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SWIMMING BEHAVIOUR OF SCHOOLING HERRING AND SPRAT AS RECORDED FROM A SURVEY VESSEL

by

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Introduction

Fish in schools swim polarized and syncronized (Pitcher 1983), and a school appear as a unit of limited extent. Schooling is an unfavourable behaviour for fish abundance estimation by conventional echo integration as vessel avoidance may cause substantial underestimation (Olsen 1987).

Vessel avoidance may be a response to low frequency noise generated by propeller cavitation and the running diesel engines (Mitson 1989). The emitted sound have a certain directivity (Urick 1967), and are caracterised by a vessel specific frequency spectrum (Bercy & Bordeau 1987). We have related the swimming behaviour of schooling herring and sprat during a survey in the North Sea to an avoidance behaviour model (Olsen et. al 1983a), stating that schooling fish reacts at some distance by swimming with an increased speed radially away from the vessel generated stimuli. As the vessel comes closer the fish may start descending with an unfavourable tilt angle for measurements of reflected echo energy, or dissappear out of the path of the vessel totally by fast horizontal evasion. The strength of the reaction will decrease if the fish is swimming at greater depth.

The high syncrony and cohesion between the schooling individuals creates aggregations with a volume proportional to the number of individuals and the cube of the fish length (Pitcher & Partridge 1979). This indicates the possibility of school biomass estimation by acoustic measurements of school dimensions if relations between school dimensions and biomass exists. We have measured the dimensions and fish density of herring and sprat schools during the mentioned North Sea survey, and related school geometry to school biomass.

Materials and Methods

The investigation were carried out by R/V "Eldjarn" during a herring survey in the North Sea June-July 1988. The schools were recorded by a 34 kHz Simrad SM 600 true-motion, multi-beam sonar (Bodholdt 1982). About 300 schools were located and dimensioned, and the swimming behaviour of 140 schools were quantified as they were approached by the vessel. The fish density of 128 schools were measured by a calibrated echo integration system consisting of a 38 kHz Simrad EK 400 echo-sounder connected to a digital echo-integrator. To identify the species, length, weight and biological condition, sampling were carried out regulary by a standard pelagic trawl (type Fotø). The sonar recordings were obtained during the dayligth an dusk hours (06 00 - 22 00 GMT), when the ligth level was supposed to be well above the limit for schooling (Class, Wardle and Mojsiewicz 1986).

Large and maturing herring (24.8 - 27.5 cm in average) were recorded in the Northern North Sea (North of 57° 30′), and medium sized (16.8 - 22.9 cm in average) and small immature herring (7.3 - 8 cm in average) outside the east coast of Great Britain. In this area, there were also some recordings of large sprat (12.9 - 14.0 cm in average).

The sonar recordings were taped via a palcoder (Cox Pal 153 WS/GS), and later displayed by a JVC video system (Model CR-6600E). The recordings were analysed according to a method described by Misund (1987) with the behaviour of the schools quantified in intervals of 10 s. The vertical extent, echo trace length and integrator value of schools recorded by the echo-sounder were also recorded, and the fish density calculated according to Johannesson and Losse (1977) when applying a target strength = 20 log L - 71.9 (Foote 1987).

Results

The measurements of horizontal swimming speed varied from 0.0 up to 5.0 m/s. Generally, the horizontal swimming speed were perhaps less influenced by the length of of the schooling herring and sprat than expected as the measurements indicated little difference both in the average and the variation of the horizontal swimming speed for the length groups from 14.0 to 27.5 cm. The length groups between 7.0 and 12.9 cm performed a slower average and less variation in the horizontal swimming speed. Both the radial horizontal and vertical swimming speed were rather independent of the length of the schooling individuals (Fig. 1 B, C). Most length groups avoided the vessel radially (average $V_r > 0.0$ m/s), but few of the length groups showed vertical avoidance (average $V_v < 0.0$ m/s).

The uneven distribution ($p < 0.05$, chi-square test) of radial swimming direction (Fig. 2A), shows that the schools generally moved away from (298 of 486 observations), but in about the same direction as the approaching vessel (average radial direction 14^{o}, angular deviation 101.9^{o}). The distribution seems to have tree modes, which may indicate that the schools were zigg-zagging in front of the vessel as a response to the directivity of the vessel generated sound (Fig. 2B). This tendency was clearly demonstrated in some of the recorded situations (Fig. 3).

Contrary to the avoidance behaviour model, the horizontal swimming speed increased significantly with the horizontal distance vessel-to-school within the range 25-330 m (Table 1, Fig. 4A). The avoidance was significantly dependent of the swimming depth of the schools, as both the horizontal and downward ($V_v < 0.0$ m/s) swimming speed were faster for the schools recorded at greater depths (Table 1, Fig. 4B,C). There were no clear connections between direction of bearing vessel-to-school or the area of schools and the swimming parameters (Table 1).

Table 1. Spearman's rank correlation between the swimming parameters and horizontal distance vessel-to-school, direction of bearing, swimming depth and school area (V_h: horizontal swimming speed, V_r: radial horizontal swimming speed, V_v: vertical swimming speed, p: level of significance, n: no. of measurements).

	Distance		Bearing		Depth		School area	
	r_s	p	r_s	p	r_s	p	r_s	p
V_h	0.21	<0.05	0.08	>0.05	0.19	<0.05	0.11	>0.05
V_r	-0.06	>0.05	-0.08	>0.05	0.06	>0.05	-0.03	>0.05
V_v	-0.07	>0.05	-0.01	>0.05	-0.29	<0.05	-0.04	>0.13

The result of the avoidance tendencies is demonstrated in Fig. 5, which shows that the proportion of directly approached schools not hit by the echo-sounder beam increased from about 16 % for the smallest length groups to about 41 % for the largest length groups.

Generally, there were substantial variations in the fish density measurements for schools within all the fish length groups (Fig. 6). The fish density (p) declined in proportion to the fish length (L) by the relation:

$$p = 15680\ (L)^{-2.83} \qquad r^2 = 0.50$$

The sonar and echo-sounder measurements revealed significant rank correlations between the lengthwise, crosswise and vertical school dimensions (Table 2). An average proportion of crosswise-to-lengthwise-to-vertical dimension of about 3.0:1.5:1.0 indicate an ellipsoid school shape with the longest axis across the direction of swimming. The proportion of echo-sounder transect length and lengthwise sonar measured school extent was in average 1.2:1, and the dimensions were significantly correlated (Table 2).

Table 2. Avaerage value, standard deviation and rank correlation between the school dimensions (CW: crosswise, LW: length wise, H: vertical, TL: transect length, r_s: Spearman's rank correlation, p: level of significance, n: no. of measurement)

	CW	LW	H	TL	CW:LW	CW:H	LW:H	LW:TL
Average	39.15	19.84	13.02	22.86				
St. Dev.	16.72	13.42	9.51	19.90				
N	128	128	128	128				
rs					0.52	0.39	0.38	0.54
p					<0.05	<0.05	<0.05	<0.05

The distributions of recorded school volumes for the different length groups shows that most of the schools were rather small, but there were great variations (Fig. 7A). However, there was a significant tendency ($r_s = 0.26$, $p < 0.05$) towards larger schools for the largest length groups. The biomass of the schools was closely correlated to the horizontal school dimensions, weaker correlated to the vertical school extent and fish weight, and not correlated to the fish density (Table 3). In addition, there was only a weak and not significant correlation between the biomass per unit volume and the fish weight (Table 3).

Table 3. School biomass (B) correlated to crosswise (CW), lengthwise (LW) and vertical (H) school extent, fish density (p), and fish weight (W), and biomass per unit volume (B/V) correlated to fish weight.

	B:CW	B:LW	B:H	B:p	B:W	B/V:W
Correlation coeffisient	0.61	0.69	0.28	-0.01	0.18	0.15
Level of significance	<0.05	<0.05	<0.05	>0.05	<0.05	>0.05

These results adds up to rather close relationships between the geometric dimensions and the biomass of the schools (Fig. 7B,C).

Discussion

The results indicates clearly that schooling herring and sprat tended to avoid the survey vessel, and that the avoidance incresed with the length (and swimming ability) of the schooling fish. The zigg-zagging tendency with the longest axis of the school area across the swimming direction may be a response to the directivity of the vessel generated sound. The horizontal swimming speed declined as the vessel approached, and both the horizontal and vertical swimming speed increased with the swimming depth of the schools. The former might have been caused by a greater positioning error at longer range, while the latter may be a response to a stronger sound stimuli field at the greater depths. This may indicate that the horizontal and vertical range at which the swimming behaviour recordings were obtained, may have caused the deviations between the recorded behaviour and the avoidance model predictions (Olsen et. al. 1983).

The recorded fish density-to-fish length relationship has the same slope as similar relationships given by Serebrov (1976) and Pitcher & Partridge (1979). The level of the recorded relationship is about 66 % of the Serebrov-relationship ($(2.44\ L)^{-3}$), but only 5 % of the Pitcher & Partridge-relationship ($(L)^{-3}$). The large deviatation between the level of the Pitcher & Partridge-relationship and the recorded one probably reflects difference in schooling behaviour in aquarias of limited extent and natural conditions.

No significant correlation was observed between the biomass per unit volume and the weight of the fish. This agrees with the general pattern that number of fish per unit volume is inversly proportional to the third power of the fish length while the fish weight is proportional to the third power of the fish length.

The school geometry and fish density measurements revealed connections between the biomass and volume or area of the schools. Similar connections have been found by purse seine capture of sonar measured herring and mackerel schools (Misund 1987, 1988, Wheeler & Chaulk 1987) or echo-integration of sonar measured herring schools (Misund & Øvredal 1988). The relationships we have presented, incorporates schools with different density and length of the individuals.

There are many sources of errors connected to the measurements presented here. An accurate speed log is fundamental, and periodic errors in this unit resulted in a sonar recordings where the schools swam towards the vessel and erraneous echo-integrator values. Only behaviour and density measurements obtained when the log was supposed to provide accurate vessel speed are used in this investigation. "Stylus" and "ping" errors (Johannesson & Losse 1977), side lobe effects, sound attenuation and "school tail" caused by multiple scattering may have contributed to biases in the fish density measurements. More accurate school area measurements could be obtained by use of computerized picture analysis. If the transmitter beam-forming of the sonar is improper, the crosswise dimensions should have been corrected for a beamwidth (ϕ) of 9° instead of 5°. In addition, the applied beamwidth correction is an average value, while the actual beamwidth distortion is within the interval (0, 2 R tan ϕ).

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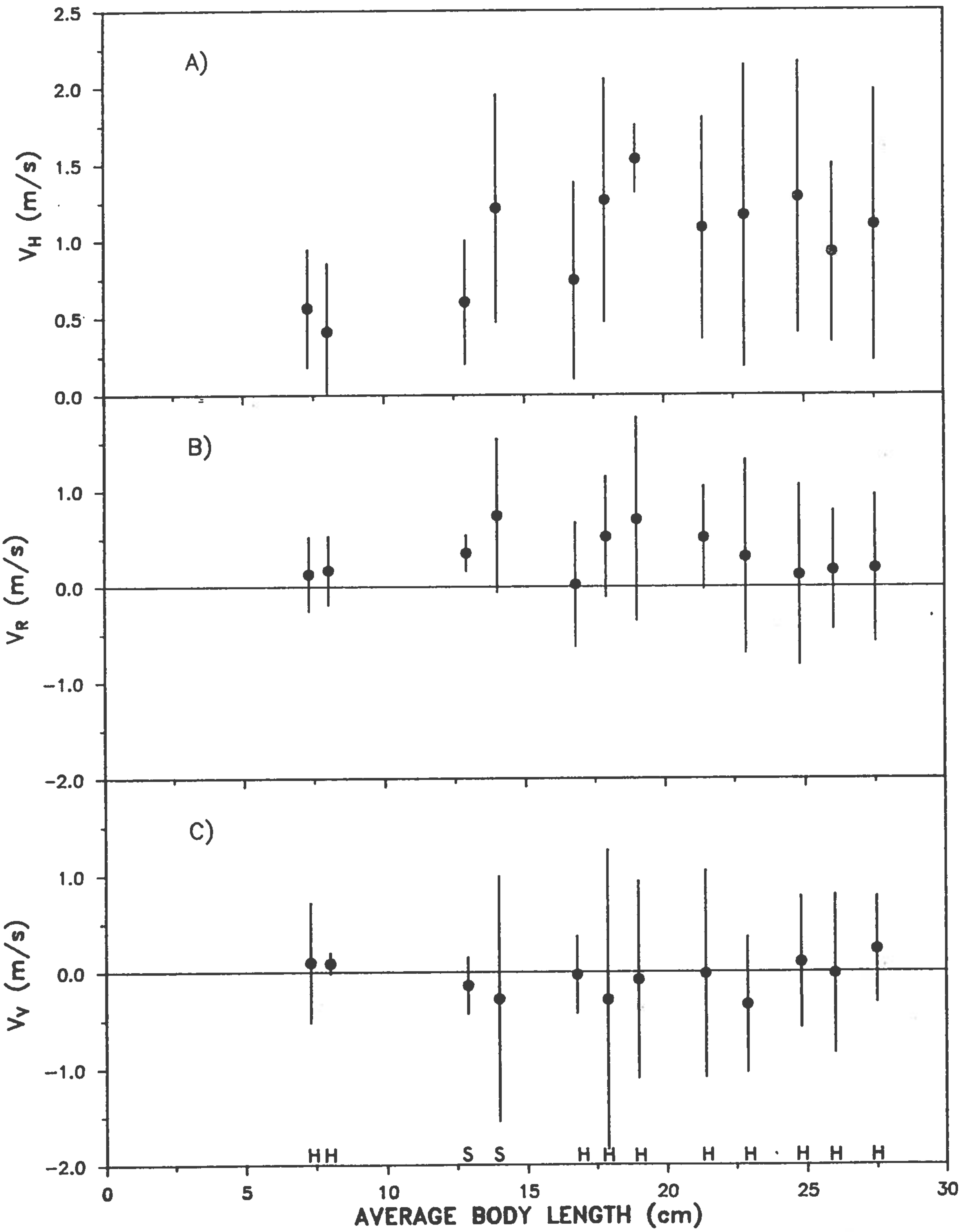
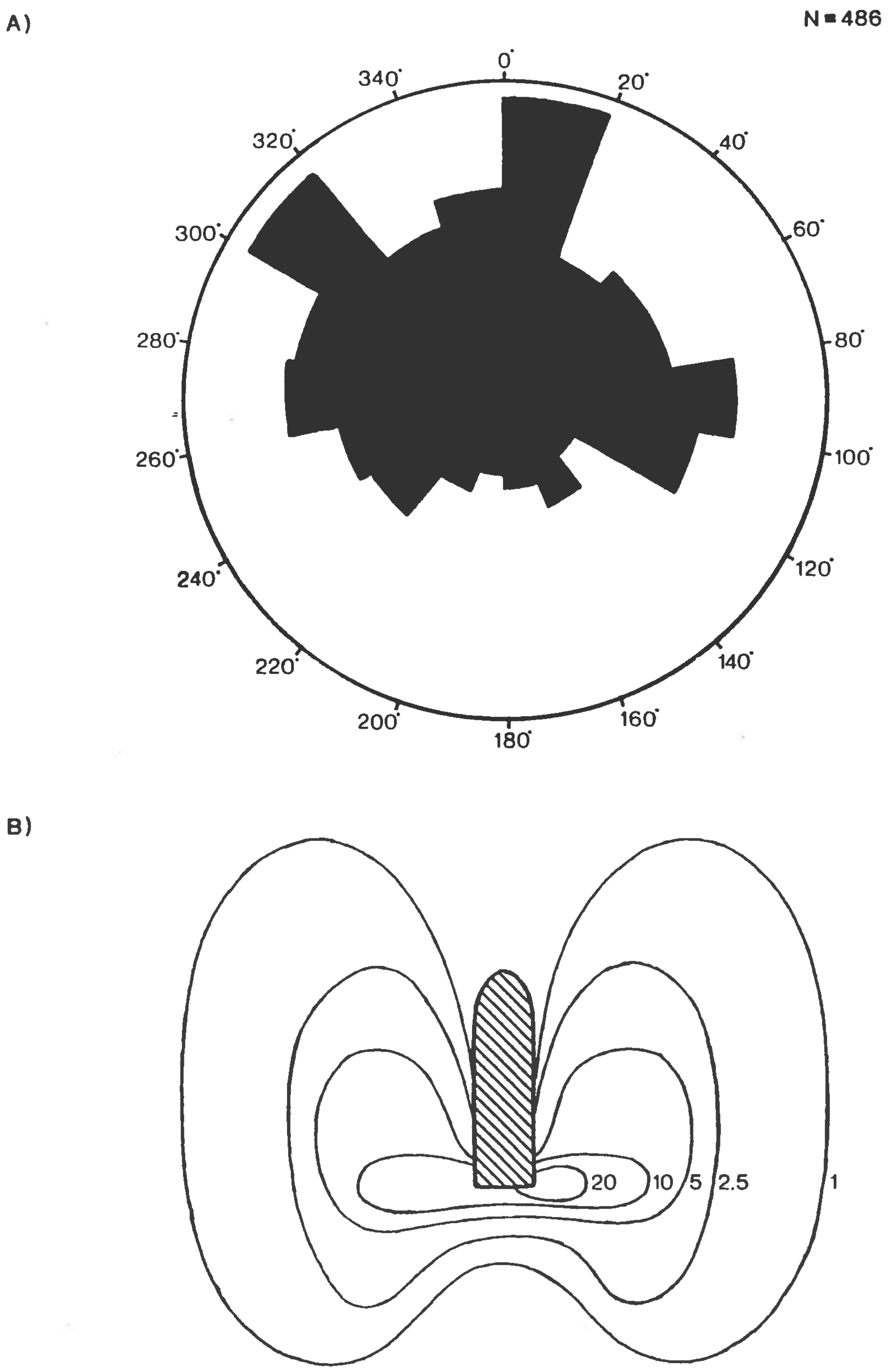


Fig. 1. A) Horizontal, B) radial horizontal, C) vertical swimming speed related to length of schooling herring (H) and sprat (S) (●: average, vertical bars: +- standard deviation).



<u>Fig. 2</u>. A) Total disribution of radial swimming direction, B) sound emission pattern from a vessel as redrawn from Urick (1967) where the countour values are pressures (dynes/cm^2) in a 1-Hz band in the octave band 2500-5000 Hz.

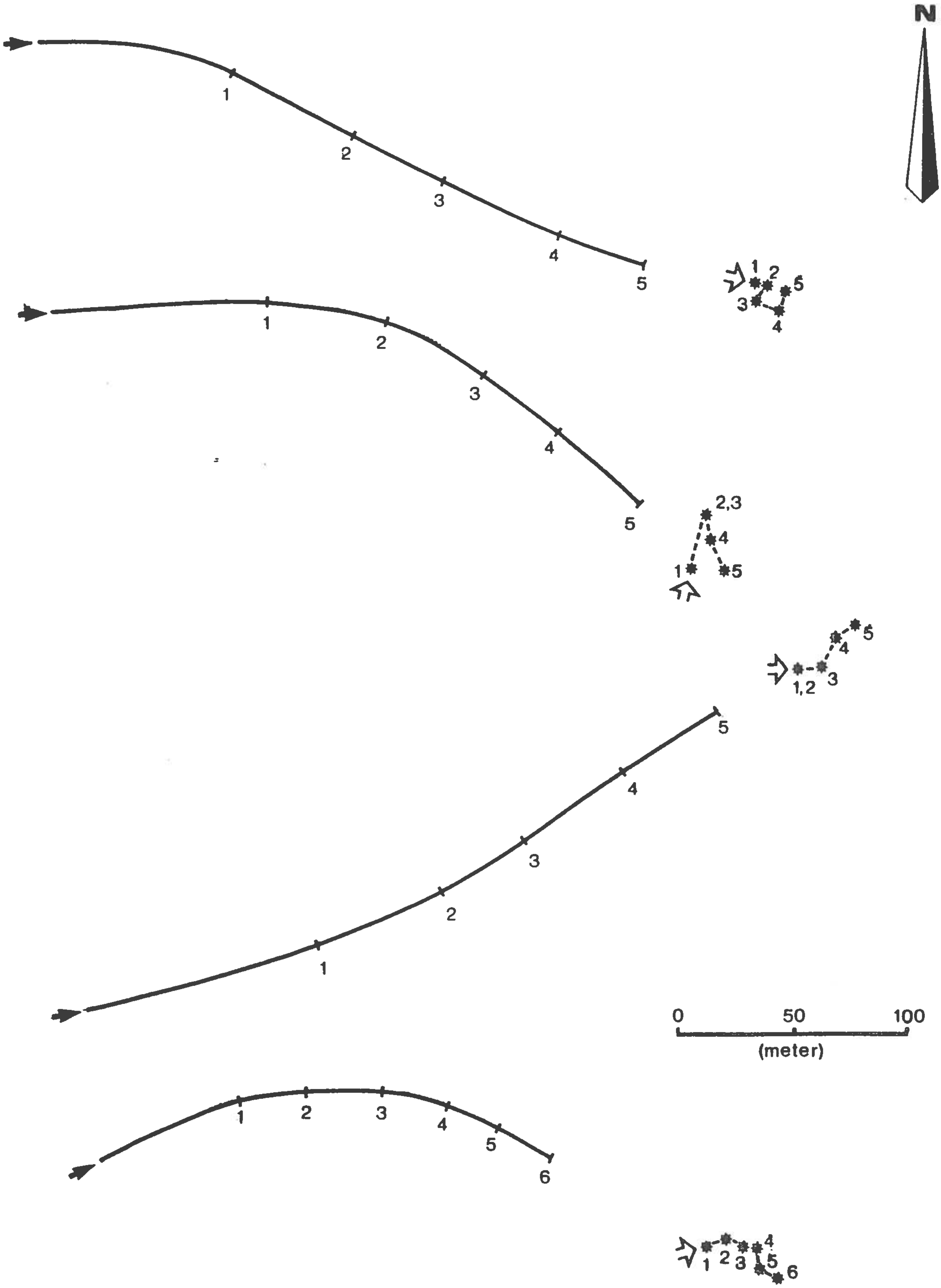


Fig. 3. Horizontal movement of herring schools when the vessel approaches (➔: vessel, ⇨: school).

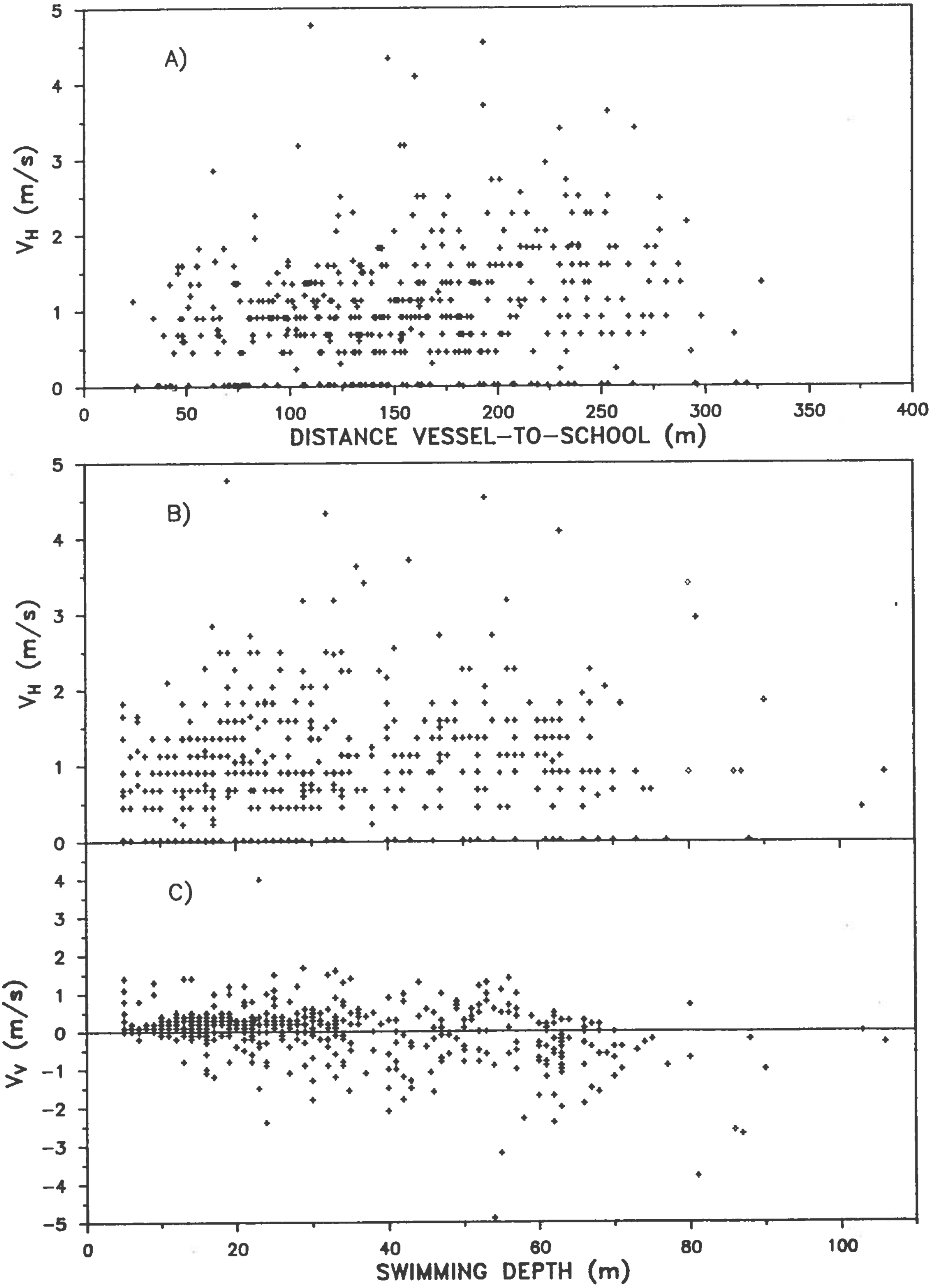


Fig. 4. Horizontal swimming speed related to horizontal distance vessel-to-school (A) and swimming depth (B). Vertical swimming speed related to swimming depth (C).

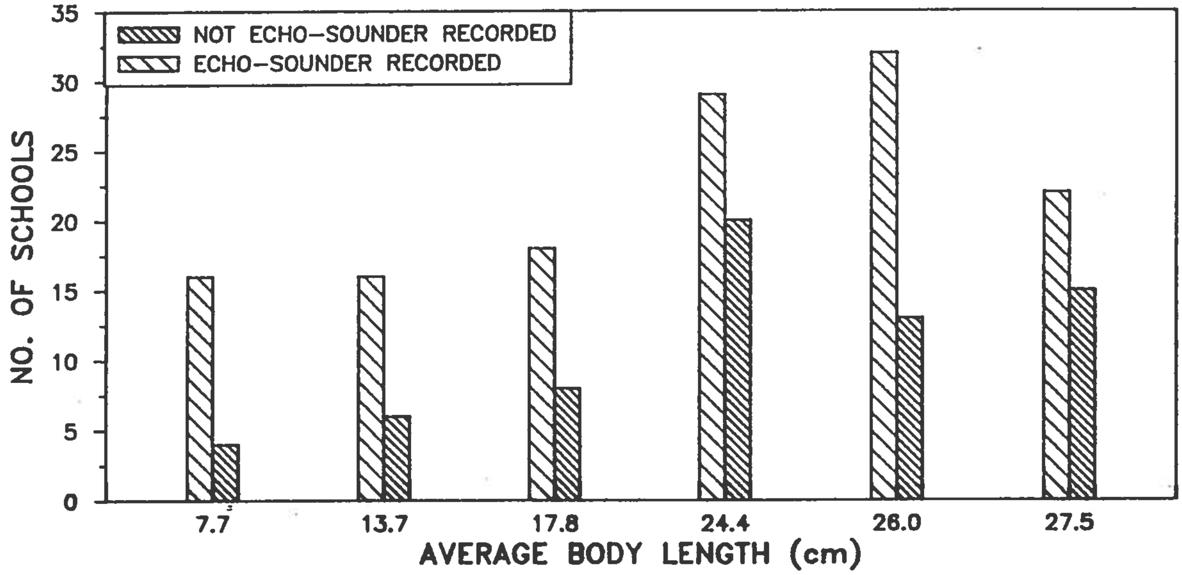


Fig. 5. Proportion of approached schools recorded or not recorded by the echo-sounder related to length of the schooling herring and sprat.

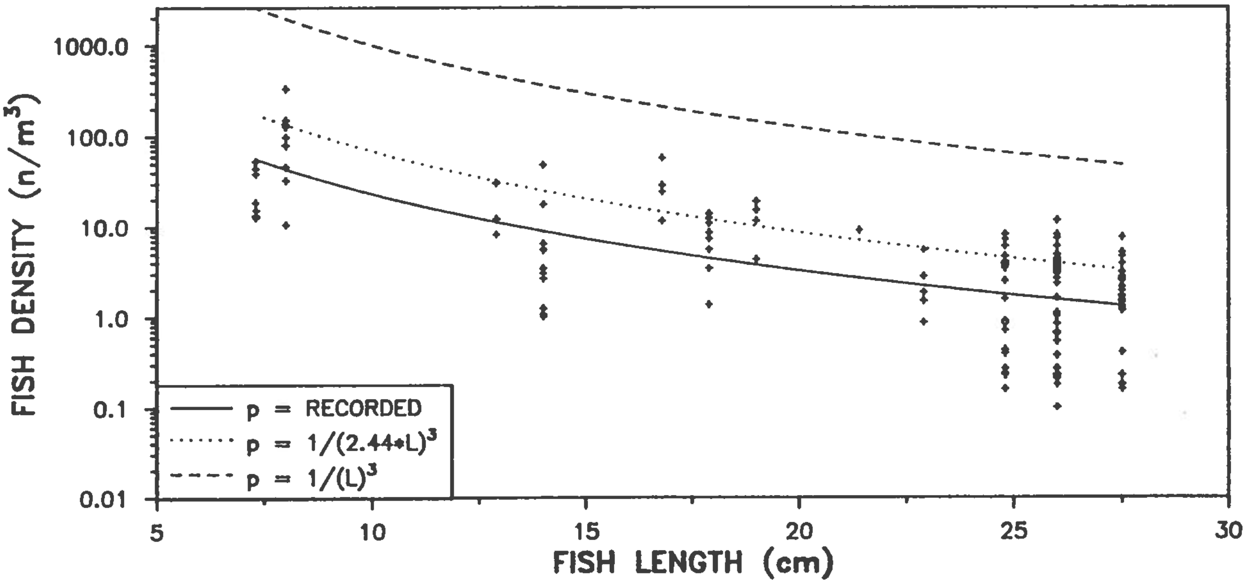
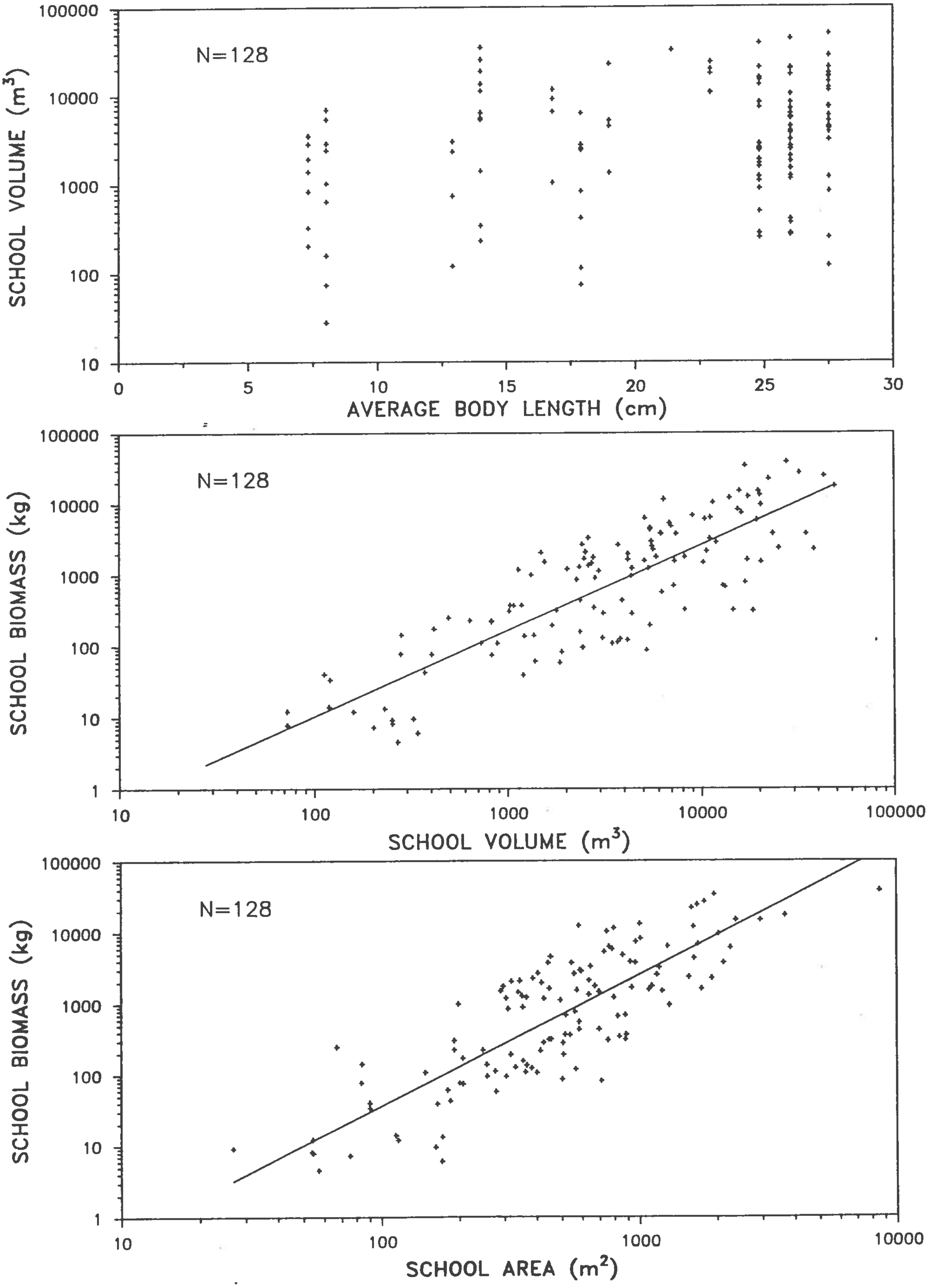


Fig. 6. Measured fish density in the herring and sprat schools related to fish size.



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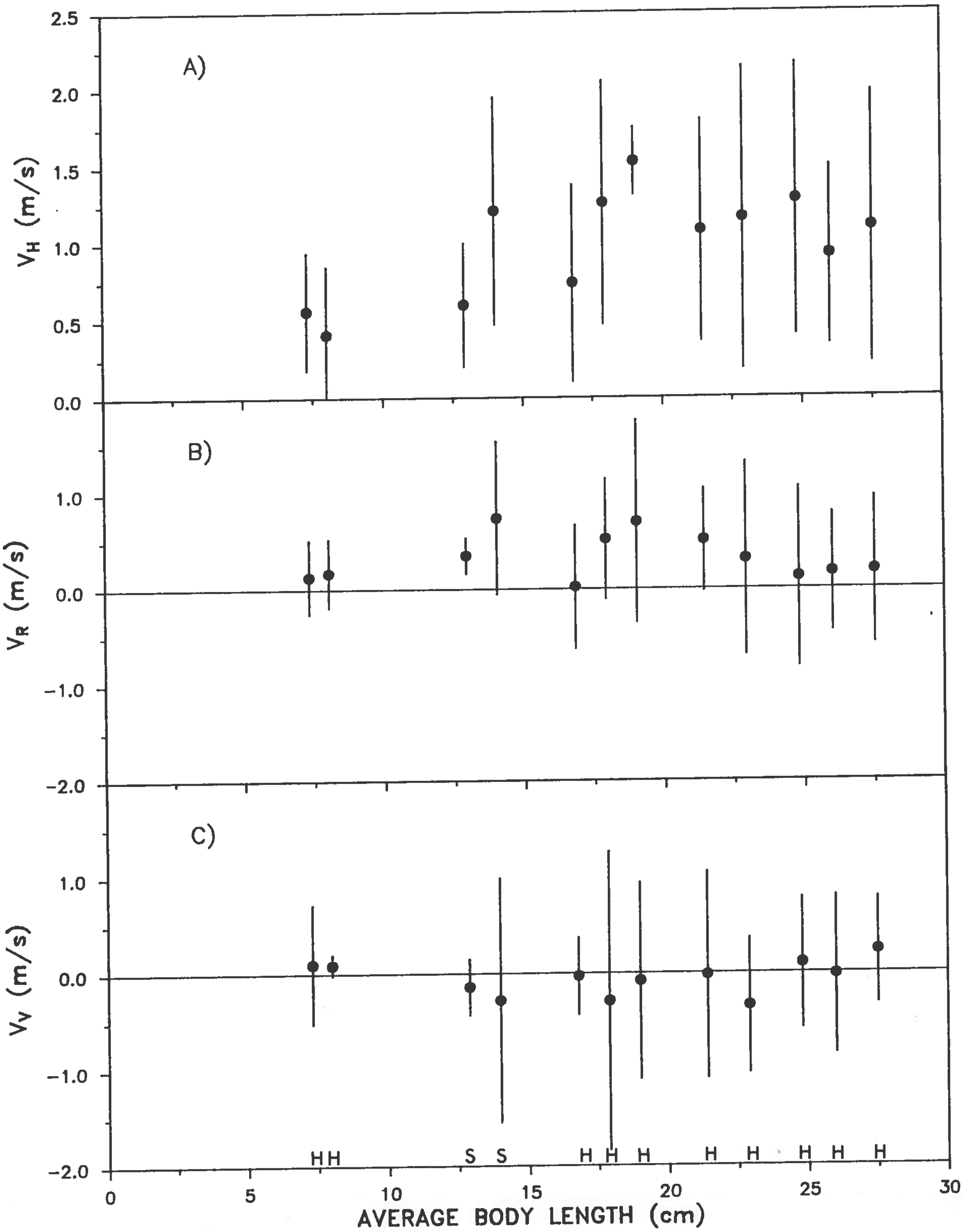

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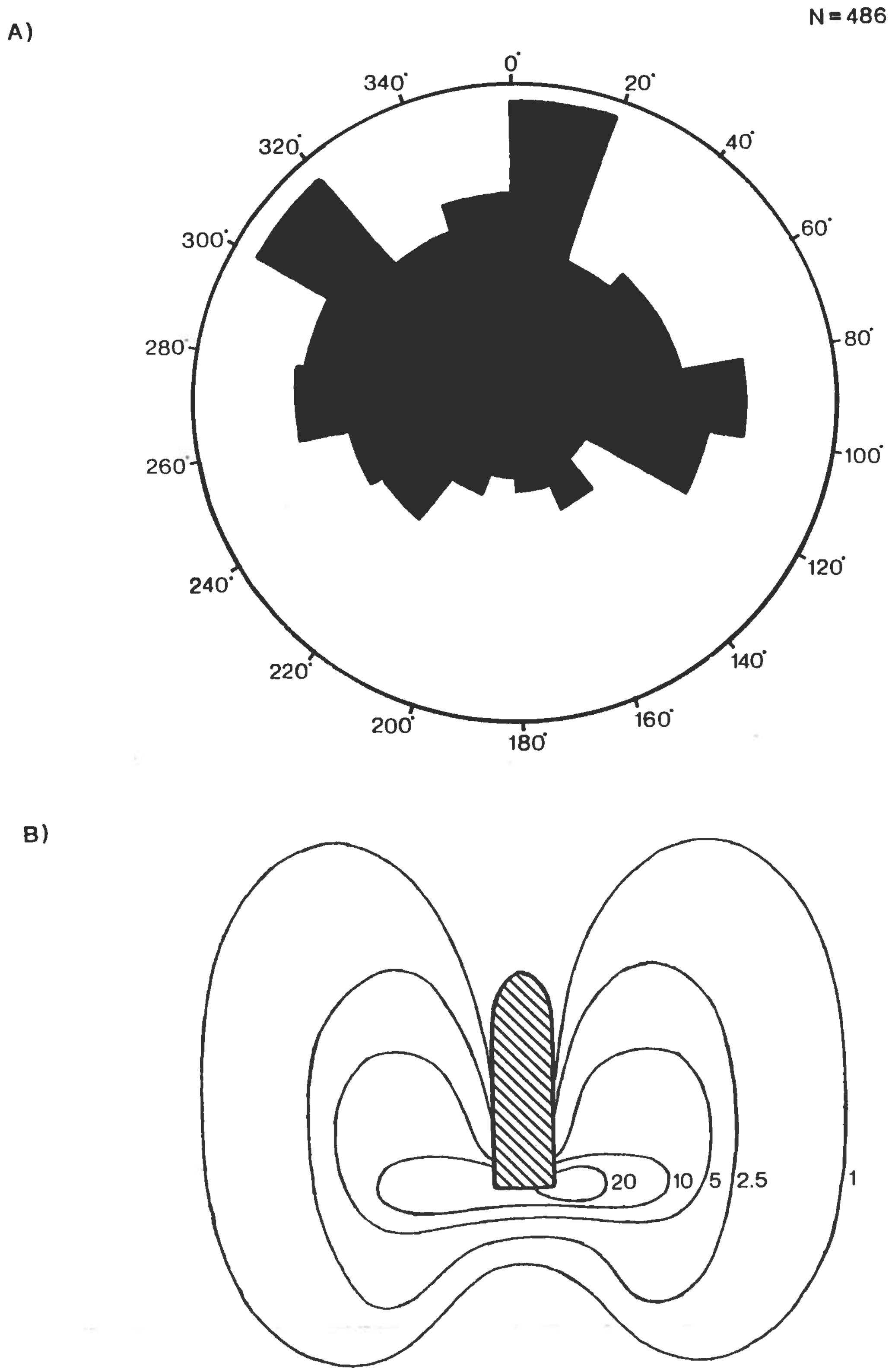

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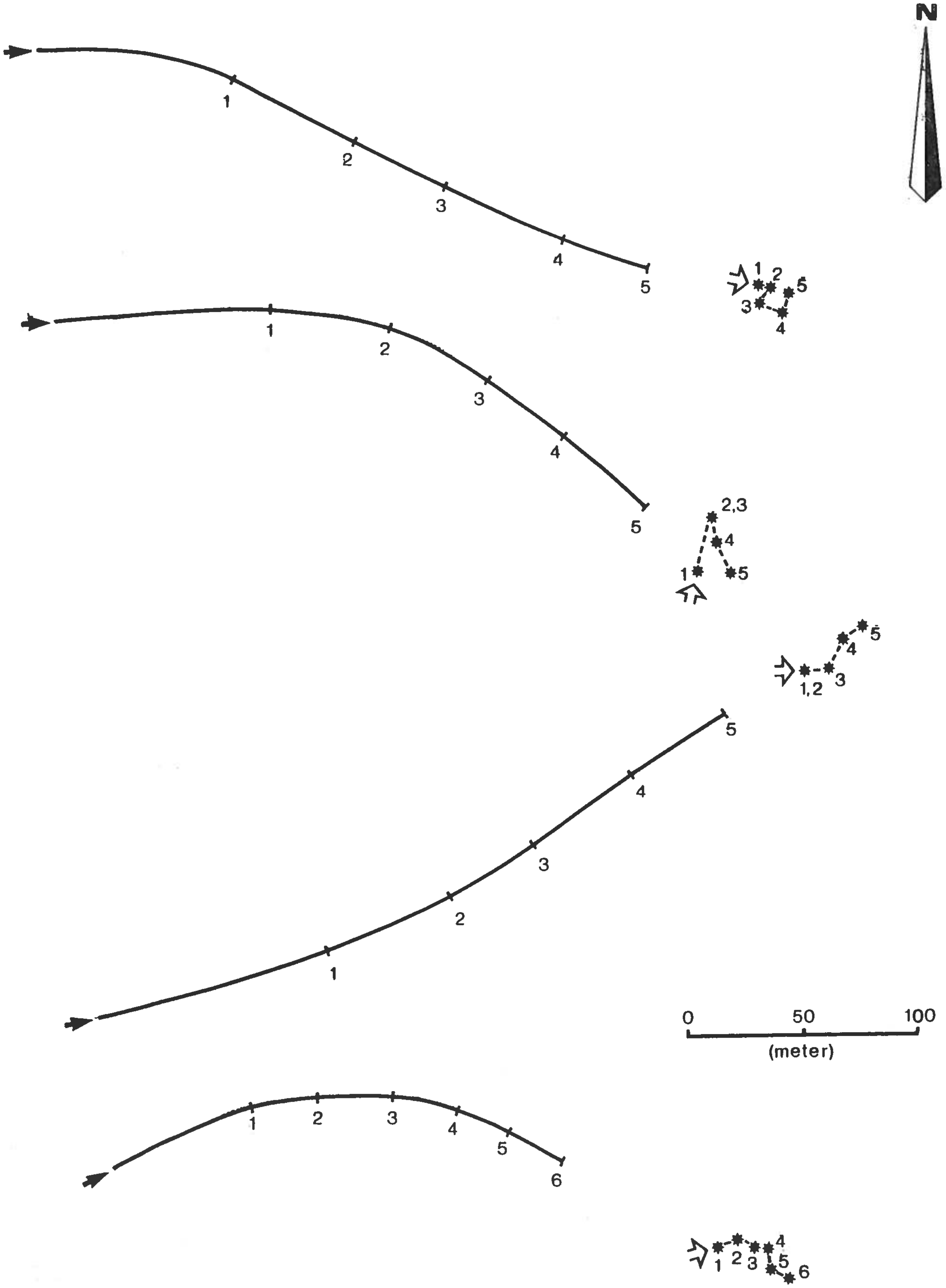

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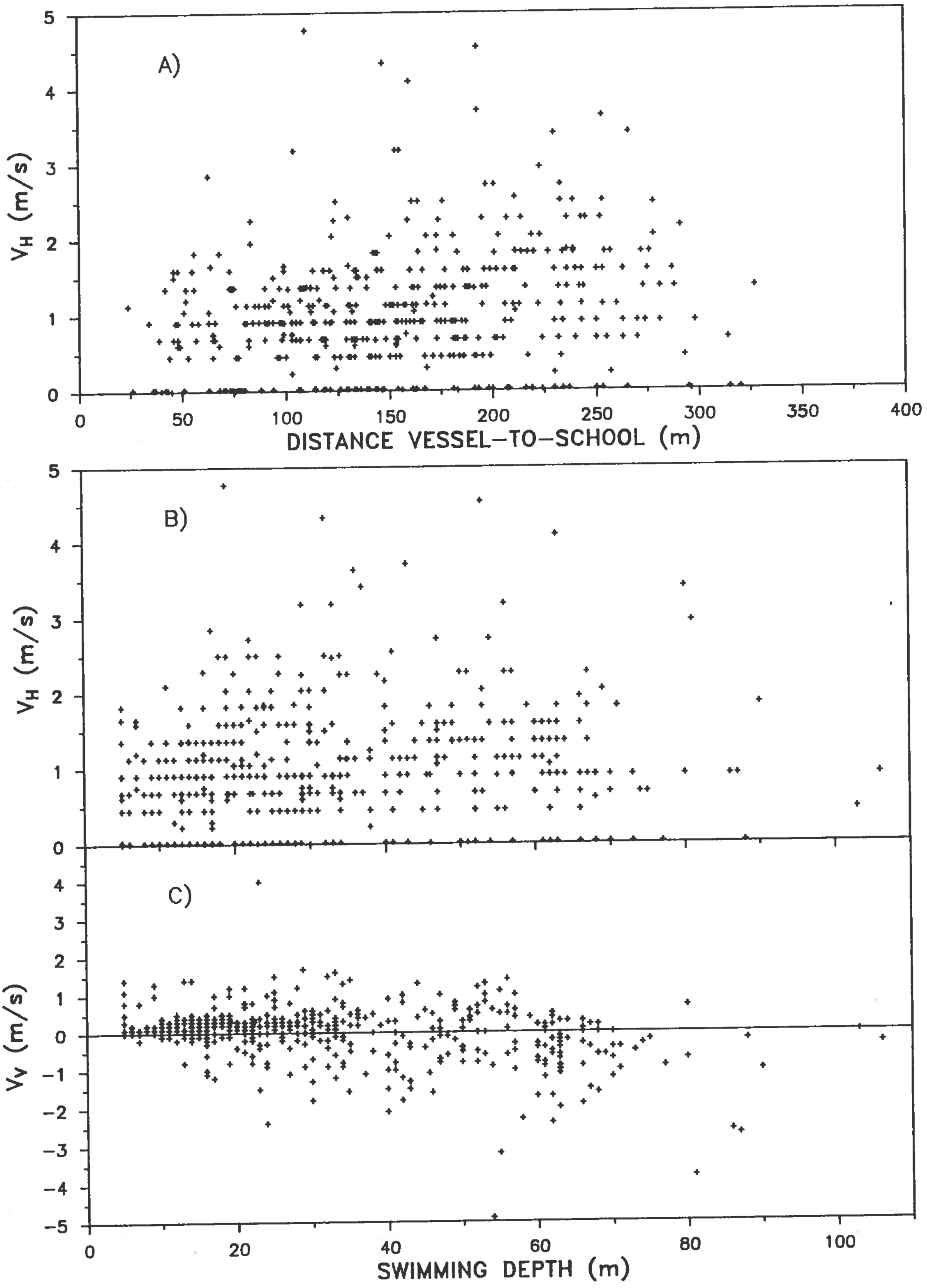

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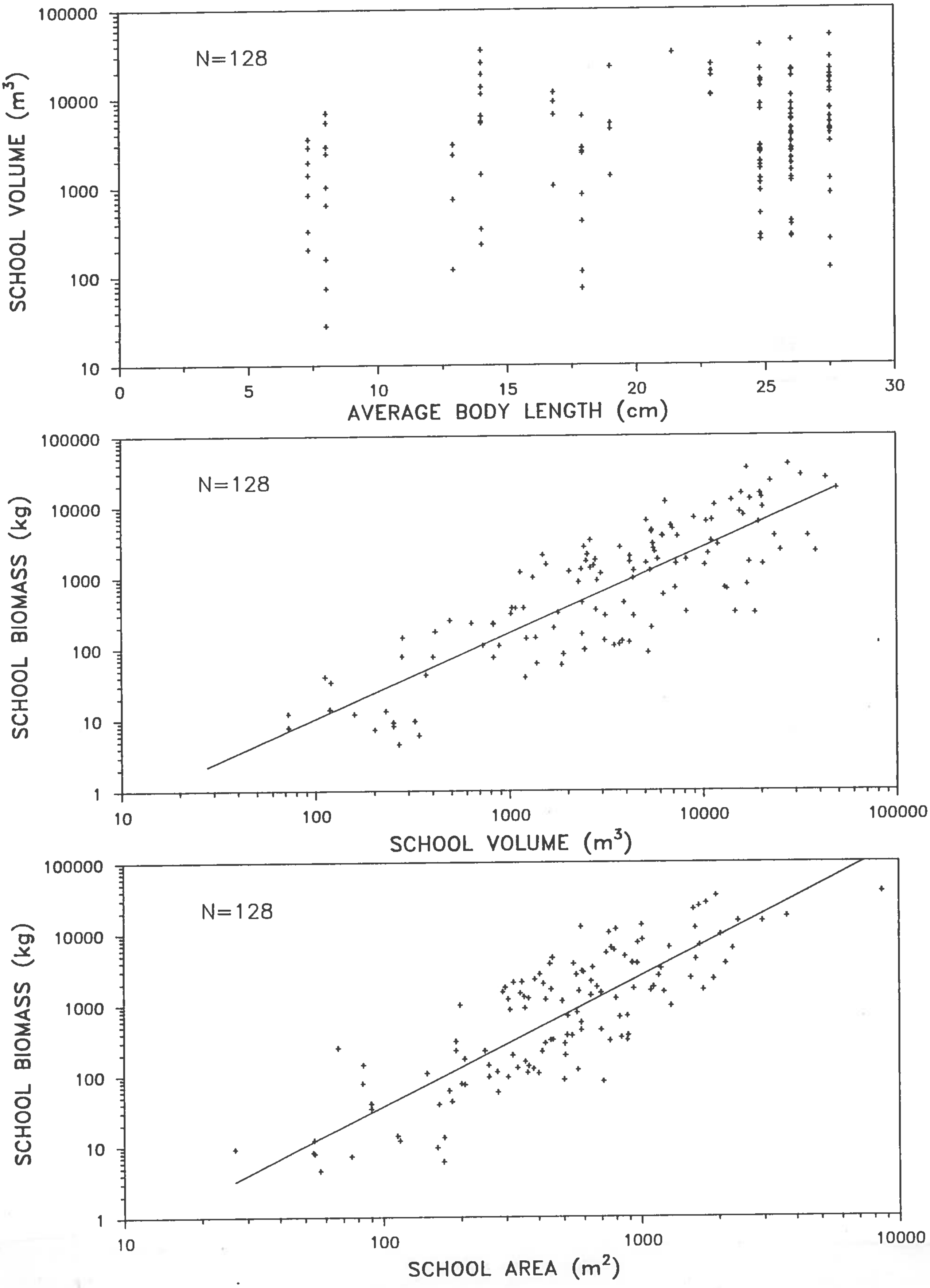

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