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Characteristics of sardinella aggregations in Angolan waters

by

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Abstract

The school dynamics and swimming behaviour of schooling sardinella in Angolan waters have been recorded by use of a 95 kHz, high resolution sonar onboard R/V "Dr. Fridtjof Nansen" during three cruises in 1996 - 1998. The schools were recorded during surveys close to the Angolan coast from Lobito to Luanda. Individual schools were tracked for 6 – 72 min, and horizontal speed, migration speed and direction calculated by reference to the GPS position of the vessel. During the trackings, trained observers took notes of behaviour, events and shape of the schools. Observers at the bridge recorded the number of sardinella schools visible at the surface, and took notes of events associated to the surface schools.

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Introduction

Clupeoid fish normally aggregate in dense schools during the daylight hours and reassemble in looser shoals during the dark hours at night (Blaxter and Hunter, 1982). This behavioural feature has fundamental impact on human activity towards the clupeoids. For fishing, it is an enormous advantage because huge biomasses of fish can be present in the aggregations. This ease detection of the aggregations, visually or acoustically. During daytime high concentrations near surface can be located as dark spots when viewed from above, at night the concentrations may be even more easy to spot in water masses with bioluminescent plankton. For acoustic detection by underwater sonar, the aggregation behaviour is similarly advantageous because the back scattered echo intensity is proportional to the average target strength of an individual fish plus ten times the logarithm of the number of individuals (Mitson, 1983). A clupeoid school of ten thousand individuals will thus back scatter forty times as much sound as a single individual of the same size. The clupeoid aggregation behaviour enable capture of large quantities of fish with limited effort when surrounding concentrations by purse seines or when filtering their exact location in the water column by aimed pelagic trawling. The consequences of unlimited fishing with such effective methods in the middle of this passing century were collapsed of the larger clupeoid stocks world-wide with a loss of fish production in the order of ten million tonnes annually (Murphy, 1980).

Now, many of the clupeoid stocks have regrown, and an increasing number of the stocks is managed on the basis of population biomass estimates obtained by fishery independent scientific surveys (Stephenson, 1991). The biomass estimates are either derived indirectly from egg counts (Hampton, 1996), or directly by use of the hydroacoustic method (Røttingen, 1990). The applicability of the latter method towards clupeoids, especially herring, has been studied rather intensively, and substantial knowledge about the reflecting properties of this species is gathered (Foote, 1987). Effects of clupeoid behaviour such as vessel avoidance (Misund et al., 1993; Vabø et al., 1998) and vertical distribution (Huse and Korneliussen, 1998) on accuracy of hydroacoustic estimates have been quantified. Attention has also been directed to the effects of aggregation density causing absorption of emitted sound (Toresen 1991, Foote et al., 1992), and variability in hydroacoustic estimates due to spatial distribution of clupeoid aggregations (Petitgas, 1993; Foote et al., 1996).

Structural and functional aspects of clupeoid schools have been investigated both in controlled conditions in aquaria and in the field. Cullen et al. (1966) found that schooling pilchard maintained a minimum approach distance of about 0.2 bodylengths, and an average nearest neighbour distance of about 1 bodylength. Statistically, the structure of the school resemble that of a diamond lattice. Pitcher and Partridge (1979) found that herring preferred to school with neighbours at 45° and 135° to the side and - 30° below and 30° above. The volume of the school was proportional to the number of individuals and the cube of the body length. This implies that the packing density of clupeoid schools decrease with increasing fish lengths as has been confirmed by field measurements by optics (Serebrov, 1974) and hydroacoustics (Misund, 1993). The packing density in freeswimming schools, typically about 2 individuals m^{-3} for 30 cm herring, is about an order of magnitude lower than in «aquaria» schools, however. In nature, clupeoid schools are organised by similar sized individuals (Freon, 1991), and Pitcher et al. (1985) also observed that individuals preferred neighbours of similar size. This may indicate that there is an hydrodynamic advantage in fish schooling. However, predator avoidance is probably the main function of fish schooling (Pitcher and Parrish, 1993), and clupeoids commonly live in close proximity with their predators. Feeding migrating herring schools followed by predating cod experienced intra and interschool events every 15 minutes, and predator attacks occurred on average each 27 minutes (Pitcher et al., 1996). Schooling is also claimed to enhance feeding (Pitcher and Parrish, 1993), but hungry herring tend to form schools with lower density and with tendencies towards splitting (Robinson and Pitcher, 1989).

The clupeoids *Sardinella aurita* and *Sardinella maderensis* form pelagic aggregations together in the coastal waters off Angola. Since 1986, these sardinella stocks have been surveyed regularly by the standard hydroacoustic method. At present the biomass of the stocks is in the order of 0.5 million tonnes with potential for a substantial fishery. To study behavioural aspects of sardinella of relevance to future fisheries and of significance to acoustic survey estimates, we have quantified characteristics of sardinella aggregations by acoustic measurements and visual observations by R/V «Dr. Fridtjof Nansen». Surface appearance of schools were recorded by observers at the bridge, the packing density and geometry of the schools quantified by calibrated echo integration and sonar, and the swimming behaviour of the schools recorded by sonar tracking. The recordings were made during three surveys off Angola, the first in July 1996, the second and the third in May 1997 and 1998, respectively.

Materials and Methods

R/V «Dr. Fridtjof Nansen» is equipped with a 95 kHz Simrad SA950 sonar, and a calibrated echo integration unit with a 38 kHz Simrad EK500 echo sounder connected to a BEI post processing system (Foote et al., 1992). During the 1997 survey, the sonar was rebuilt to a SF950 type sonar without changing the acoustic characteristics. The sonar was normally operated with full transmission power, gain step 6 - 7, display gain 8 - 9, and with the AGC, Normalisation and Ping-to-Ping filters set to step weak. The tilt was kept from - 3° to - 8° depending on the bottom depth and surface reverberation. To detect and measure schools recorded by the sonar during the 1996 survey, a school detection programme on a HP work station (Misund et al., 1994) connected to the sonar was run continuously, and with the following settings; min range 25 m, max. range 300 m, threshold 15, min interval 8, min width 10, min gap 5, detection window 30, detection counts 4.

School measurements

To make a representative quantification of the structure of fish schools occurring near surface off Angola, the following strategies were applied during the 1996 exercise. A regular survey using sonar, and conventional echo integration was performed with east-west transects covering the coast out to 200 m depth from Luanda to Lobito. When an area with frequent recordings of schools both at the sonar and the echo sounder were encountered, the regular survey was stopped for conducting special acoustic measurements of the schools in the area. The speed of the vessel was reduced to 5 - 8 knots, and when the sonar detected distinct schools in front of the vessel, the vessel was turned as precisely as possible to pass directly over the school. The school detection programme connected to the sonar was operating continuously, and both the sonar and the school detection program was operating with the same settings as during the regular survey. When a selected school was recorded by the school detection program, the school number given by the detection programme was noted on the sonar echogram so that the actual school could be identified during postprocessing of the sonar data. If the vessel was successfully manoeuvred over the school so that it was recorded on the echo sounder, the same school number was also noted on the echo sounder echogram. The sonar recordings where then analysed by a program written in the SAS software to find the maximum area (A) of the selected schools when being recorded from 75 m to 300 m in front of the vessel. The s_A-value of the selected schools was found by delimiting the schools by the school box option when postprocessing the echo sounder recordings by the BEI-system. The vertical extent (H), average depth (D) and recorded transect length (TL') of the selected schools recorded by the echo sounder were then measured by a ruler on the echogram and scaled to real dimensions. The transect length (TL) was then corrected for the beam pattern by the equation:

$$TL = TL' - 2 \circ D \circ (\tan(\beta/2)) \qquad (m)$$

where ß is the beam width (-3 dB points) of the echo sounder.

The fish density (ρ) of the schools was found by the equation:

$$\rho = s_A/(4\pi \circ \sigma \circ 1852 \circ TL \circ H) \qquad (n\ m^{-3})$$

where $\sigma = 10^{(20 \log L - 72)/10}$, and L is the average length of the fish in the schools. The volume (V) of the schools was estimated by assuming and ellipsoid shape and using the equation:

$$V = 4/3 \circ \pi \circ A \circ H/2 \qquad (m^3)$$

Finally, the biomass of the schools was found by multiplying the volume, fish density, and average weight of the fish in the schools.

School tracking by sonar

To study the swimming behaviour of pelagic, schooling fish off Angola, the Simrad sonar was used during all three surveys to track selected sardinella schools to record the dynamics, swimming behaviour and direction of movement. The vessel approached a selected school as gently as possible until the school was at a distance of about 200 m, and then stopped carefully. The vessel was then manoeuvred carefully to keep the school within a distance of 100 to 250 m. If the school came closer then the vessel was stopped. During the tracking the sonar was trained and tilted to obtain an optimal recording of the school. When a tracking situation was established with the school in a rather stable distance from the vessel, the position of the vessel and the range, bearing and depth of the school were recorded at 2 minute intervals for as long as possible. The tracking was stopped when the school disappeared. Any observations which lasted for less than 2 minutes (2 records) was disregarded, the longest period of observation was 72 minutes. Approaches and coalescing with other schools, or splitting of the target school, were recorded and a drawing of the outline of the school was made each time the school changed shape significantly. The sonar recordings of tracked schools were analysed by programs written in the SAS software to visualise the swimming behaviour of the schools, and quantify the swimming speed and swimming direction of the schools.

Surface school observations

Sardinella is known to appear at surface during daytime. In an attempt to determine the frequency and periodicity of this behaviour, the appearance of sardinella schools at the surface was recorded visually from the bridge between sunrise and sunset (06:00-18:00 local time). This was done for 4 days during the 1996 and 1998 surveys, and for 13 days during the 1997 survey. Numbers of shoals sighted were pooled into 15 minute intervals. Presence of sea birds and their attacks or attempted attacks on aggregated sardinella were also noted. Solar radiation intensity was recorded automatically at 10 minute intervals by the ship-borne Anderaa meteorological station. These data were used to investigate the relationship between surface occurrence of shoals and light intensity.

Trawl sampling strategy

Schools in the areas of the measuring, tracking and visual observation exercises were sampled by pelagic trawl to identify the species and measure the size of the fish observed. In many cases, especially during trawling on discrete shoals, the sonar was used to guide the vessel onto shoals. In total 29, 28 and 12 trawls were done during the 1996, 1997 and 1998 cruises , respectively. A random sample of fish representative of the total catch was taken from the trawl, the size of the sample depending largely on the species mixture of the catch. In cases where the catch was small, the total catch was sampled. To determine the catch composition of the trawl the number and weight for each species in the random sample was recorded. This sample was then raised to the total catch. A random sample of about 100 sardinella, if available, were measured to the nearest 0.5 cm below total length to obtain the size composition of the catch. Maturity stage and stomach contents of about 20 sardinella were recorded for each trawl.

Environmental characteristics

Vertical profiles of temperature, salinity and oxygen taken regularly with a Seabird 911 CTD Plus Sonde generally showed a layer of warm surface water (21° - 24°C) in the upper 20 m of the water column and then decreasing gradually with depth during the three surveys. The corresponding oxygen profiles showed a layer of high oxygen (> 4 ml/l) in the upper 20 to 30 m and then a sudden decline down to about 70 m. The salinity were relatively high (in excess of 35.5 psu) throughout the water column. Current measurements made by an Acoustic Doppler Current Profiler (ADCP) showed a very weak flow not exceeding 0.1 $m.s^{-1}$ close to shore with the flow generally being of a southerly direction south of Cabo Ledo and north to north westerly north of Cabo Ledo. Further offshore the current speed accelerated to a maximum of 0.6 $m.s^{-1}$ with most flow being in a southerly direction.

Results

Altogether 96 schools were measured by sonar and echo sounder during the 1996 survey in Angola. Most schools were measured off Punta da Palmeirinhas, but schools were also measured off Cabo Ledo and between Punta Do Morro and Cabeca Da Baleia. The schools measured were distributed at a depth from 11 to 35 m (average depth 17 m), and the area of the schools varied from 33 to 1777 m^2 (average area 504 m^2). The vertical extent of the schools averaged 6.5 m, and varied from only 1 m up to 25 m. Assuming that all schools measured were sardinella with a mean length of 29.5 cm and a mean weight of 0.295 kg (average length and weight of sardinella in 17 of the trawl samples in 1996), the fish density in the schools varied from minimum 0.1 fish m^{-3} to maximally 11.8 fish m^{-3} (Fig. 1) The average density of the schools was 2.8 fish m^{-3}, which is remarkably similar to the average fish density in herring schools on the northern hemisphere. The estimated biomass of the schools varied from about 10 kg to about 20 000 kg. The biomass definitely increased with an increase in the area of the schools (Fig. 2).This relationship is expressed through a significant regression ($r^2 = 0.60$, $p < 0.05$) between the area and biomass of the schools which follow the equation:

$$\text{School biomass} = 4.6 \bullet (\text{School area}) \qquad \text{(kg)}$$

The relationship between school area and school biomass is additive and can therefore be used to convert summed school area per nautical distance as measured by sonar to fish density per nautical distance.

School tracking

During the cruises, 17 - 27 schools were tracked for 2 - 72 min, mainly off Punta da Palmeirinhas (area A in Fig. 3), off Cabo Ledo (area B in Fig. 3) and near Lobito (area C in Fig. 3) . In many cases the tracking was initiated on schools that appeared at the surface, and that also could be recorded by the sonar. Some schools appeared in midwater so that the recorded schools were distributed from average depths in the range 1 - 33 m. An example of swimming direction and swimming speed of a tracked school is given in Fig. 4. The schools were swimming at horizontal speeds of 0.42 - 3.37 ms^{-1} (average 0.91 ms^{-1} in 1996 and 1.23 ms^{-1} in 1997), and moving in the direction of migration at speeds of 0.09 - 2.27 ms^{-1}. The distribution of migration direction and migration speed for the schools are given in Fig. 5. In all 3 areas, most schools were heading east towards the coast (26 cases), fewer west-wards (16 cases) or southwards (13 cases). 9 schools only were heading northwards.

The sardinella schools were rather dynamic. In many cases rather short duration of the tracking was caused by fragmentation or dispersion of the schools so that the school echo faded from the sonar display, and further tracking became impossible. Intraschool events occurred at average rates of 0.63 events min^{-1} in 1996 which indicate an happening within the school every 1.6 min. In 1997 and 1998 the average intraschools event rates were about 50 % lower (Fig. 6). A similar reduction in activity was found for the interschool event rates (Fig. 6) which averaged 0.097 events min^{-1} in 1996, 0.064 events min^{-1} in 1997 and 0.058 events min^{-1} in 1998. Thus interschool events took place every 10.3 min in 1996, but only every 17.2 min in 1998. Among the intraschool event categories, change of shape dominated (Fig. 7) with an average frequency of 0.35 events min^{-1} which mean that the shape of schools changed every 3rd minute. For the other intra- and interschool events, the average frequencies varied from 0.01 - 0.06 events min^{-1} only. A fragmented appearance was most common among the schools, but distinct shapes as circle, oval rod and crescent were also quite common. Ring structures and amorph appearance were rather rare.

The schools seemed little disturbed by nearby predators. Seabirds were remarkably absent when considering the large number of surface schools. A few gannets were observed in the Lobito area, but they were only once observed to attack the sardinella schools. Fish predators as barracuda were caught during aimed trawling on sardinella schools, especially in the Palmeirinhas area. Sharks were observed at surface both off Cabo Ledo and Lobito. However, it was not observed that schools were chased by fish predators during the trackings. Several seals were also observed in the Lobito region. Nevertheless, a distinct, noisy, and water splashing flash could occasionally be seen to be performed in sardinella schools at surface. This flash is probably an antipredator maneuver which can be effective to scare and confuse both bird and fish predators.

Surface school observations

The visual observations from the bridge revealed that sardinella shoals appeared at surface in a bimodal pattern (Fig. 8). Shoals were seen at the surface in large numbers from 06:00 in the morning (sunrise) to 11h00. In the middle of the day from 11:00 to 14:00 shoals seemed to be diving but returned to the surface from 14:00 to 18:00 although with a lower frequency than in the morning. There seem to be a dome shaped relation between the number of schools at surface and solar radiation (Fig. 8). Maximum number of schools at surface occurred at a radiation of about 300 Wm^{-2}, while number of schools at surface leveled off for lower radiation and higher radiation.

Discussion

The school measurements revealed an average packing density of about 3 fish m^{-3} in the sardinella schools which is comparable to that of schools of herring of similar length (Misund, 1993). The linear relationship between school area and school biomass was established by sonar measurement and echo integration of selected schools. The relationship has predictable capability and is additive so that summed school area over a nautical distance as recorded by sonar can be converted to fish density. The measurements were conducted in three different areas with a high number of schools close to surface encountered during the survey. The relationship is therefore based on a representative selection of schools close to surface off Angola, and can therefore be used to convert daytime sonar recordings of school area to school biomass in later abundance estimation surves in the area. Alternatively, the relationship can also be used to convert aerial measurements of horizontal school area to

school biomass. The sardinella seem to maintain rather dense shoals at night, but if indeed a different relationship between the area and biomass of the night-time and daytime shoals exists, it was not investigated.
The sardinella schools were very dynamic with intra- and interschool events occurring as often as each 1.6 minutes and each 10.3 minutes in average, respectively. An about 50 % reduction in event rates from 1996 to 1997 and 1998 can possibly indicate a seasonal influence since the 1996 trackings were made in June while the 1997 and 1998 recording were made in May. Schools changed shape each third minute in average, and a fragmented appearance was most common. Distinct geometric shapes as circle, oval, rod and crescent were also quite prevalent.

The schools seemed little affected by predators. There were remarkably few seabirds, a few gannets were seen to launch attack very seldom. Seals, sharks and barracudas were recorded near the schools, but attacks were never observed. A characteristic, noisy and water splashing flash performed synchronously by the schooling sardinella may possible be an effective manoeuvre to scare and confuse both bird and fish predators.

The distribution of migration direction of the tracked schools showed that eastwards and westwards movements dominated. This indicate that the sardinella in the area is moving towards and out from the coast. Possibly this migration behaviour is linked to the high frequency of large internal waves on the continental shelf off Angola. The internal waves mix plankton in the water column, and near the coast the fronts of internal waves were visible as bright stripes at surface parallel to the coast.

A large number of surface schools were sighted during the cruise. The schools seem most active at the surface during early morning and in the afternoon, and with a minimum of surface school activity during mid-day. Fish in surface schools seem to be feeding, and our results indicate that sardinella in the area have two feeding periods daily, in the morning and in the afternoon. The number of surface schools seem inversely related to the level of solar radiation. As the sea water in the area often is rather turbid with low visibility (Secchi depth recordings during the three cruises varying between 2 - 15 m), high solar radiation may enable prey detection subsurface. During days with high solar radiation, sardinella can thereby possibly reduce exposure at surface.

For commercial fishing by purse seining, the surface appearance of the sardinella schools will ease detection of the schools and fishing will be possible without sophisticated sonar equipment. For conventional acoustic surveys by echo integration through a hull-mounted transducer, the surface distribution may lead to substantial underestimation of biomass. A short, comparative echo integration and sonar survey during daytime in 1996 showed that the sonar recordings gave about 10 times higher biomass than the echo integration when using the established school area-to-school biomass relationship to convert the sonar recordings to biomass. This bi-modal hourly distribution of surface schools and the relation between surface schools and solar radiation must be taken into account if conducting aerial surveys of the sardinella stocks in the area.

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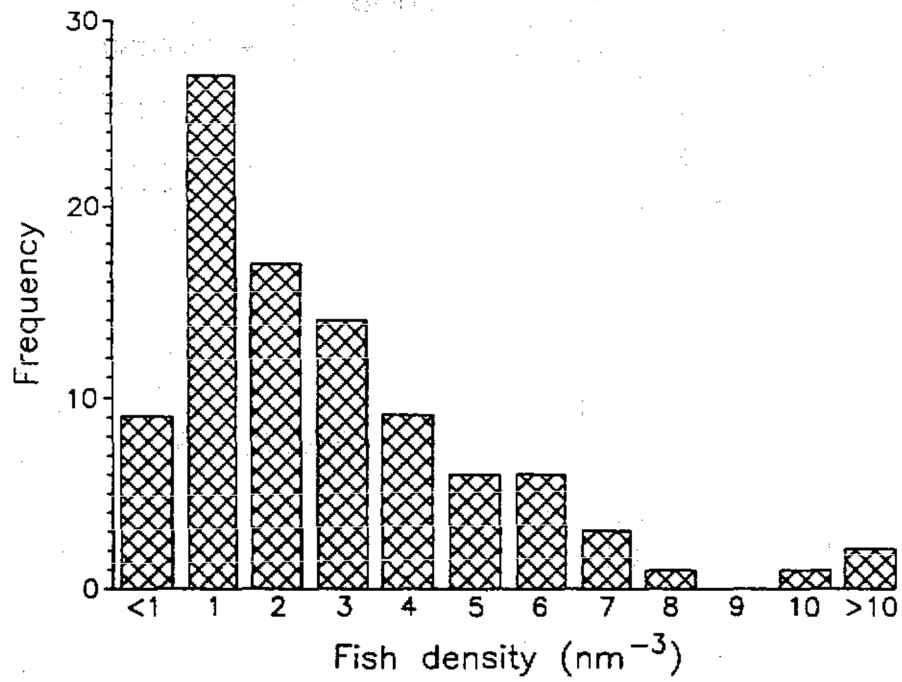

Figure 1. Distribution of fish density in sardinella schools off Angola, June 1996.

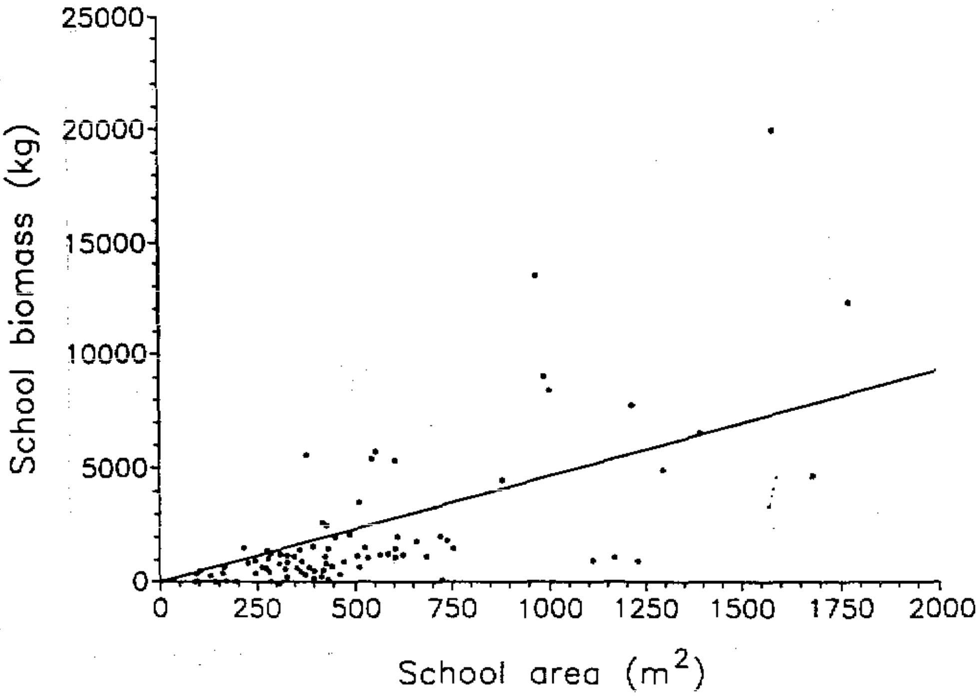

Figure 2. Relationship between school area and school biomass for sardinella schools off Angola, June 1997.

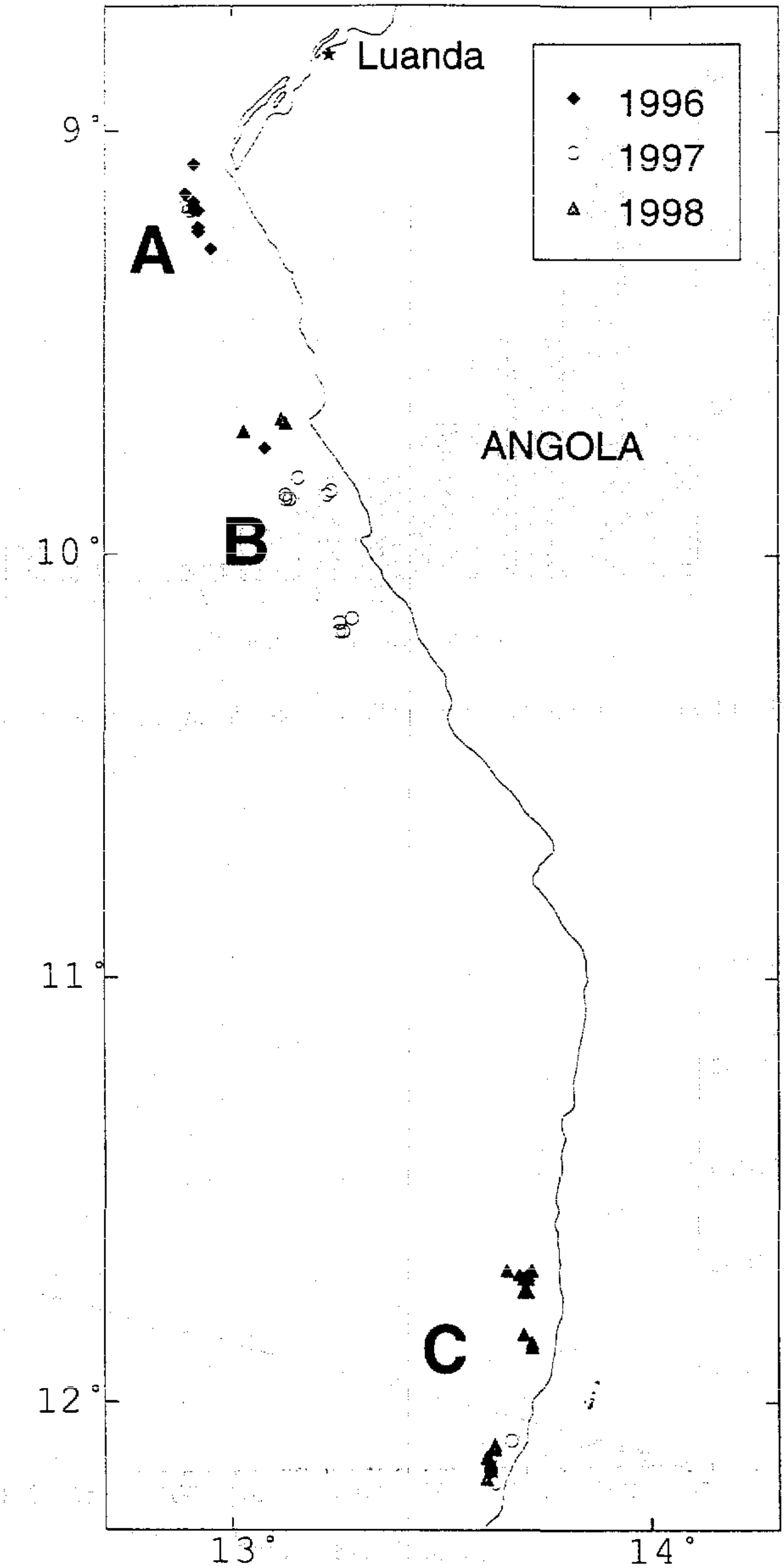

Figure 3. Geographic distribution of tracked sardinella schools off Angola, 1996 - 1998. A: off Punta da Palmeirinhas, B: off Cabo Ledo, C: north of Lobito.

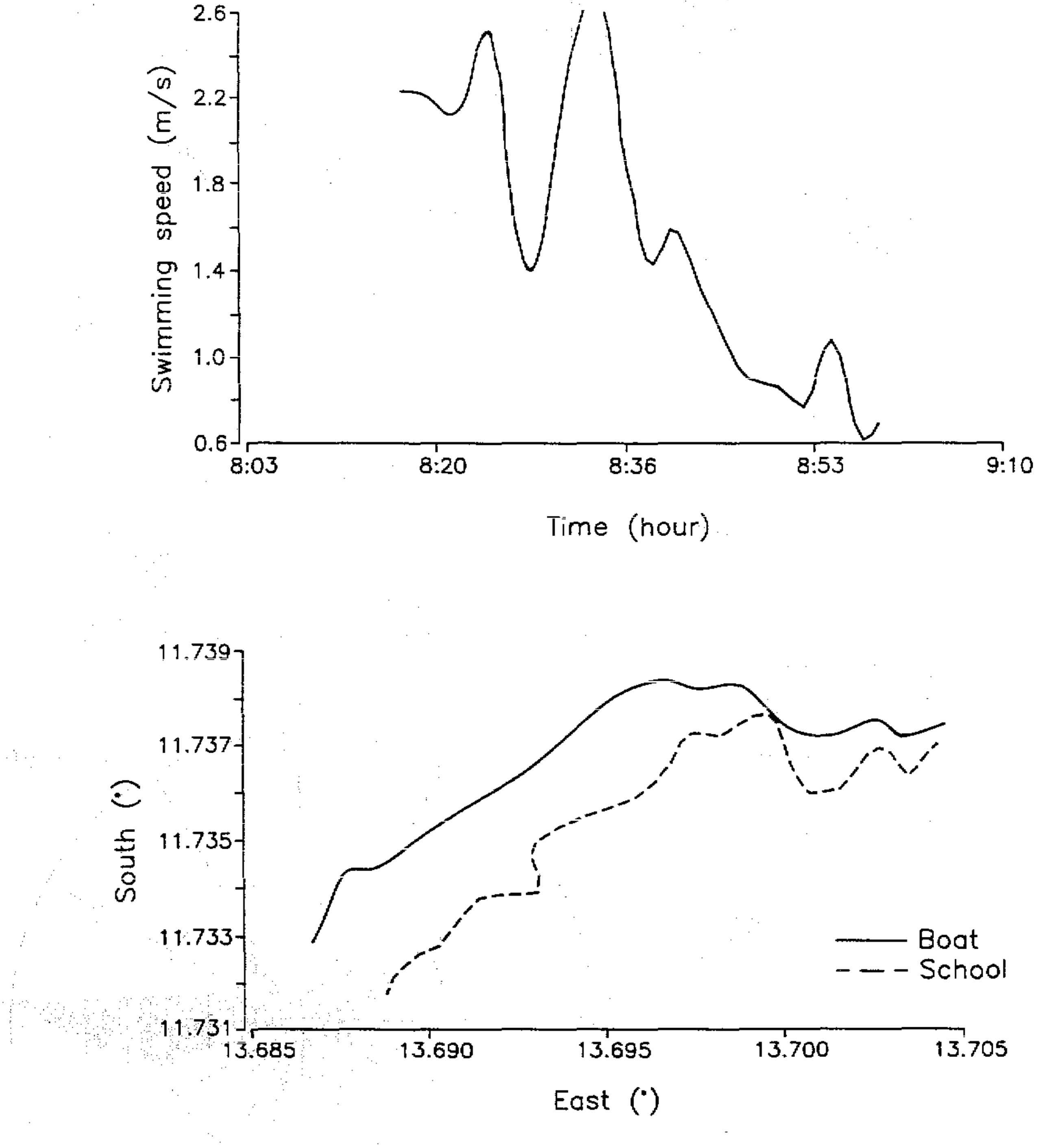

Figure 4. Tracking of single sardinella school off Angola.

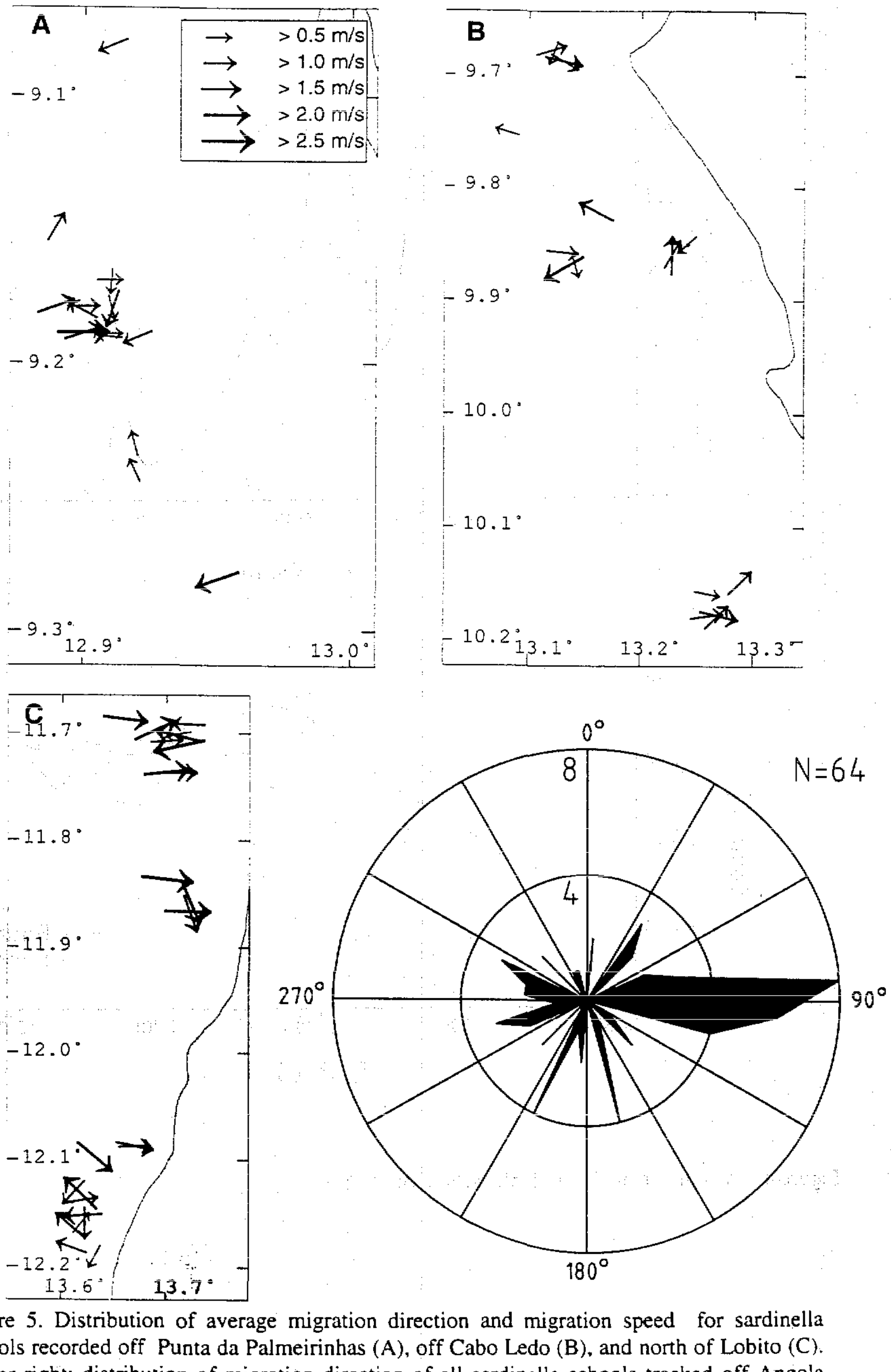

Figure 5. Distribution of average migration direction and migration speed for sardinella schools recorded off Punta da Palmeirinhas (A), off Cabo Ledo (B), and north of Lobito (C). Lower right: distribution of migration direction of all sardinella schools tracked off Angola 1996 - 1998.

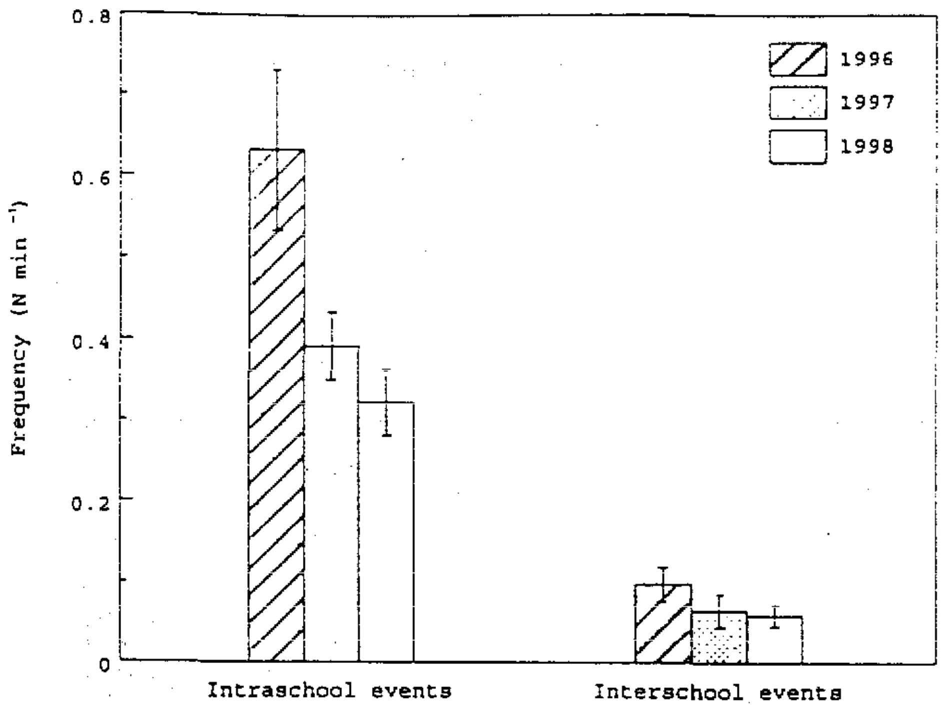

Figure 6. Intra- and interschool event rates for sardinella schools tracked off Angola, 1996 - 1998.

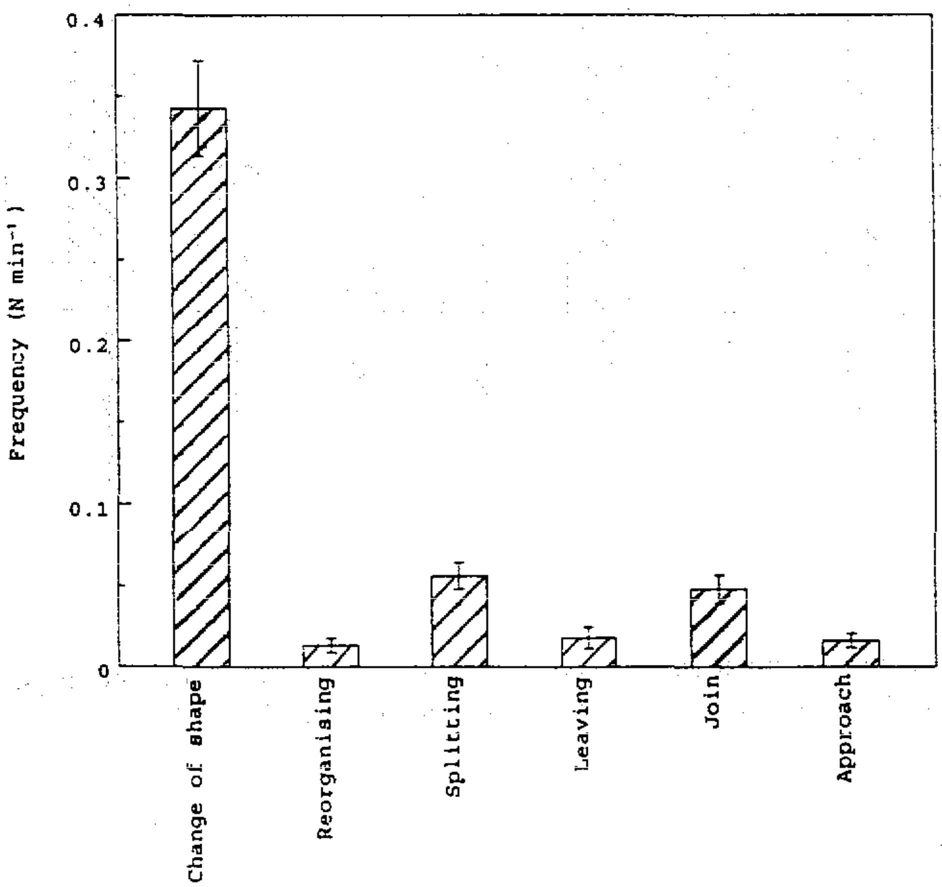

Figure 7. Event rates for the inter school categories change of shape, reorganising, splitting, and leaving, and the inter school categories join and approach for sardinella schools tracked off Angola, 1996 - 1998.

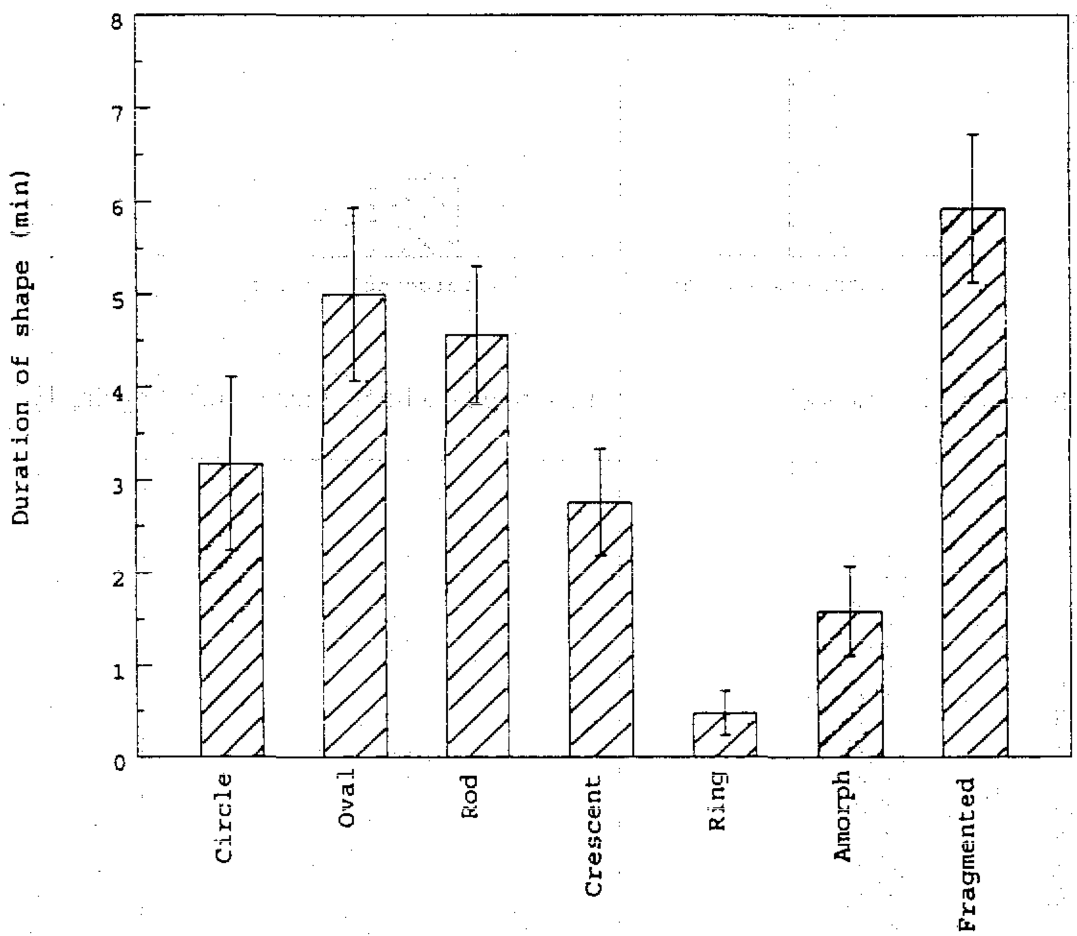

Figure 8. Distribution of duration of school shape categories (circle, oval, rod, crescent, ring, amorph, fragmented) for sardinella schools tracked off Angola, 1996 - 1998.

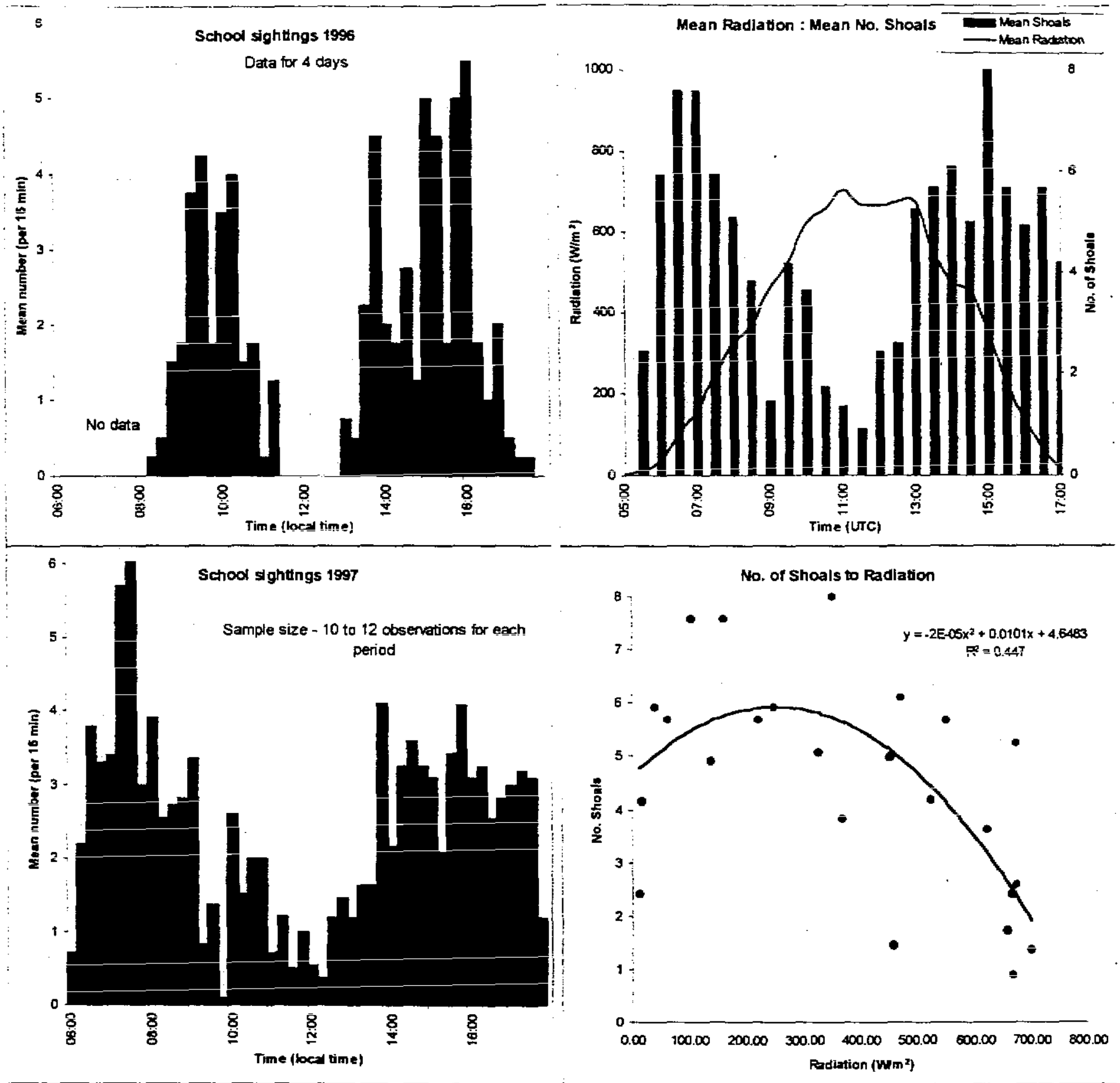

Figure 9. Hourly mean distribution of school sightings 1996 (upper left) and 1996 and 1997 (lower left), hourly mean distribution of school sightings 1997 related to hourly mean solar radiation 1997 (upper right), mean schools sightings related to mean solar radiation 1997 (lower right).