

The link between migration, the reproductive cycle and condition of *Sardinella aurita* off Mauritania, north-west Africa

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The annual migration pattern of round sardinella *Sardinella aurita* up and down the north-western African coast between 12° N (Senegal) and 22° N (western Sahara) was shown to be associated with spawning activity and a distinct seasonality in fish condition, based on monthly sampling from commercial catches (2000–2003). Some *S. aurita* were found to spawn throughout the entire year, but a peak in spawning existed during the summer (June to September). The spawning cycle is apparent from seasonality in maturity stages, but is also demonstrated by the increase in gonad mass and fat content of the fish in springtime, the period preceding spawning. During the months after spawning, although feeding is maintained, the physical condition of the fish collapses, and fat content rapidly declines.

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Key words: Mauritania; migration; sardinella; seasonality; small pelagic fish; spawning.

INTRODUCTION

Many commercial fish stocks are heavily exploited and therefore extensively studied, but the distribution of research is disproportionate with a greater intensity of studies in the developed world, compared to developing countries. The round sardinella *Sardinella aurita* Valenciennes, 1847, is a pelagic fish species that is substantially exploited by both industrial and artisanal fisheries in the economic exclusive zone (EEZ) of the developing nation Mauritania, north-west Africa, especially since large freezer trawlers from the European Union, mainly of Dutch origin, became active in the area in 1996. In the early 1990s, the yearly average landing was c. 48 000 t (1990–1994), but after 1996, the total annual landings were tripled to c. 170 000 t (1999–2003) (FAO, 2004). Time series since 1995 of biomass estimates of *S. aurita* off Mauritania based

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on acoustic surveys carried out by the Norwegian R.V. *Dr Fridtjof Nansen* show a continuous decline, and also the catch per unit effort (CPUE) of the main fisheries for round sardinella in Mauritanian waters during the same period has been decreasing, therefore, the stock is currently estimated to be overexploited (FAO, 2006).

With such an increase in exploitation, essential biological studies of the species are required in order to enable proper management and sustainable exploitation of the stock. One of the key elements for management of fish stocks is knowledge about the reproduction of the fish. For instance, knowledge about the proportion mature fish at size is necessary for estimation of spawning stock biomass (SSB) and an important factor in the design of selective fishing gear. The proportion of mature fish in the catch has also been suggested as a computationally less intensive way of assessing the exploitation status of the stock (Froese, 2004). Published studies on the reproduction of the indeterminate spawner *S. aurita* in the Mauritania area are scarce and >25 years-old, and they only focused on the spawning season and migrations of the fish. These studies have shown that the adults migrate annually up and down the north-western African coast between 12° and 22° N (Boely *et al.*, 1982; Garcia, 1982). Migration starts off Senegal in May, and by August most of stock is distributed in the northern part of the Mauritanian EEZ. Acoustic surveys by the R.V. *Dr Fridtjof Nansen* during the last decade have confirmed this high abundance of round sardinella in Mauritanian waters until December (FAO, 2006). In early winter, the species moves rapidly to the south again. This migratory route is assumed to be closely linked to seasonal variation in the sea surface temperature (SST), which is highest off Mauritania during the summer (Vakily & Pauly, 1995). Spawning takes place, mainly during the fish's journey north (May to September), all along the coast. Larvae are recruited in two nursery areas where they grow until they join the adult stock, one off Senegal between Gambia and Dakar (c. 14° N), and the other off Mauritania in the Banc d'Arguin area (c. 20° N) (Boely *et al.*, 1982).

The present study was carried out to gain an improved understanding of the spawning activities of round sardinella in Mauritanian waters. It used a high sampling resolution to investigate the link between seasonality in individual fish condition and the migration through Mauritanian waters. The work is based on sampling of catches from pelagic fisheries in the Mauritanian EEZ during the years 2000 to 2003.

MATERIALS AND METHODS

DATA COLLECTION

Throughout the period 2000–2003 >15 000 round sardinellas were analysed, normally in samples of 25 fish, taken during day and night. The material came from Dutch pelagic trawlers whose activities make up >60% of the total catches of round sardinella in the Mauritanian EEZ (ter Hofstede & Dickey-Collas, 2006). Samples were collected randomly by observers and fishermen. Scientific observers of the Mauritanian Institute for Research of Oceanography and Fisheries (IMROP) and Wageningen Institute for Marine Resources and Ecosystem Studies (IMARES) took samples while monitoring discards aboard Dutch pelagic trawlers off Mauritania (ter Hofstede & Dickey-Collas,

2006). All fish were processed within a few hours after being caught. Samples were also randomly obtained by the Dutch fishermen themselves. These samples were deep-frozen at sea within a few hours of being caught and processed at the mainland in the laboratory of the IMROP. The processing of the fish for biological analyses was performed by scientific staff from IMROP and IMARES. All had received extensive training and their skills were checked frequently by expert scientists. The variables collected were fork length (L_F) (to the cm below), ungutted mass (M), gutted mass (M_{Gu}) and gonad mass (M_G , g) and sex, maturity, stomach fullness and fat content. The methods for defining maturity, stomach fullness and fat contents are described below and given in Tables I, II and III. Information on age could not be collected, since the methods for ageing round sardinellas caught off north-west Africa have yet to be fully determined and tested. All measured variables of individuals were estimated from random samples of fish, which were then raised to catch (ter Hofstede & Dickey-Collas, 2006). This prevented the introduction of bias due to raising procedures (Morgan & Hoenig, 1997). The entire sampling programme took place with the full co-operation of the fishing industry.

SPAWNING ACTIVITIES

The maturity stages of round sardinella were recorded macroscopically using the scale given in Table I (modified from Fontana, 1969). The L_F at which 50% of the population reached maturity (L_{F50}) was determined by sex as a function of the logit transformed maturity proportions (p) and L_F : $L_{F50} = -b_s^{-1}[(p^{-1} - 1) + a_s]$, where s is sex, p is proportion mature (0.5), a is the intercept and b is the length coefficient (Royston & Altman, 1994; Allison, 1999).

Seasonality in the spawning activities based on the annual maturity cycle was determined by sex from the relative frequencies of maturity stages, on a monthly basis for the period 2000–2003. Because there are mixes of mature and immature fish together

TABLE I. Key for the macroscopic determination of the maturity stages of *Sardinella aurita* (after Fontana, 1969)

| Stage | | Female | Male |
|-------|------------------|--|---|
| I | Immature | Ovaries small and firm | Testes very small and knife-blade shaped |
| II | Sexual resting | Ovaries bigger, transparent and tube shaped | Testes larger than stage I |
| III | Late developing | Ovaries firm, some oocytes may be visible | Testes firm, no liquid running out after incision |
| IV | Ripe | Ovaries large and less firm, oocytes visible | Testes very soft, liquid runs out after slightest incision |
| V | Spawning | Gonads very large, ovarian membrane very thin, oocytes run out after slightest pressure on abdomen | Testes large and soft, sperm runs out after slightest pressure on abdomen |
| VI | Spent | Ovaries flabby and vascular, numerous hyaline spaces can be seen through ovarian membrane | Testes flaccid, signs of very fine vascularization |
| VII | Recovering spent | Ovaries empty | Testes flaccid and strongly vascular |

TABLE II. Classification of stomach fullness (categories 0–4) of *Sardinella aurita*

| Category | Stomach fullness |
|----------|---|
| 0 | Stomach completely empty |
| 1 | After incision at the end of the stomach a very small amount of food particles emerge |
| 2 | After incision about 20 mm of food particles emerge |
| 3 | Stomach is almost full. Also the two lobes of the stomach are partly filled |
| 4 | Stomach completely full |

in the catch (discounting observer error), it is likely that catchability effects caused by partial recruitment will only affect the results in a minor way.

CONDITION

Several biological features other than maturity stage were used to examine seasonality in the reproduction of round sardinella in the Mauritanian EEZ. These features are described below and concern (a) the gonado-somatic index (I_G), (b) the condition of the body (K) and (c) the feeding condition. For all features, seasonality was determined by sex and on a monthly basis. The I_G was calculated for each sampled mature individual by: $I_G = 100M_G(M_{Gu} - M_G)^{-1}$. The condition based on the carcass (K_c) was calculated from: $K_c = 100(M_{Gu} - M_G)L_F^{-3}$ (Heincke, 1908; Nash *et al.*, 2006).

The feeding condition of each sampled mature individual was determined macroscopically by looking at the stomach fullness (Table II) and the fat content (Table III). Stomach fullness was defined as the volume of food present in the stomach. For determining stomach fullness, there are five categories from 0 to 4, of which 0 is completely empty and 4 is completely full. Fat content is defined as the amount of fat in the abdominal cavity of the fish. It is classified in four categories from 0 to 3. Category 0 indicates no fat and category 3 indicates that all the intestines are completely covered with fat.

RESULTS

SPAWNING ACTIVITIES

Round sardinella matured with L_F almost equal between the sexes. Within the population, males started maturation at a L_F of c. 18 cm, 50% had reached maturity at 22.6 cm, and at c. 32 cm all males had reached maturity (Fig. 1). Females attained maturity approximately between 19 and 33 cm with 50% reaching maturity at c. 21.9 cm L_F . Both sexes started spawning at c. 22 cm L_F , and, as expected, the percentage of mature fish at stage V (spawning)

TABLE III. Classification of fat content (categories 0–3) of *Sardinella aurita*

| Category | Fat content |
|----------|--|
| 0 | No fat at all |
| 1 | Small chains of fat along intestines |
| 2 | Chains of fat cover half of intestines |
| 3 | Intestines completely covered with fat |

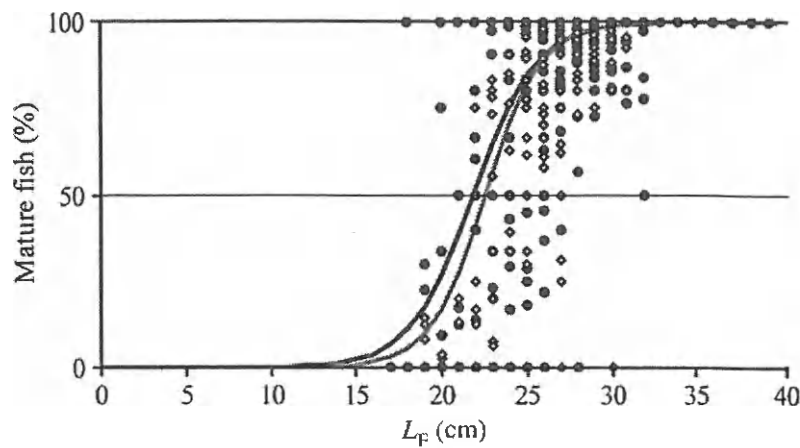


FIG. 1. Percentage of mature male (\diamond , —) and female (\bullet , —) *Sardinella aurita* in relation to fork length (L_F) during the period 2000–2003.

increased with L_F (Fig. 2). Judging from Fig. 2, some problems have probably arisen by distinguishing individuals in the stage spent (stages VI and VII) from immatures (stages I and II), since some individuals with a L_F of <22 cm appeared to be spent.

It is clear that spawning occurred throughout the entire year (Fig. 3); however, both sexes displayed a rise in spawning during the summer (June to September) when about a quarter of the mature stock was at spawning stage V. Consequently, the percentage ripening (stages III and IV) were highest during the preceding period (March to May) and the peak in stage spent (VI and VII) followed the spawning period in winter (November to January).

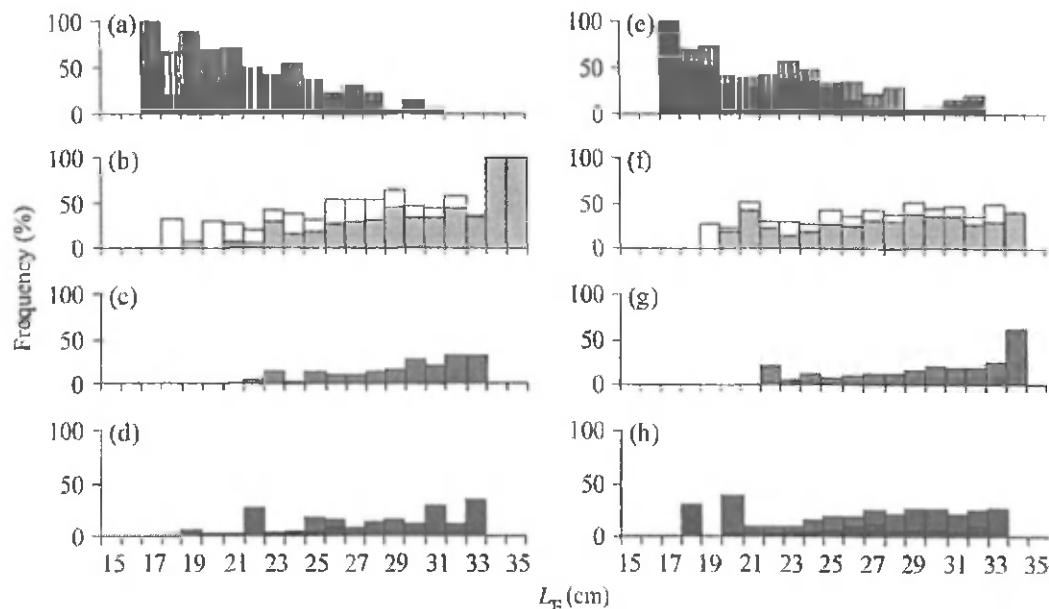


FIG. 2. Frequency (percentage) of maturity stages by fork length (L_F) for *Sardinella aurita* during the period 2000–2003: (a) male and (e) female immature stages I (□) and II (■), (b) male and (f) female ripening stages III (□) and IV (■), (c) male and (g) female spawning stage V (■), (d) male and (h) female spent stages VI (□) and VII (■), as described in Table 1.

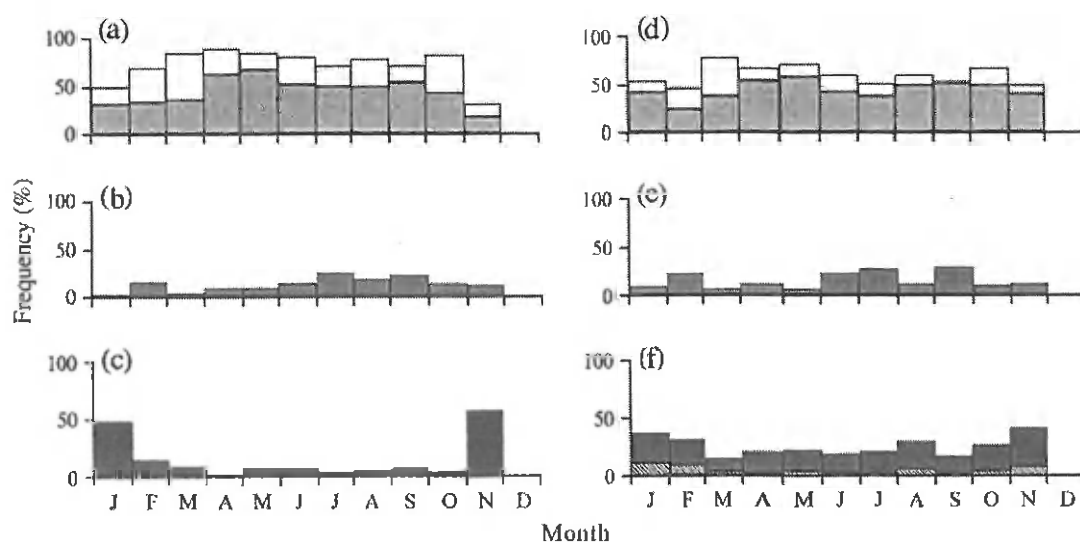


FIG. 3. Frequency (percentage) of maturity stages by month for mature *Sardinella aurita* during the period 2000–2003: (a) male and (d) female ripening stages III (□) and IV (▒), (b) male and (e) female spawning stage V (■), (c) male and (f) female spent stages VI (■) and VII (▨). Stages are described in Table I.

CONDITION

The monthly value of K_c of round sardinella off Mauritania was in accordance with the seasonality in the maturity cycle. For both sexes synchronously, the condition of the body increased in the months before the rise in spawning activity and during this spawning period, K_c dropped from 1.8 at the beginning in June to 1.5 at the end in September (Fig. 4). This signal was also seen in

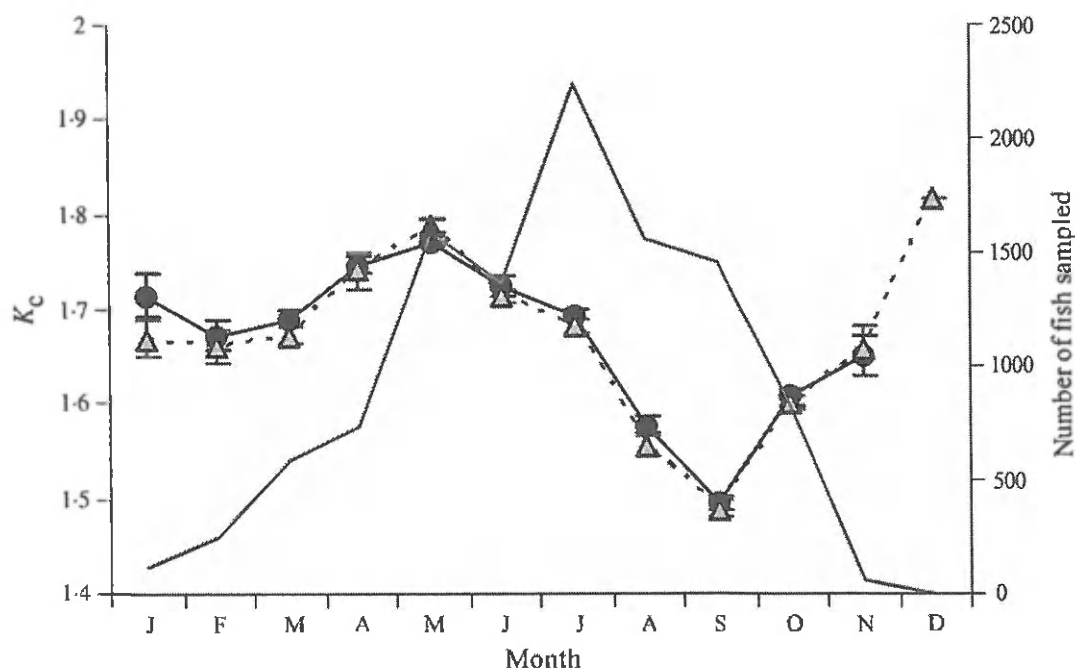


FIG. 4. Monthly mean \pm s.e. condition (K_c) for mature male (---△---) and female (—●—) *Sardinella aurita* during the period 2000–2003. The total number of fish sampled (—) is also given.

other biological features of *S. aurita* throughout the year, *i.e.* M_G and feeding conditions (as defined by stomach fullness and fat content). Both sexes displayed a clear development of the gonads preceding the spawning period (Fig. 5). From March to June, the value of I_G increased from 2.5 to >6.0%. This growth came to a stop and slightly diminished during the months when spawning of round sardinella was at its highest. Despite regular sampling of fish in the fourth quarter, almost no gonads were weighed, but judging the status of the gonads during the first quarter, it was assumed that these shrink after the spawning period (June to September).

A lower incidence of feeding during the spawning period was apparent in both mature males and females, since the percentage of empty stomachs was highest during this period (Fig. 6). Furthermore, the percentage of category 0 of fat content (meaning 'no fat') showed a strong increase for both sexes from June to October (Fig. 7). The development throughout the year in the state of both the stomach fullness and the fat content suggests that round sardinella stopped feeding and relied on their stored energy during the peak period of spawning.

DISCUSSION

The major fishery on round sardinella in Mauritania (64% of the total catches), namely that of the Dutch freezer trawlers, show a significant seasonal pattern in the catches of this species with highest catches in the summer (June to July) and lowest catches in the winter (December to January) (ter Hofstede & Dickey-Collas, 2006). Since round sardinella is the main target species of the fleet and catches are not restricted by quotas, this indicates that the species displays a yearly migration pattern into and out of this zone. Although all

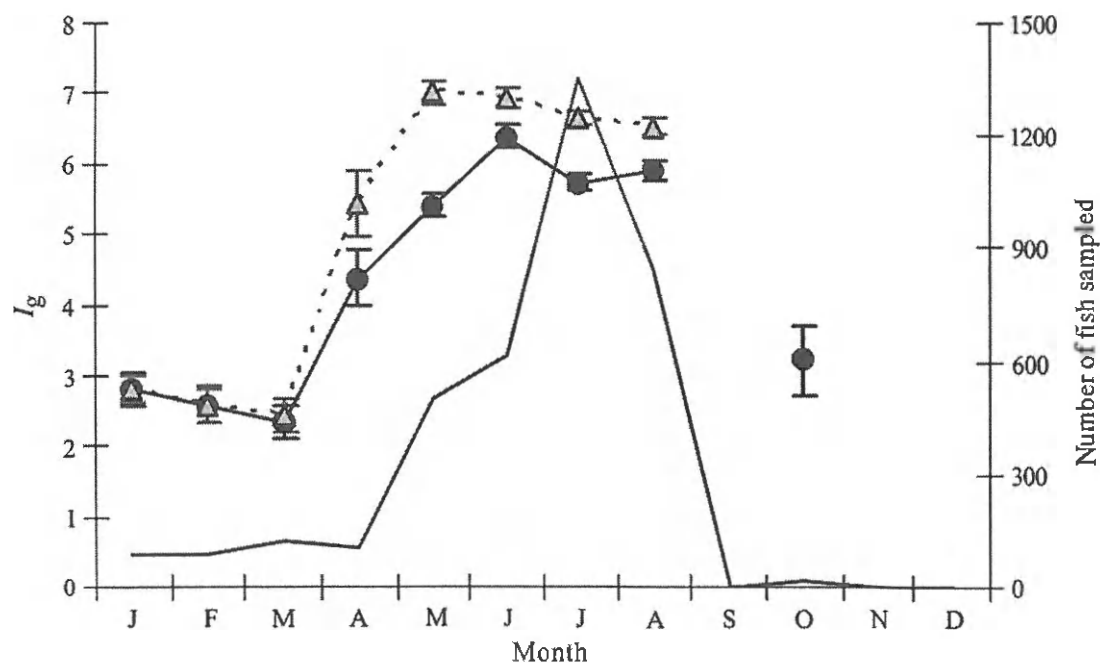


FIG. 5. Monthly mean \pm S.E. gonado-somatic index (I_G) for mature male (--- Δ ---) and female (— \bullet —) *Sardinella aurita* during the period 2000–2003. The total number of fish sampled (—) is also given.

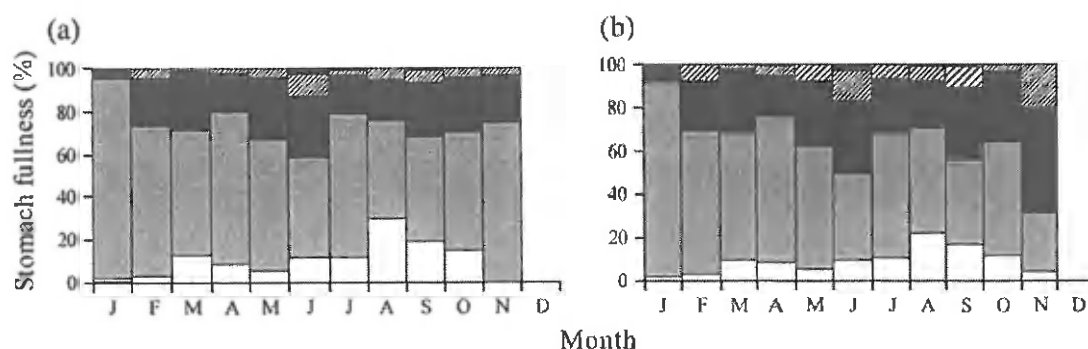


FIG. 6. The monthly percentage of stomach fullness for mature (a) male and (b) female *Sardinella aurita* during the period 2000–2003. 0 (□), 1 (■), 2 (■), 3 (■) and 4 (■): categories of stomach fullness ranging from empty (0) to full (4) (see Table II).

information is extracted from fish caught in only a small zone of the distribution of the stock, the northern area of Mauritania is the central part of the population's range and can therefore be considered as a representative part of the distribution range (Samb & Pauly, 2000). The peak in abundance of *S. aurita* off Mauritania during the summer is in accordance with the migration pattern described in the early 1980s (Boely *et al.*, 1982; Garcia, 1982). When the maturity ogives are applied to the total catch of round sardinella (landings plus discarded fish; ter Hofstede & Dickey-Collas, 2006), it is apparent that 96, 95, 96 and 86% of the catch was mature in 2000, 2001, 2002 and 2003 respectively. Age determination of these fish is still unreliable and it is important to consider any indicators of stock exploitation (Cotter *et al.*, 2004; Froese, 2004). One very simplistic approach is following the criteria from Froese (2004), where the percentage of mature fish in the catch suggests that round sardinella is not overexploited in the Mauritanian EEZ, since almost 100% of the catch has been able to spawn. Declining trends in biomass estimates and CPUE during the last decade, however, have resulted into a general belief that the stock is currently overexploited off Mauritania (FAO, 2006).

The present study used monthly sampling of *S. aurita* from commercial catches (2000–2003) to show that the migration pattern is associated with seasonality in both spawning activities and fish condition. Judging from the

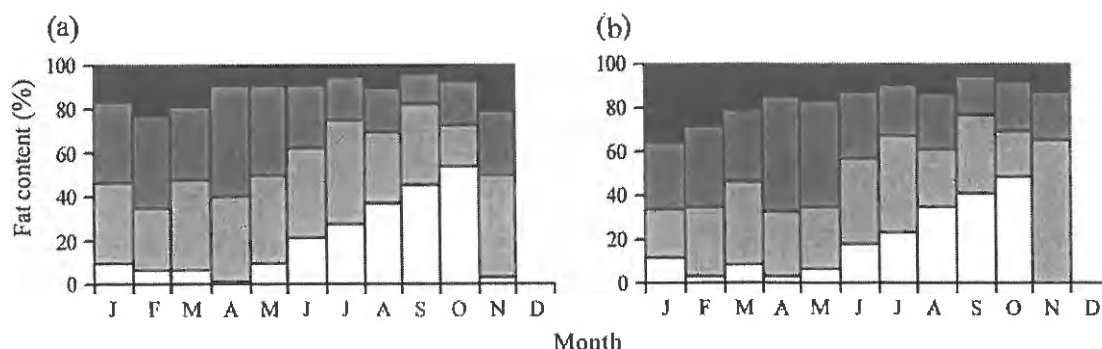


FIG. 7. The monthly percentage of fat content for mature (a) male and (b) female *Sardinella aurita* during the period 2000–2003. 0 (□), 1 (■), 2 (■) and 3 (■): categories of fat content ranging from no fat (0) to high fat (3) (see Table III).

maturity stages, *S. aurita* spawns in the Mauritanian EEZ throughout the entire year, but a peak in spawning exists during the summer (June to September). This seasonality can also be observed through the increase in gonad mass and fat content of the fish in springtime, and a collapse in the physical condition after spawning, despite the continuation of feeding. The observed cycle in spawning activity is in accordance with another recent study in the adjoining area just north from Mauritania. Observations on egg distributions of *S. aurita* off the western Saharan coast (21–23° N) indicate that there is no spawning in winter (January and February) and that the peak spawning period is in July (Ettahiri *et al.*, 2003). The results from these two studies complement each other and confirm the spawning and migration theories on *S. aurita*.

The spawning period of *S. aurita* in Mauritania is similar to those of other stocks in the eastern Atlantic Ocean. A more southern stock off Ghana showed the same moderate spawning throughout the entire year, with a major season from July to October (Quatey & Maravelias, 1999). This is emphasized by a clear resemblance in the gonad maturation pattern between the two stocks, since the I_G of the Mauritanian stock is at its lowest during the beginning of the year and shows a strong increase during spring before the spawning period, likewise the I_G of the Ghanaian stock as described by Quatey & Maravelias (1999). Also north of Mauritania, *i.e.* in the north-western Mediterranean Sea, round sardinella was observed to spawn during the period July to October (Palomera & Sabatés, 1990). In contrast to the similarity in spawning period, round sardinella displays different reactions to changes in SST in the three areas. In the north-western Mediterranean Sea, the spawning periods coincides with an increase in SST (Palomera & Sabatés, 1990), while in the Ghanaian waters the spawning season coincides with a decline in SST (Quatey & Maravelias, 1999). Off Mauritania, conversely, the fish attempt to remain within a range of preferred temperature (Longhurst & Pauly, 1987), resulting in the observed migratory pattern that is closely linked to the annual SST-cycle (Vakily & Pauly, 1995). These differences are probably related to an optimum temperature range for spawning of 22–25° C, since this is the preferred temperature in the north-west Mediterranean Sea during peak spawning (Palomera & Sabatés, 1990), it is also related to peak spawning of the stock in north-west Africa (Conand, 1977), and off Ghana spawning does not start until the mean SST falls below 25° C (Quatey & Maravelias, 1999).

In conclusion, it was confirmed that round sardinella enters the Mauritanian EEZ from the south in springtime and returns after the summer. This migration is linked to spawning activities in the area, judged by the observed seasonality in the maturity stages, in combination with the physical condition of the fish throughout the year. From the seasonality in K_e , I_G and fat content, it was concluded that the fish are in a good condition when entering the Mauritanian zone, use most of their reserves during the spawning activities without maintaining it through feeding, and after spawning retreat to the south in order to recover.

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