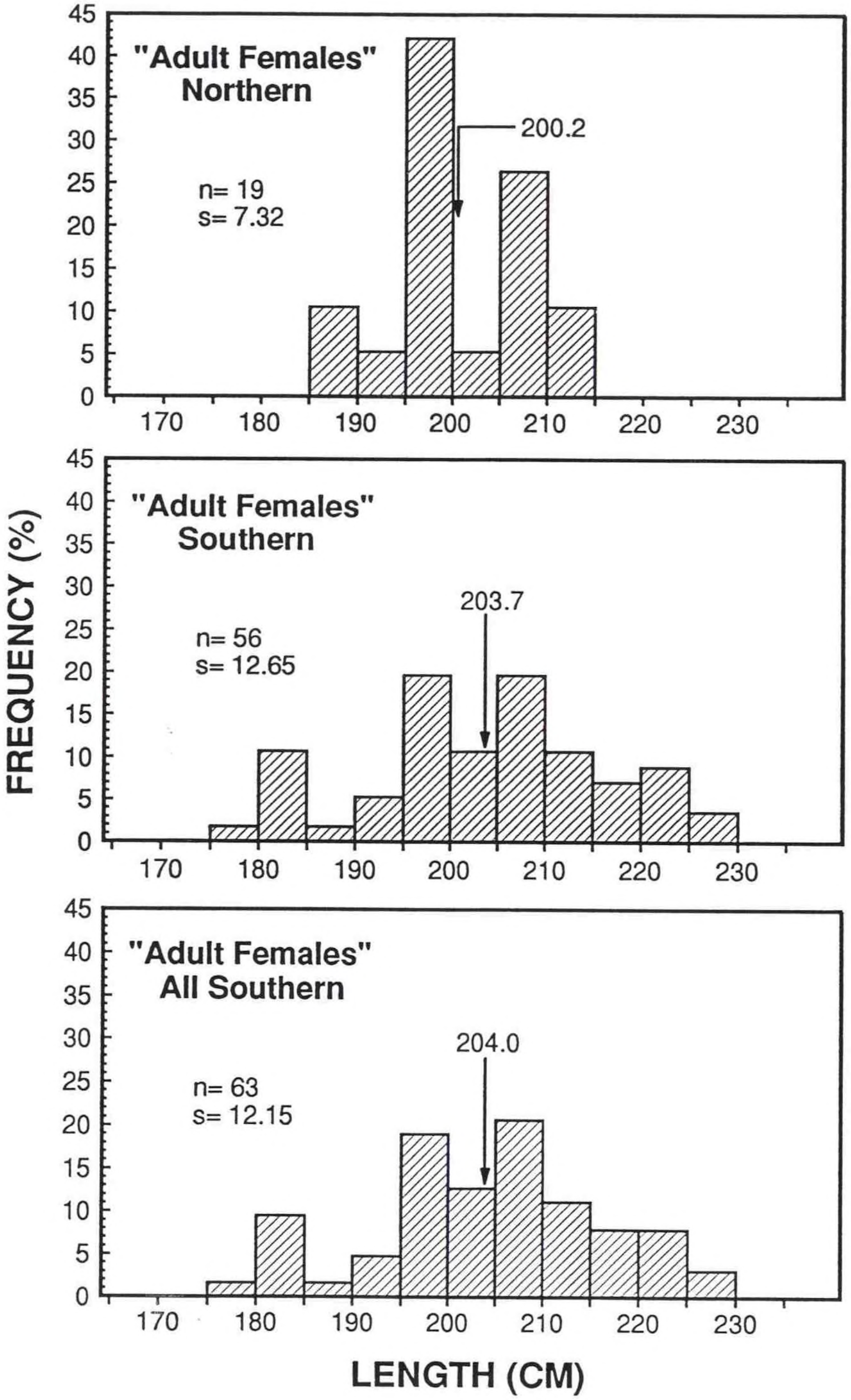


Figure 5 - Length frequency distributions for "adult female" striped dolphins from the northern, southern (high density area) and entire southern region. Sample size, mean and standard deviation included for each sample.

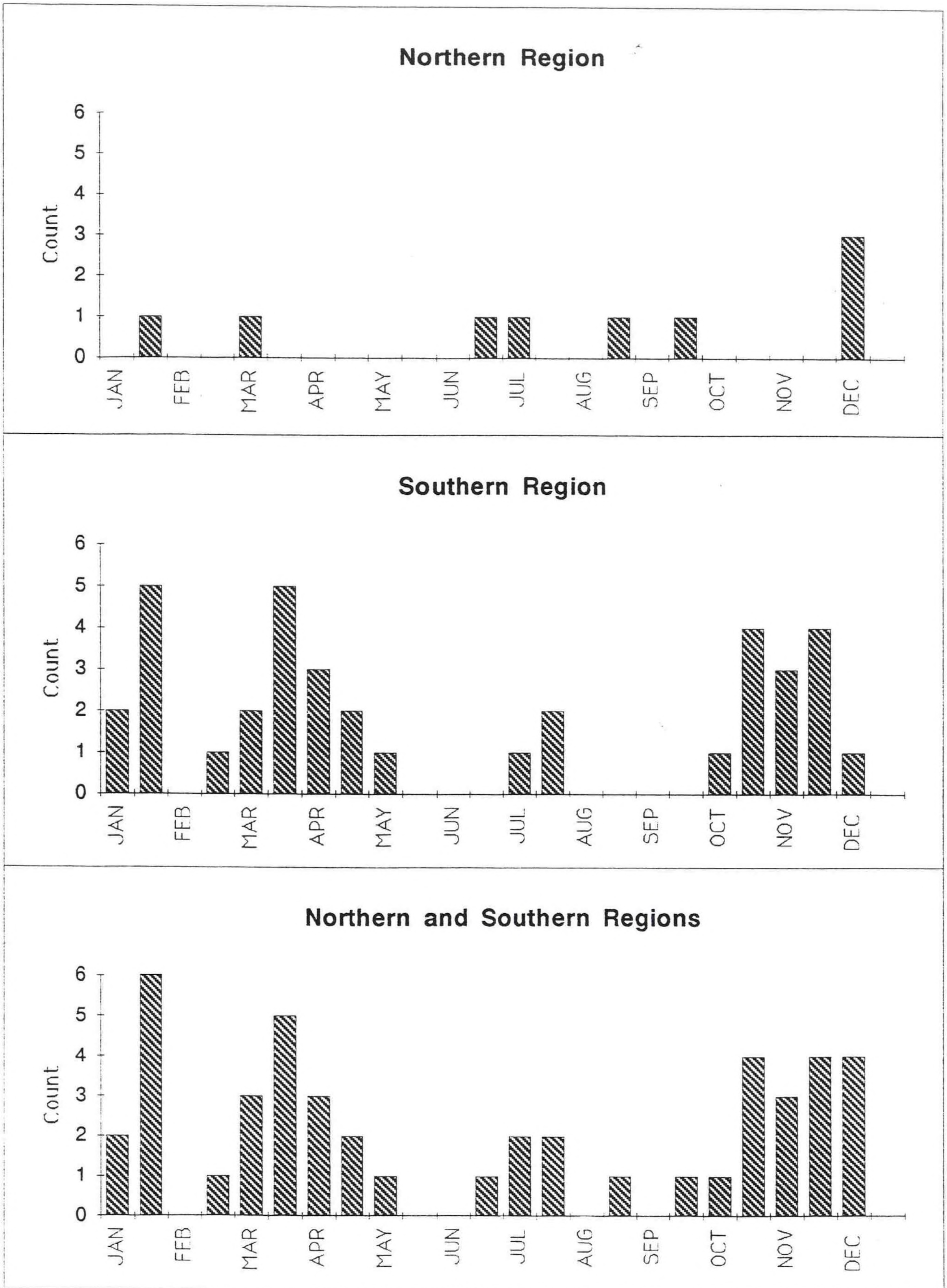


Fig. 6. Distribution of calculated birth dates for the three regions described for figures four and five.

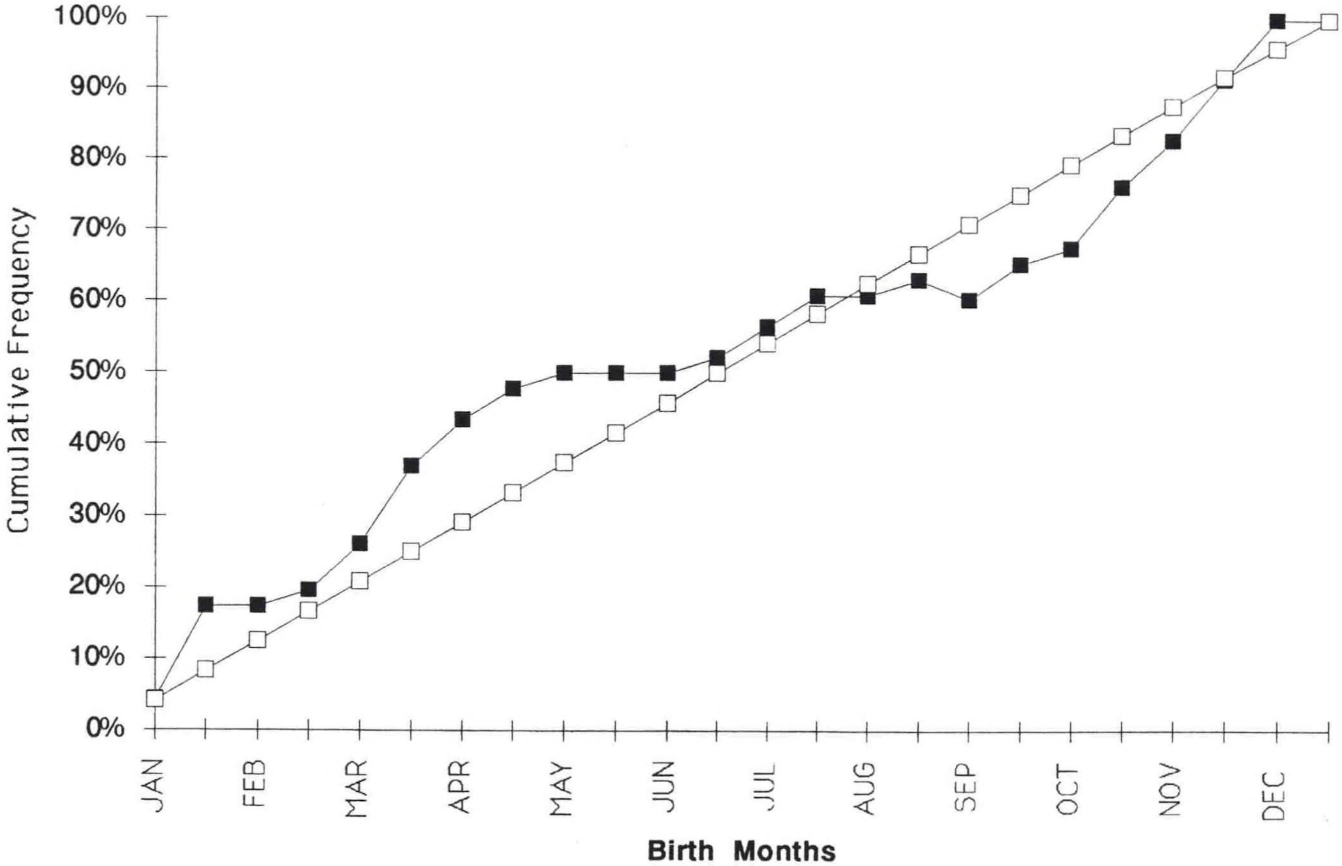


Fig. 7. Cumulative distribution of calculated birth dates for striped dolphins from all regions. Plot of open boxes represents cumulative distribution of births if births were uniform throughout the year; closed boxes represent estimated cumulative distribution of births.

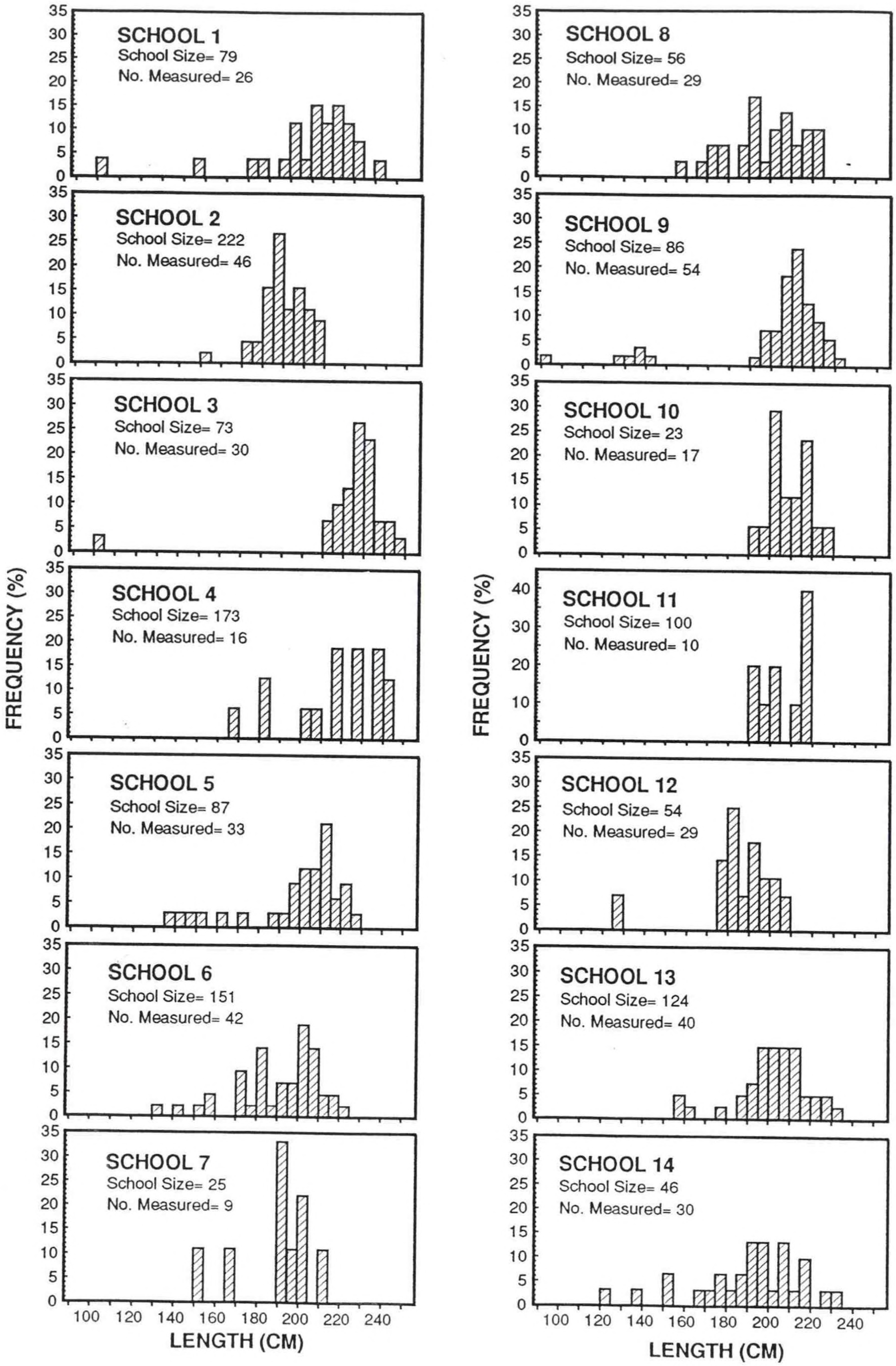
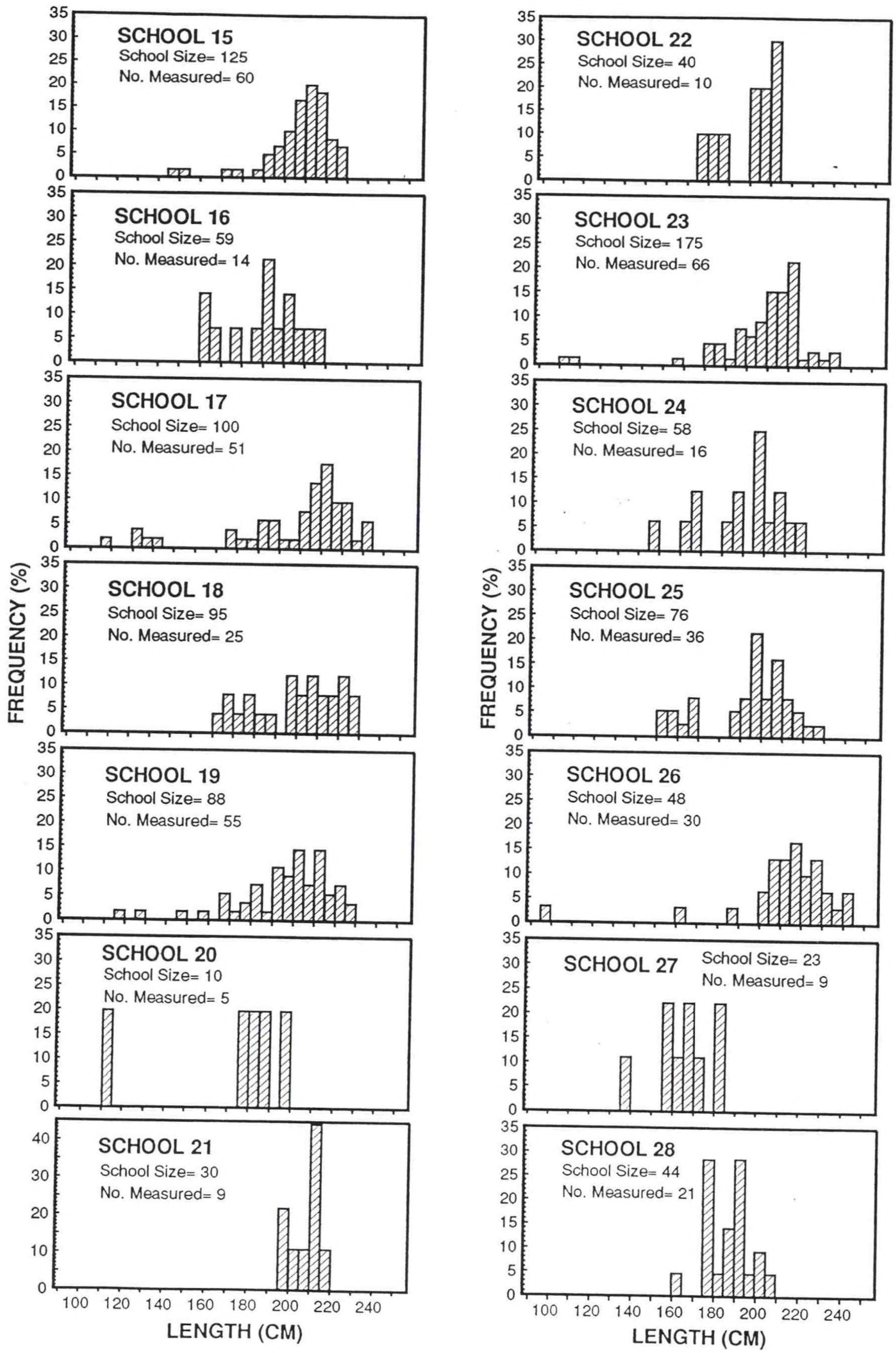


Fig. 8. School size, sample size and length distribution for each school of striped dolphin.


SCHOOL 15
School Size= 125
No. Measured= 60
SCHOOL 16
School Size= 59
No. Measured= 14
SCHOOL 17
School Size= 100
No. Measured= 51
SCHOOL 18
School Size= 95
No. Measured= 25
SCHOOL 19
School Size= 88
No. Measured= 55
SCHOOL 20
School Size= 10
No. Measured= 5
SCHOOL 21
School Size= 30
No. Measured= 9
SCHOOL 22
School Size= 40
No. Measured= 10
SCHOOL 23
School Size= 175
No. Measured= 66
SCHOOL 24
School Size= 58
No. Measured= 16
SCHOOL 25
School Size= 76
No. Measured= 36
SCHOOL 26
School Size= 48
No. Measured= 30
SCHOOL 27
School Size= 23
No. Measured= 9
SCHOOL 28
School Size= 44
No. Measured= 21
FREQUENCY (%)
FREQUENCY (%)
100 120 140 160 180 200 220 240
LENGTH (CM)
100 120 140 160 180 200 220 240
LENGTH (CM)