THE BIOLOGY OF THE KENYA REEF FISH OF THE GENUS SIGANUS

By

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted with my approval as the supervisor.

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ABSTRACT

In this study four siganid species were identified in the Kenyan inshore waters, namely Siganus sutor (Valenciennes, 1835), S. luridus (Rüppell, 1828), S. argenteus (Quoy & Gaimard, 1825) and S. stellatus Forsskal, 1775. S. sutor is the commonest constituting almost 100% in the fishermen's catches in the Mombasa region.

The growth rates for S. sutor have been determined by counting daily growth bands on the otolith corroborated with knowledge of the spawning times. Using this method the growth parameters L_∞ (the mean length fish would reach if they were to grow to very old age) is 36.0 cm standard length and K (a growth coefficient) is 0.13 at the Kenya coast.

The length-weight relationship of S. sutor shows a straight line relationship described by the equation of the form log W = 2.96 log l - 1.56, r = 0.97, $P < 0.01$. The relative condition factor (K_n) shows a two peak tendency throughout the year. There is a peak in January and another in April. The lowest (K_n) values are in March and August which may be a suggestion that the low values of (K_n) in these months come as a result of the spawning activities of the fish.

Siganids, particularly S. sutor, have two major spawning seasons at the Kenya coast. For S. sutor the first spawning peak is in January/February and the other in late May/June even though individual ripe fish occurred inconsistently in months off the spawning seasons. The times of spawning have been determined by analysis of the changes in the relative weight of the gonads to body weight, time of appearance of juveniles and the seasonal occurrence of the maturity stage. The relative condition factor (K_n) throughout the year also indicates strongly that S. sutor has two major spawning seasons at the Kenya coast.

S. sutor has a group-synchrony type of oocyte maturation where there is separation of developing from resting oocytes. Six stages have been used as a scheme for staging gonadal development; the criteria for assigning the testis to a given maturity stage are macroscopic and for the ovary the individual stages by macroscopic criteria is further validated by histological examination and analysis of oocyte size classes on Gilson's preservations.

Ovaries of S. sutor show an oocyte frequency diameter distribution that is strongly bimodal containing a mode of small and large oocytes and, in some ovaries intermediate size oocytes (210-300 μm)

completely missing. Younger ovaries and indeed those that are spent have got one mode of oocytes ($\leq$ 150 µm) since in the former the large oocytes (> 150 µm) have not been formed while in the latter such oocytes have been shed. Bimodal ovaries are heavier than unimodal ovaries since the former have large oocytes (480 µm) which have a volume of about 885 X as great as oocytes of 50 µm.

A mean fecundity of 5.85×10^5 eggs per female of S. sutor has been determined per spawning at stage 4, excluding all atretic oocytes. As oocytes grow from stage 4 to 5 at the peak of development a further 5% are lost to atresia. At spawning, therefore, S. sutor has a mean fecundity of 5.56×10^5 eggs per female per spawning and hence a potential annual mean fecundity of 1.1×10^6 eggs since each female probably spawns twice in a year.

CHAPTER 1

1. INTRODUCTION

1.1 Literature review

Kenya's marine fisheries potential is rather small mainly due to a very narrow continental shelf (approximately 8,500 km^2) except for the North Kenya Bank where the shelf widens to about 50 nautical miles. This is aggravated by a combination of other negative factors. There are no upwelling phenomena in Kenya coastal waters, in fact downwelling is suspected. Also during the southeast monsoon (April-October) there is a fast north-moving East African coastal current which makes artisanal fishing rather hazardous. During the northeast monsoon (November-March) there occurs a complete reversal of the monsoon gyre and the wind generated surface circulation, the East African current, is weakened and the water flows Eastwards. This reversal of winds is associated with the generation of a weak Somali current which comes down off the coast as far as Malindi. It is during this time that most of the fishing activities are carried out at the Kenya coast. Moreover, the Equatorial current brings nutrient depleted tropical oceanic water to the Kenya coast.

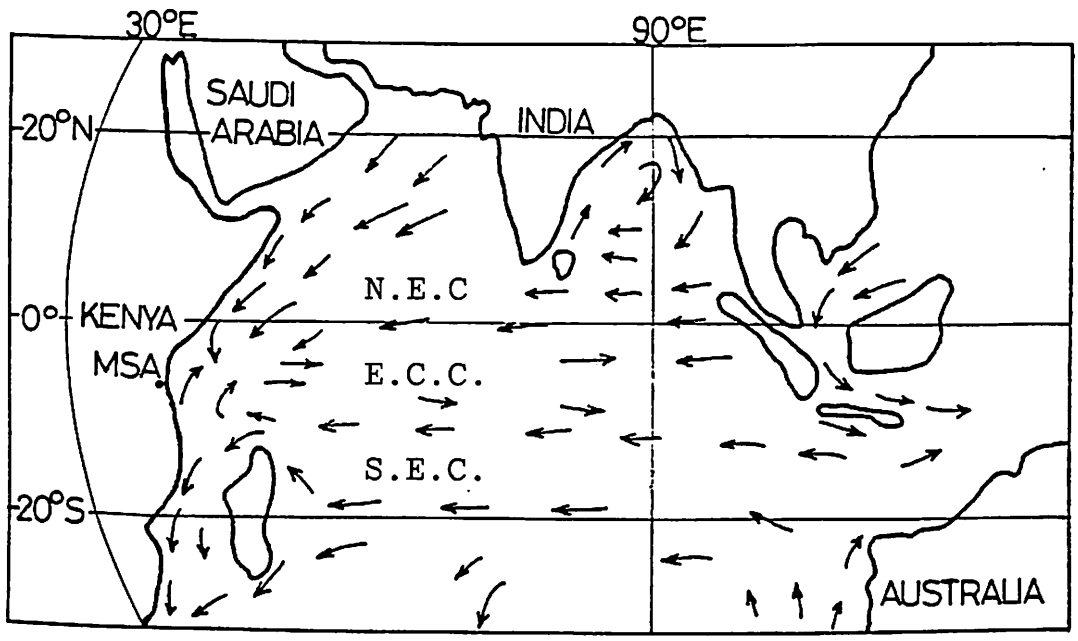

Fig. 1.1: Indian ocean-surface currents circulation November to March. N.E.C. - North Equatorial Currents; E.C.C. - Equatorial Counter Currents, S.E.C. - South Equatorial Currents; MSA - Mombasa.

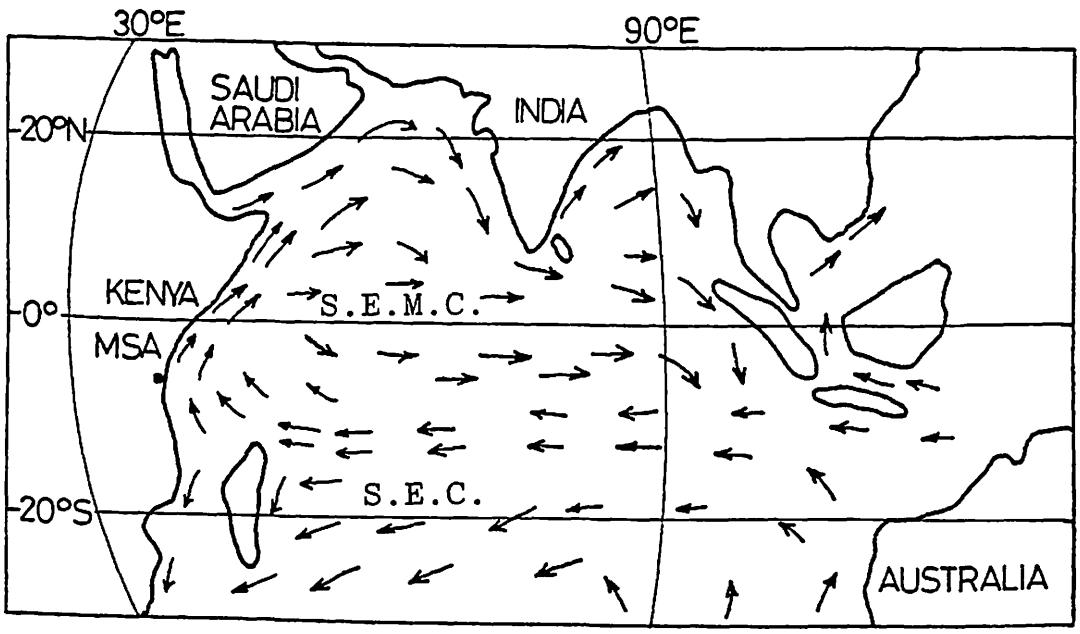

Fig. 1.2: Indian ocean-surface currents circulation April to October. S.E.M.C. - Southwest Monsoon Currents; S.E.C. - South Equatorial Currents; MSA - Mombasa.

We may divide the marine fishery carried out at the Kenya coast into four categories: the inshore reeffishery, demersal offshore fishery, and pelagic offshore fishery for both small fish and tuna. The latter is carried out by high-powered foreign vessels.

The inshore reeffishery is the most important for Kenya both economically and socially. It is estimated that there are an average of 2.09 canoes and 0.56 dhows km^{-1} of coastline in Kenya. This is a clear indication of a high level of inshore fishery exploitation, which makes the need to study the biology of reef fishes all the more important for management of the fishery. Moreover, Iversen (1984) pointed out that the Kenya reef is a rather productive and important area where the marine fishery takes place today.

The siganids contribute 50% of the total artisanal fish catch of the inshore reeffishery (Nzioka, 1984), a fact that makes clear the need to study their biology. The situation might already be serious for the siganids because according to the local fishermen the average size of fish caught is getting smaller.

The main gear used to catch the siganids is the traditionally made dema trap. On the average over 95% of the catch of all traps comprises the siganids. This means that the trap is designed to catch this particular group of fish (Nzioka, 1984). This is

advantageous from the point of view of the fishery management of these fishes which can be fairly straight forward. It should be noted, however, that it cannot be stated without further investigation that there are more siganids in our coastal waters than the other fishes and therefore the reason why they predominate in the trap catches. The reason may be partly that their fishing is more efficient. The dema trap is designed to catch Tafi, other fishes are a bye-catch. To achieve this aim first, the door into the trap must be constructed separately and inserted into the trap at the 'V' end to about half way inside. Secondly, the 'V' shape at the entrance into the trap (Plate 2.1) must not exceed 45^{o} and its edges should not be made too long otherwise fish does not get in at all; one of my fishermen friends told me once.

Such phenomena as onset and time-course of sexual maturation, fecundity, food and feeding habits, migration, and mortality rates need to be studied since these are central in fishery biology. These phenomena must be related to growth studies. It is largely with the latter studies that fishery biology has established itself as a field in its own right. It is the sum of reproduction, growth, and survival of individual fishes which provides from year to year

the catch taken by the fishery. The knowledge of how fishes of a given stock grow is essential for stock assessment purpose (Pauly, 1980).

As a pre-requisite to a study of the above phenomena it was necessary to determine the identity of the siganid species that occur in our coastal waters especially since there is considerable confusion in the literature regarding the identification of the siganid species (Lam, 1974). According to Woodland (1983) - who is now revising the family Siganidae - the Siganidae are a relatively small Indo-pacific family with 26 or perhaps 27 species. Species richness is highest in the Indo-Malayan region and lowest in French Polynesia with East Africa occupying an intermediate position.

The Siganidae are also sometimes called Teuthidae but Woodland proposed to the International Commission on Zoological Nomenclature that the genus Teuthis Linnaeus, 1766, be suppressed in favour of the genus name Siganus Forsskal, 1775 (Lam, 1974). Because of this taxonomical confusion a number of species reported previously have had to be renamed (Lam, 1974). For Siganus oramin (Bloch & Schneider, 1801) used by Monacop (1973) and Soh and Lam (1973) Woodland uses S. canaliculatus. S. rostratus (Valenciennes, 1835) used by Tsuda and Bryan (1972) is renamed S. argenteus

(Quoy & Gaimard, 1825). Woodland (1985) thinks that there are four siganid species at the Kenya coast, namely, S. sutor (Valenciennes, 1835), S. luridus (Rüppell, 1828), S. argenteus (Quoy & Gaimard, 1825) and S. stellatus Forsskal, 1775. What Smith (1977), who worked on the East coast of Africa calls S. oramin is what Woodland now calls S. sutor. This has been confirmed by Bianchi working at Bergen, Norway (Personal communication). A year-long survey at Mombasa, Kilifi, Diani, Shimoni and Vanga and a careful taxonomical examination has shown that at the Kenya coast the dominant siganid species is S. sutor and that the other three species listed by Woodland are quite rare in the fishermen's catches between Malindi and Vanga.

We need to know the distribution and abundance of each species. Earlier workers tended to lump all species on the coast of East Africa as siganids (Nzioka, 1984). Lam (1974) did the same for the Palau species.

Knowledge of how fish in a given population grow is essential and the ability to determine the age of fish is such an important tool in fishery biology because age data in conjunction with length and weight measurements can yield information on population structure, mortality, age at first maturity, life

span and production (Bagenal, 1978; Pauly & David, 1980; Gjøsaeter et al., 1984). Although in many cases age cannot be known with complete certainty it can be estimated with a certain degree of confidence and accuracy by statistical approaches based on an analysis of modes of length-frequency distribution or of the progression of modes in a time-series of such distributions. It can also be estimated by counting growth marks on otoliths, scales, and bone provided one can establish the periodicity of such marks. While these are fairly accurate and reasonably precise methods for determining the age of temperate fish, there is still need to develop better methods for tropical fishes (Bagenal, 1978). According to Brothers (1979) aging tropical fishes by means of microstructures in the otolith seems to be the most promising method available at the moment. This method is based on earlier observations by Pannella (1971, 1974) that otoliths of some tropical and temperature fishes contain primary growth increments which seem to be formed with a daily periodicity. This was an important finding that undoubtedly formed the basis for obtaining potentially very accurate age estimates in a reasonably simple way. Since this finding the number of fish species that have been found to have primary otolith increments has been steadily growing

(Gjøsaeter et al., 1984).

Data on length and weight of fish are commonly analysed to yield biological data and are employed as one of the standard methods in fishery biology (Le Cren, 1951). Although length-weight data are used with different objectives, for S. sutor it has been used with two main objectives; (a), in describing mathematically the relationship between the two parameters so that one may be converted into the other and (b), to measure the variation from the expected weight for lengths of individual fish as an indicator of condition and gonadal development (Tester, 1940; Le Cren, 1951; Bagenal, 1978).

Knowledge of the reproductive biology of fishes such as the siganids is the surest way to assess their fishery potential (Macer, 1974). Fecundity estimates combined with a knowledge of abundance of eggs in the plankton have been used to estimate adult fish stocks (Macer, 1974). Information on spawning behaviour is important for recruitment studies. Such studies can also throw light on the problems of fry production both in induced and natural spawning. Hatchery fry production is essential for selective breeding. Since siganid mariculture has been shown to be practicable (Lam, 1974) there is real need to better ways of obtaining fry, since catching wild juveniles

for stocking purpose is not only unreliable but also competes with the traditional fishery and depletes natural populations (May et al., 1974).

Knowledge of the biology of fishes is essential but particularly so in Kenya where the marine fisheries potential is small, and sound management regulations are of the greatest importance. The biology of fishes is a necessary tool for preparing a meaningful model of the fishery.

1.2 Aims of the present work.

The aims of this work are:- first, to identify the siganid species present in the Kenyan inshore waters. Second, to study some aspects of the biology and ecology of the siganids with special emphasis on reproductive biology, age and growth studies.

The aspects of the reproductive biology studied include the type of spawning of the population and individuals, fecundity estimates and gonad maturation cycles. Age and growth studies involve the determination of growth rates from otolith daily bands corroborated with the knowledge of spawning times.

CHAPTER 2

2. GENERAL MATERIAL AND METHODS.

2.1 Sampling area.

This study was carried out from January to December 1985. The material was obtained from lagoons and creeks near Mombasa island. Fig. 2.1 shows the area of Mombasa island with sampling areas. Fig. 2.2 shows fish landing centres at the Kenya coast.

2.2. Preliminary sampling.

2.2.1 Plankton sampling.

A preliminary survey for fish eggs and larvae was carried out from January to March 1985 all along Tudor creek, Mombasa (sites marked T). Two plankton nets were used; one with a mesh size of 500 μ and an opening of 1 meter; and the other with a mesh size of 350 μ and an opening of 0.7 m. These nets were towed at the water surface for 15, 30 and 45 minutes respectively, the variation in trawl time being aimed at varying the volume of water filtred.. The plankton collected was preserved in 10% formalin solution and later examined for siganid fish eggs and larvae under a dissecting microscope. Sampling for fish eggs and larvae was routinely done on a fortnightly basis during the three months period.

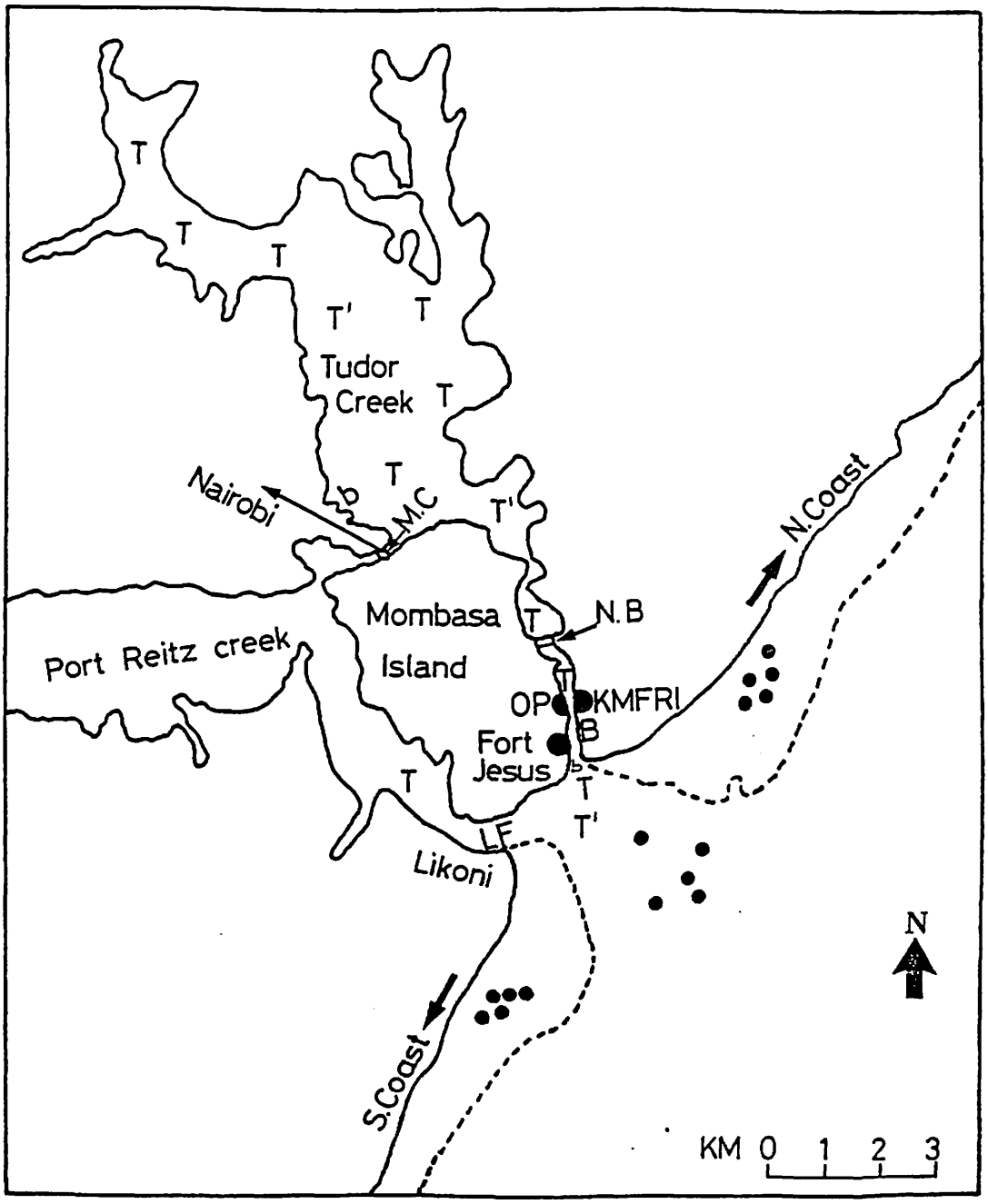

Fig. 2.1: Mombasa island, Kenya coast showing locations of fishing sites (●), Plankton trawled area (T), Beach seining site (B), K.M.F.R.I. - Kenya Marine and Fisheries Research Institute, NB-Nyali bridge, OP-old port-Mombasa, LF-Likoni ferry, MC-Mukupa cause way,------ Reef edge.

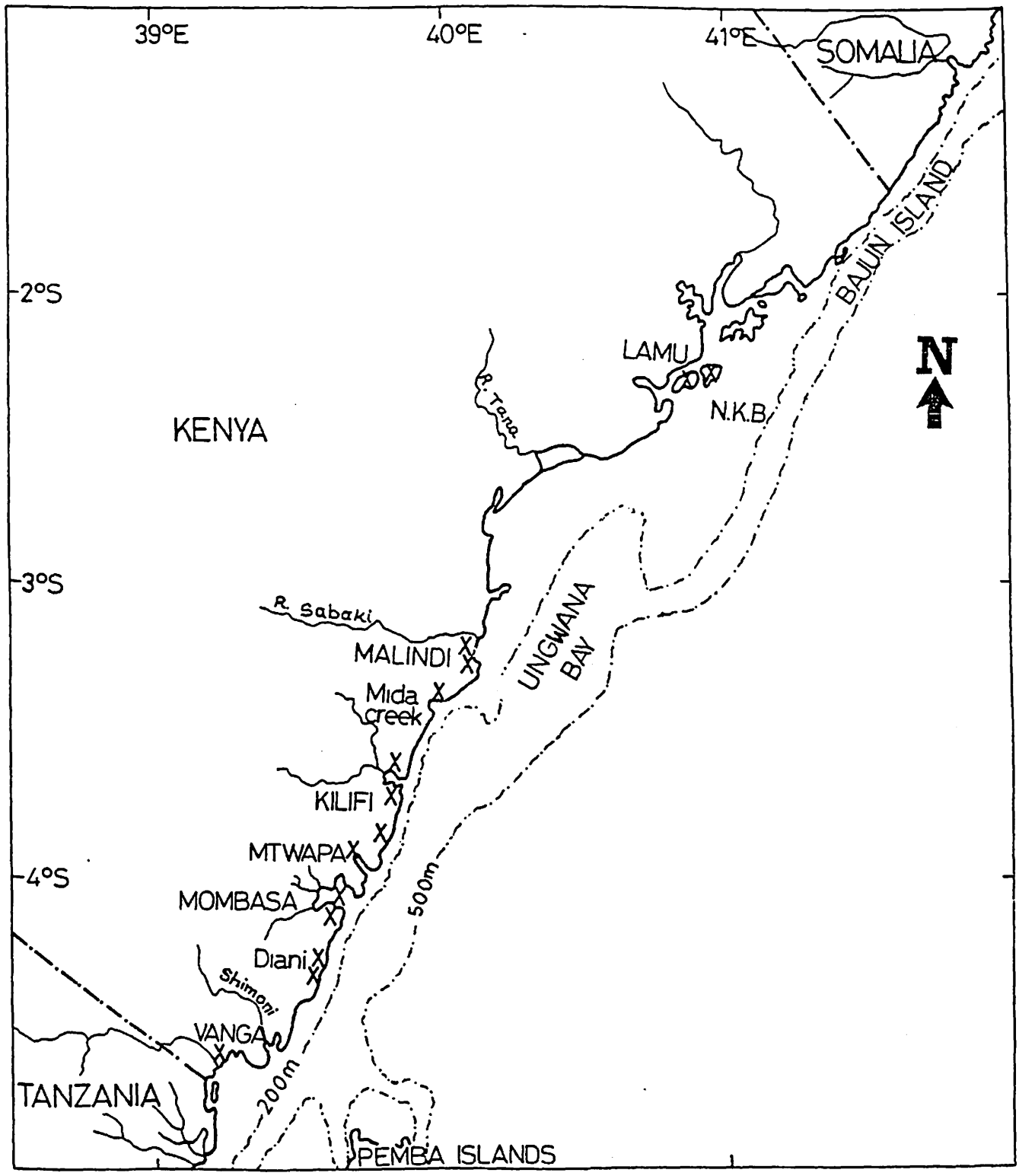

Fig. 2.2: The Kenya coastline showing ports, creeks, estuaries and fish landing sites (X).

After the surface tow, the nets were lowered deeper in the water column (7-15 meters) and were trawled as before. However, it must be pointed out that it was impossible to have the net at any accurately known depth in this range. During this excercise it was thought necessary to investigate into the phenomenon of vertical migration as a behaviour which may have been determining the position of siganid larvae in the vertical water column during the time of sampling. To account for this, several sample points were decided upon along Tudor creek (sites marked T^1). Plankton nets were sunk to the bottom with the aid of attached weights at each sample point and towed up the water column vertically and plankton collected and stored as before.

2.2.2 Beach seining.

In January 1985, a search for siganid juveniles was carried out at the mouth and all along Tudor creek. Areas of concentration were at a sandy beach 150 m east of Kenya Marine and Fisheries Research Institute (K.M.F.R.I.), site marked B on fig. 2.1, Nyali bridge, old port-Mombasa and the Kenya Meat Commission plant. The juveniles were caught by a beach seine, 25 meters long and mesh size of 4 mm. Beach seining was done fortnightly during the lowest

spring tides since it was then that the sea weed beds, on which the juveniles feed, were exposed. The standard length of juveniles was measured on a measuring board to the nearest 0.5 mm.

2.2.3 Dema traps.

It was necessary to know the most effecient and least expensive gear used to catch the adult siganids. For this, fish landing sites in Mombasa, Kilifi and Diani were surveyed. The local fishermen were interviewed and several visits to their fishing grounds made in their canoes. The majority of the fishermen use dema traps since these are, not expensive, are easy to make and repair when worn out. Seine nets and cast nets are used by other fishermen but these are expensive to purchase, repair and are laborious. A few others use handlines but according to most fishermen this is a very ineffective way of catching siganids.

The dema trap is made traditionally at home by the fishermen. A good dema trap lasts for about four months but more often than not fishermen lose most of their traps due to dragging ocean currents. The demas vary in size; there are the small ones about 3 ft in height, the medium sized ones (5.2 ft high) - are the most commonly used - and the largest

which are about 7 ft in height. A medium size dema is shown in Plate 2.1. The small ones are not very much used by the fishermen because the entrance to the trap is small in the sense that it does not allow large fish to enter. The largest one has limitations too, in that most of the fishermen have smaller canoes than this trap thus carrying it to the fishing ground, setting and checking it can be a problem.

Demas are constructed using splinters of mangrove trees both on the top and side faces. The bottom face-one that rests on the sea floor when the trap is set - is constructed with reeds (some water plants) which majority of fishermen in Vanga and Mombasa fetch at Gazi Mangrove swamp and Msambweni on the south coast of Kenya. The whole structure is held firmly by supporting struts.

The mesh size in the traps are consistent with an area of 3.6 cm^2 in the small trap and 10.8 cm^2 in the medium size ones. The fishermen construct the medium size trap within a narrow range (4.6 cm $\pm$ 0.47) of mesh size but surprisingly with no accessory devices. The trap has one door through which fish enter into the traps anteriorly. On the bottom the soft reed face is untied at one corner, folded back and the fish are removed from the traps. Bait is fed into the trap through this bottom opening before

Plate 2.1: A medium size traditional dema trap. Note the supporting struts and the 'V'-shape where the doorway into the trap is situated.

it is finally sealed up and eventually the trap set.

2.3 Definitive sampling routine.

Sampling for siganid fish eggs and larvae was stopped in March, 1985, since they were never identified in the plankton. Also on a separate project ran by K.M.F.R.I. research personnel from March to the end of the year the siganid fish eggs and larvae were not found in the plankton.

Juveniles were caught by a beach seine 25 meters long by 2 meters wide and a mesh size of 4 mm on a sandy beach 150 meters east of Kenya Marine and Fisheries Research Institute (K.M.F.R.I.). At the other sampling areas (marked b), siganid juveniles were not at all caught. Beach seining was done fortnightly, during the lowest spring tides since at other times the sea weed beds on which the fish feed are covered by water at levels that make beach seining impossible.

Adult fish were caught using baited traditional medium size dema traps. Sampling for adult fish was done at the mouth of Tudor creek (traps set on the bottom at a depth of 8-14 meters) during the north-east monsoon when the water is calm and on the outer slope of the reef at Bamburi and Shelly beach (traps set on the bottom at a depth of < 2.5 meters) during

the rough southeast monsoon.

Since all fishing was done with the local fishermen using their canoes, sampling followed their routine and was undertaken fortnightly around the neaptide and occasional weekly sampling which was therefore done around both neap and spring tides. For logistic reasons fishing was confined to the vicinity of Mombasa island. This was important since accurate weighings of small gonads had to be made before fixation. While fishing was confined to the Mombasa area the trends of the siganid fishery at other fish landing centres along the coast north and south of Mombasa was followed by twice monthly visits to Malindi, Kilifi, Shimoni and Vanga. Catches at Diani were examined thrice in a week. At the landing site fishermen catches were examined for the type of siganid species caught, the number of each species and the standard length of a random subsample (samples were picked from the baskets using random numbers) of about 50 fish was measured.

2.4 Fishing method

All traditional fishing is controlled by the tides in the sense that fishermen visit their traps when the tide is ebbing. The traps are set and left in the water for a duration of roughly 24 hours

when they are visited to remove the fish trapped and replenish the amount of bait. The actual fishing process takes roughly 4 hours during which 7 traps are serviced.

Many canoes of one, two or three man capacity and equiped with a sail and other equipment necessary for fishing set out an hour after high tide. The canoes drift out with the receding currents for about 2 hours during which most of the rocky shore covered with sea weeds (algae) are exposed. Here bait is collected for the traps before setting them. It is important to time the tide in such a way that at the time you have finished gathering ample bait you have an hour to low tide. Plate 2.2 shows the exposed sea weed covered rocky shore at the mouth of Likoni creek at around low tide. The traps were visited, their position marked by a small white plastic piece tied to the trap on the bottom by a long nylon string. Each trap is pulled up by the nylon string and placed on top of the canoe. Whether there is fish or not the soft reeds on the bottom face are untied, at one corner, fish removed and bait placed through the same space after which the flap is sealed tightly before the trap is lowered back to the bottom (Plate 2.3). The reed-made side of the trap must always rest on the sea floor. This is important because this face

Plate 2.2: Exposed sea weed rocky shore at the mouth of Likoni creek, Mombasa, Kenya.

Plate 2.3: Setting a dema trap. Note the mesh pattern and the supporting struts. The side shown is the one which will face away from the sea bottom when the trap is set.

is better able to avoid destructive friction on the sea floor than the rigid faces since the traps are dragged a lot by ocean currents. Besides this face is not as difficult to construct and repair as the more rigid sides. The fishermen in the Mombasa region set traps at low tide and then visit them everyday next low tide.

CHAPTER 3

3. SIGANID SPECIES IDENTIFICATION.

3.1 Taxonomic characters.

Siganids have a laterally compressed, oval, deep or slender body covered with small scales. The mouth is small with a single row of fine, close-set teeth in each jaw. The dorsal fin has 13 strong spines and 10 soft rays preceded by a forward projecting spine, embedded in varying degrees in the nape; the pelvic fins have 2 strong spines which are separated by 3 soft rays, a characteristic that is unique to the family; the anal fin has 7 strong spines and 9 soft rays-variations in the number of dorsal and anal spines and rays are extremely rare; the spines are venomous (Woodland, 1985).

The species associated with the coral reefs are usually brightly coloured and ornately patterned; the other species are often drab and become variously mottled with brown at death. All siganids are moderately sized herbivorous fishes. They live in shallow coastal waters. Some live in pairs around coral but others live in schools around rock and coral reefs, mangroves, estuaries and brackish lagoons.

3.2 Kenyan species.

Woodland suggests that there are four siganid species at the kenya coast including S. luridus (Ruppell, 1828), S. argenteus (Quoy & Gaimard, 1825), S. stellatus Forsskal, 1775 and S. sutor (Valenciennes, 1835). Since what he calls S. sutor could conceivably be S. canaliculatus (Park, 1797) which Smith (1977), who worked on the East coast of Africa, calls S. oramin (Bloch & Schneider, 1801), then there was need to study carefully the identity of siganid species at the Kenya coast.

In order to identify the fish, the coloration of the fish was noted immediately the fish were removed from the traps and colour photographs of representative specimens taken. The length of the fins was measured, their shape noted and counts of fin spines and soft rays made. Young juveniles, caught in February 1985, were stocked in circulating aerated sea water aquaria and the colours of the live undisturbed as well as of animals under the conditions of stress were noted and photographs taken.

Table 3.1 summarizes the taxonomic features of the four siganid species recovered in this study. The four were identified, as Siganus sutor (Valenciennes, 1835), S. luridus (Ruppell, 1828) S. argenteus (Quoy & Gaimard, 1825) and S. stellatus

Table 3.1: The diagnostic features of the siganids

Scientific name	S. sutor (Valenciennes, 1835)	S. luridus (Rüppell, 1828)	S. stellatus Forsskal, 1775	S. argenteus (Quoy & Gaimard, 1825
Other name	None	Teuthis lurida (Rüppell, 1828)	Teuthis stellata Forsskal, 1775	S. rostratus (Valenciennes, 1835)
English name	Shoemaker spine foot	Dusky spine foot	Brown spotted spine foot	Streamlined spine foot
Kiswahili name	Tafi mnyika	Tafi kitumbu	Tafi maenga	Tafi kitunga
No. of specimens observed	900	3	2	1
Total length (cm)	< 34.2	16.2, 16.9, -	32.5, -	-
Standard length (cm)	2.0 - 30.0	13.5, 13.8, 15.0	25.4, 28.2	18.5
Depth (cm)	< 9.9	5.9, 5.9, 6.1	11.8, 14.1	6.2
Longest dorsal spine	5th	-	4th	-
Length of last dorsal spine (cm)	1.3	-	3.2	0.7
Longest anal spine	3rd	-	last	3rd
Length of last anal spine (cm)	1.4	-	1.8	0.9

Shape of caudal fin	Concave
No. of scale rows above lateral line	27 - 30
Nature of scales	Minute
Colour of fish	Has about 40 blue round spots, ground colour depends on substrate; a dark blotch behind the operculum on both sides.

Straight	Deeply forked	Deeply forked with pointed lobes
15 - 20	23 - 28	16 - 22
Minute	Minute and cheeks strongly scaled	Small minutes scales on the anterior half of cheek.
Very dark brown	Greyish with numerous .large brown spots	Blue with lateral yellow stripes which are discontinuous

Plate 3.1: The juvenile of Siganus sutor. Note the dark blotch above the operculum surrounded by a circle of pale blue match-head size spots. In the background juveniles in fright and perhaps stress condition show black vertical striations. Photograph taken in the aquarium at K.M.F.R.I., Mombasa, Kenya.

Plate 3.2: Siganus sutor a few hours after death.

Plate 3.3: Siganus argenteus. Specimen collected at Bamburi, Mombasa, Kenya.

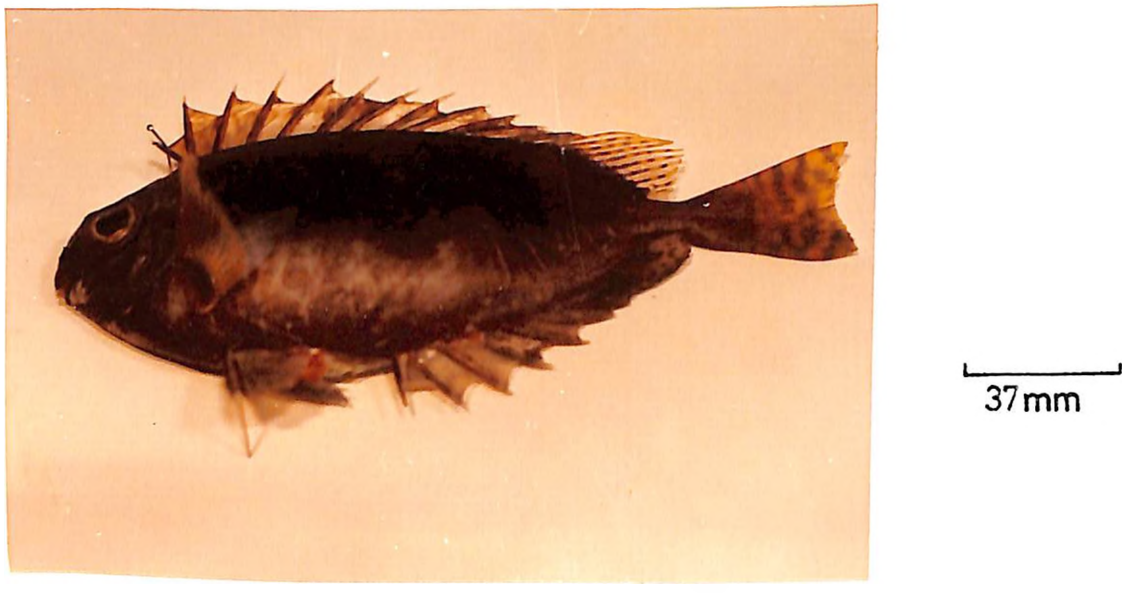

Plate 3.4: Siganus luridus. Specimen collected at Bamburi, Mombasa, Kenya.

Plate 3.5: Siganus stellatus. Specimen collected at the mouth of Tudor creek, Mombasa, Kenya.

Table 3.2: Some major characteristics used to differentiate between S. sutor and S. canaliculatus.

Character	Description	Species
Silhouette of head above eye	Distinctly concave.	S. canaliculatus
	Not concave	S. sutor
Post opercular dark blotch	Present	S. canaliculatus
	Absent	S. sutor
Blue spots and number	Present and numerous	S. canaliculatus
	*Present and fewer	S. sutor
Size of blue spots	Not sharply separated into different sizes. There is a continuous size spectrum.	S. canaliculatus
	*Sharply separated into different sizes.	S. sutor
Arrangement of blue spots	Regularly placed	S. canaliculatus
	*Irregularly placed	S. sutor
Shape of caudal fin	Forked in large fish, emarginate in fish less than 10 cm SL.	S. canaliculatus
	Forked	S. sutor
No. of scales between lateral line and base of anterior dorsal spines	21 - 27	S. canaliculatus
	*27 - 31	S. sutor

Maximum size (TL)	30 cm	S. canaliculatus
	*45 cm	S. sutor
Shape of spots	Ellipsoid	S. canaliculatus
	*Round	S. sutor
When frightened	Mottled	S. canaliculatus
	*Dark vertical bars	S. sutor

Forsskal, 1775, using FAO identification sheets, Western Indian Ocean; Fishing area 51, vol. IV, 1985 (Plates 3.1-3.5). S. sutor is by far the commonest of the four in the catches from Malindi to Vanga about 300 km to the south.

There are a lot of similarities between S. sutor and S. canaliculatus according to Woodland (FAO identification sheets). Table 3.2 gives the diagnostic features for S. sutor and S. canaliculatus. Considering the mark* (in table 3.2) it appears that it is S. sutor and not S. canaliculatus that occurs at the Kenya coast. Specimens were sent to Woodland at the University of New England, Armidale, N.S.W.; Australia and Bianchi at Bergen, Norway.

3.3 Discussion.

Since according to Lam (1974) there is considerable confusion in literature regarding siganid species identification and that Woodland and Bianchi (personal communication) note that there are a lot of similarites between S. sutor and S. canaliculatus the safest and the most logical approach to study the biology of the siganids at the Kenya coast, was, before anything else, to identify the species that are present. The situation was even more confusing (at the beginning of this work) since Smith (1977) and Bwathondi (1981)

who, unlike Woodland and Bianchi, worked on the East coast of Africa mention S. oramin (Bloch & Schneider, 1801) = S. canaliculatus (Park, 1797) which Woodland suggests could be probably S. sutor (Valenciennes, 1835). Kenyan workers too, give confusing information on species composition and abundance (Nzioka, 1984) yet this information is important to managing the fishery.

A year long survey at the Kenya coast (Mombasa, Kilifi, Diani, shimoni and Vanga) has shown that there are four siganid species at the Kenya coast (Table 3.1) as suggested by Woodland; that is:- S. sutor (Valenciennes, 1835), S. luridus (Rüppell, 1828), S. argenteus (Quoy & Gaimard, 1825) and S. stellatus Forsskal, 1775. This table also shows that in terms of abundance S. sutor is by far the commonest between Malindi to Vanga and that it constitutes close to 100% in the fishermen's catch.

Siganids have a high ability to change colours; since colours are also used as a major aid in their identification, care must be taken where colour and other characteristics tend to overlap between some species. Incidentally, this happens to be the case between S. sutor and S. canaliculatus. However, considering the characteristics shown by *(Table 3.2) there is irrefutable evidence that we have S. sutor

at the Kenya coast as opposed to S. canaliculatus named by Smith (1977) and Bwathondi (1981). Moreover, the number of scale rows between the lateral line and the base of the leading dorsal spines (26-31) and the shape, number and arrangement of blue spots (about 40, arranged in about 5 irregular rows) strongly support that the commonest siganid species at the Kenya coast is S. sutor (Woodland & Bianchi, personal communication). It also occurs that S. canaliculatus has got a post opercular dark blotch which is absent in S. sutor. The specimen drawn by Smith, (1977), Woodland (1985) and the specimens worked on in this study had such a blotch when alive and shortly after death (Plate 3.1). However, it must be pointed out that in view of the problems involved in the siganid taxonomy and considering most of the characteristics listed in table 3.2, it is most likely that the commonest siganid species in our coastal waters is S. sutor and not S. canaliculatus as Woodland and Bianchi suggest. It must also be noted that a careful comparative biology of the siganids at the Kenya coast might not be quite feasible because the other three species occur very infrequently (Table 3.1) in the catches. All in all information on species identification is important in managing the fishery since it indicates the correct species that are present, their composition and abundance.

CHAPTER 4

4. AGE AND GROWTH STUDIES

4.1 Introduction.

Knowledge of how fish in a given population grow is essential for stock assessment purposes (Pauly & David, 1980). The ability to determine the age of a fish is also equally important since such data along with length and weight measurements not only yield information on population structure, mortality, age at first maturity and lifespan but also contribute a lot to fish production studies (Bagenal, 1978; Pauly, 1980; Pauly & David, 1980; Gjøsaeter et al., 1984). Biological data from which age parameters can be estimated are of three types and these are:-

(a) length frequency data on random samples,

(b) data based on counting periodic markings on the otoliths and other skeletal parts and (c), tagging recapture data.

Many workers feel that the currently known methods can only be reasonably used to age temperate zone fish (Bagenal, 1978). However, aging tropical fish by means of microstructures on the otolith is seen as a most promising method for tropical fish (Pannella, 1971, 1974; Brothers, 1979; Gjøsaeter et al., 1984). Since one cannot simply assume that growth

increments in some species are daily marks one should, if possible, verify the reliability of the methods for each new species and probably also for new environments. Such verification attempts have shown that primary deposition on the otolith in several tropical species has a daily periodicity (Gjøsaeter et al., 1984). Workers in The Philippines have demonstrated that deposition of bands on the otolith of a Siganus sp. has a daily periodicity (Pauly, personal communication).

4.2 Material and Methods.

Otolith from males, females, and juveniles were dissected out from the cranium. The actual procedure, involved making a cut horizontally above the margin of the eyes as far back as below the procumbent first dorsal spine. A second cut was made dorsoventrally from the tip of the procumbent spine to the anteroposterior cut. The brain tissue was carefully dissected away and the otolith removed from the membranous labyrinth. The sagittae and the lapilli were easily identified. They were stored in 80% alcohol.

To count the daily primary increments the otoliths were cleaned under a dissecting microscope to remove the surrounding membranes, placed on microscope slides

and dried in an oven for 1 to 2 hours. They were then mounted in glycerine and sometimes in immersion oil under a cover slip and examined under a standard microscope. Permanent mounts of the otoliths were made in DPX.

Where the growth rings were not visible on some otoliths usually from large fish, metallurgical sand paper of very fine grain was used to grind the surface of the otolith thus improving the visibility of the rings. The actual method, involved applying a drop of water on the sand paper, the otolith lying on the tip of the index finger on its concave face, the convex face being gently ground.

Radii measurements were taken from the nucleus posteriorly and anteriorly (along the rostrum-longer arm, and the antirostrum, shorter arm) on the sagitta (Plate 4.1). These measurements were made using a calibrated eye-piece graticule on a standard microscope and a total magnification of X40.

Primary rings were only visible on the antirostrum (Plate 4.1). The smallest structure that was counted as a primary increment was a concentric unit composed of a narrow dark band and a wide light area as seen by transmitted light. Assuming that the rings counted were daily increments the fish were aged and the data used together with the standard length to

construct a Ford-Walford plot (Pauly, 1980). The growth parameters L_∞ (the mean length fish would reach if they were to grow to very old age), (indefinitely), and K (a growth coefficient), were determined using the above plot which is given by the expression of the form

$$L_{t+1} = a + bL_t$$

where, $$L_\infty = \frac{a}{1 - b}$$

$$K = - \log_e b$$

L_t and L_{t+1} pertain to length separated by a constant length interval (in the case of S. sutor L_t and L_{t+1} are separated by an interval of 60 days.

4.3 Results.

Primary growth increments on the sagitta were best read on the antirostrum (Plates 4.1 and 4.2) while such growth pattern were difficult to read along the rostrum and posteriorly. The relationship of the radius of the antirostrum and the standard length of the fish for S. sutor is shown in fig. 4.1. This relationship is given by the equation $y = 2.11 + 0.12x$ ($r = 0.87$, d.f. 41, $P < 0.01$). The number of daily bands on the sagitta of S. sutor were counted along the antirostrum and the relationship to the length of the fish is shown in fig. 4.2.

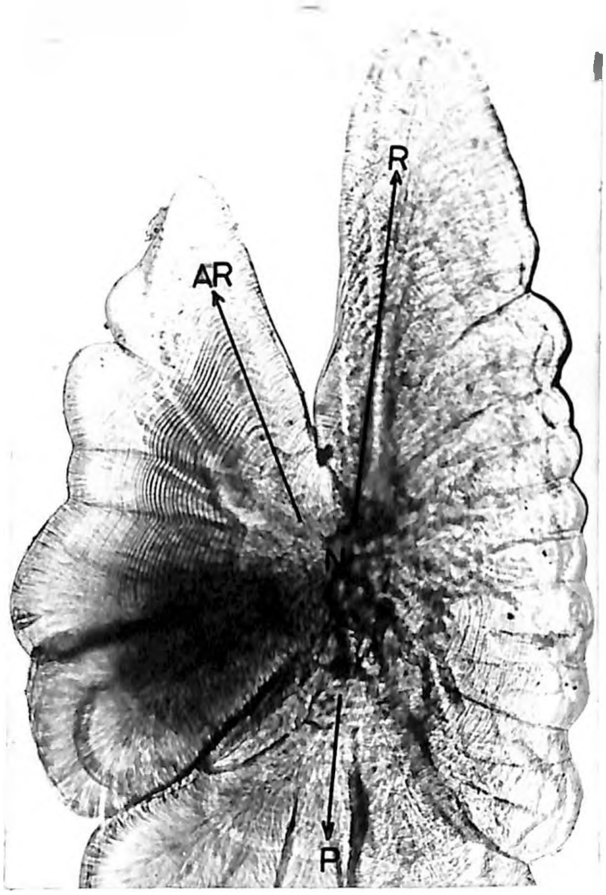

Plate 4.1: The anterior portion of the sagitta of S. sutor. Distinct rings are visible on the antirostrum (AR). R - rostrum; P - posterior (rounded). From fish of 8.2 cm standard length. (x 63).

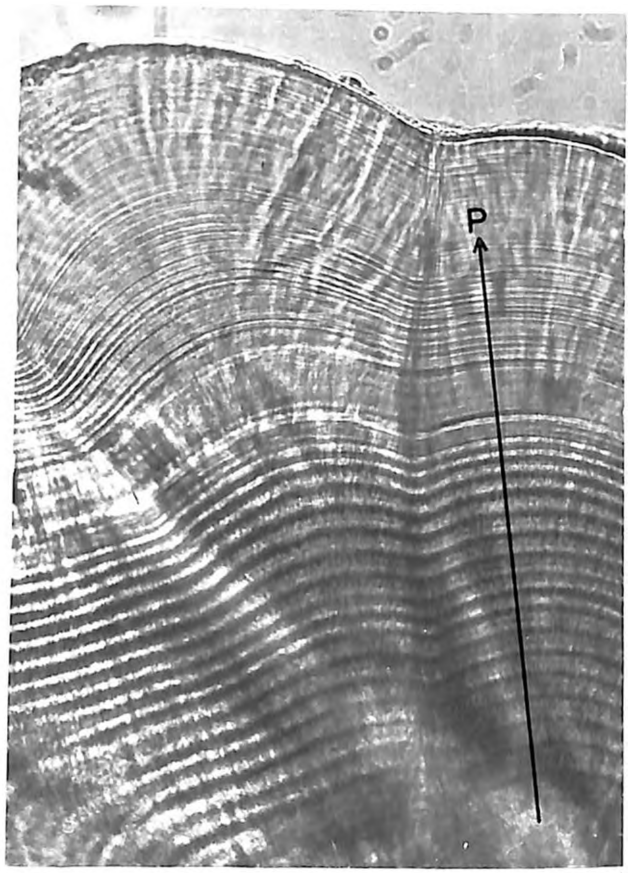

Plate 4.2: Towards the periphery (——→ P) along the antirostrum the daily growth rings are closer with narrower inter-band distance. (x 400).

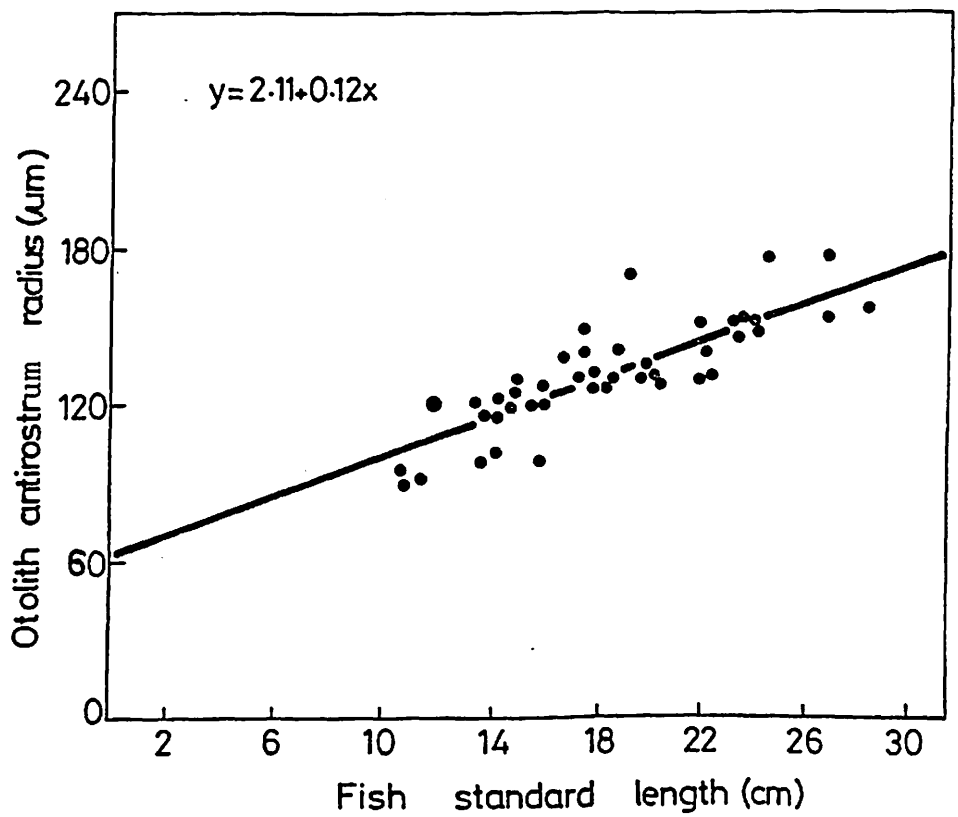

Fig. 4.1: The relationship between the antirostrum radius and the standard length of S. sutor.

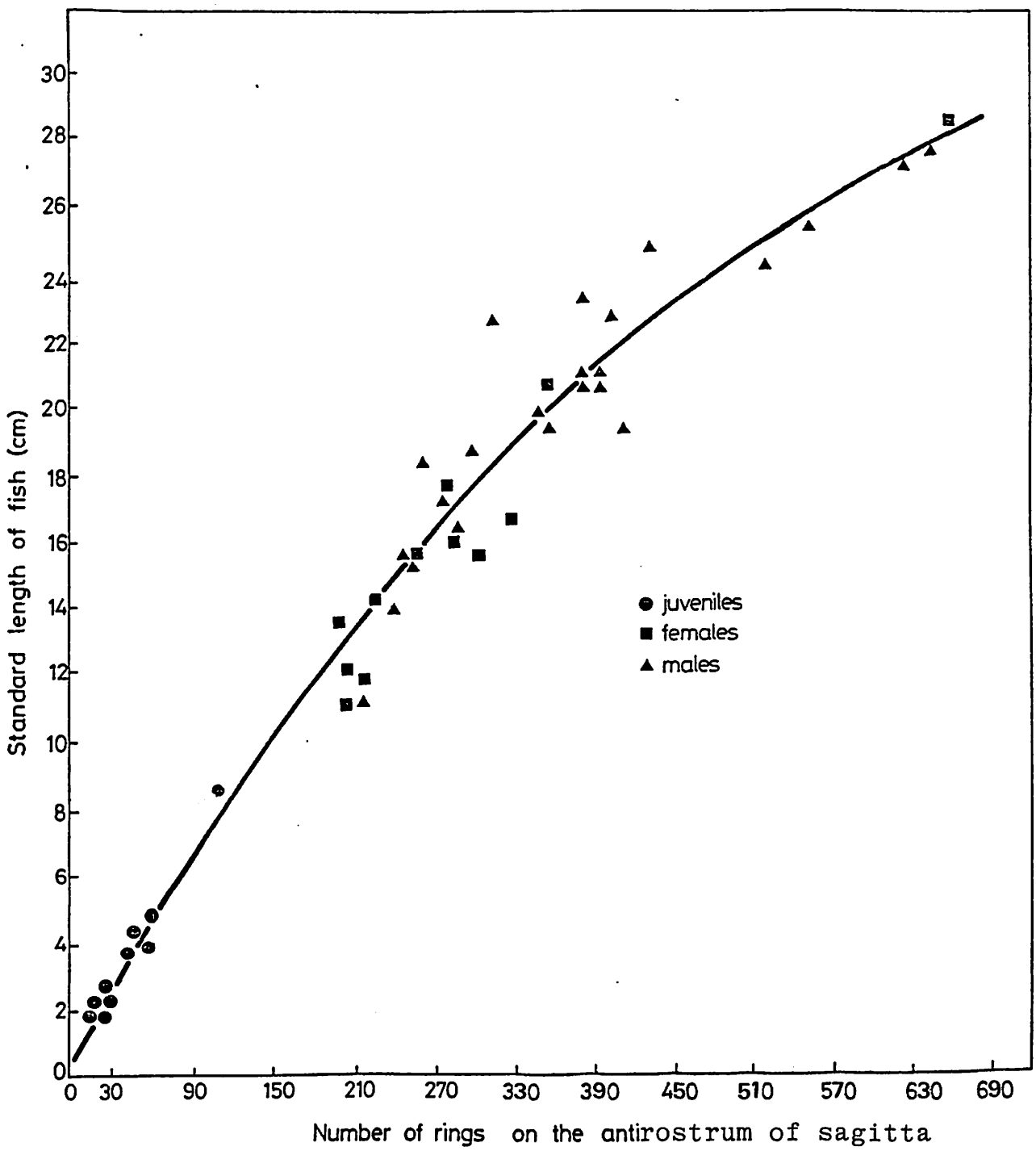

Fig. 4.2: Fish length against number of daily primary increments on the sagitta of S. sutor.

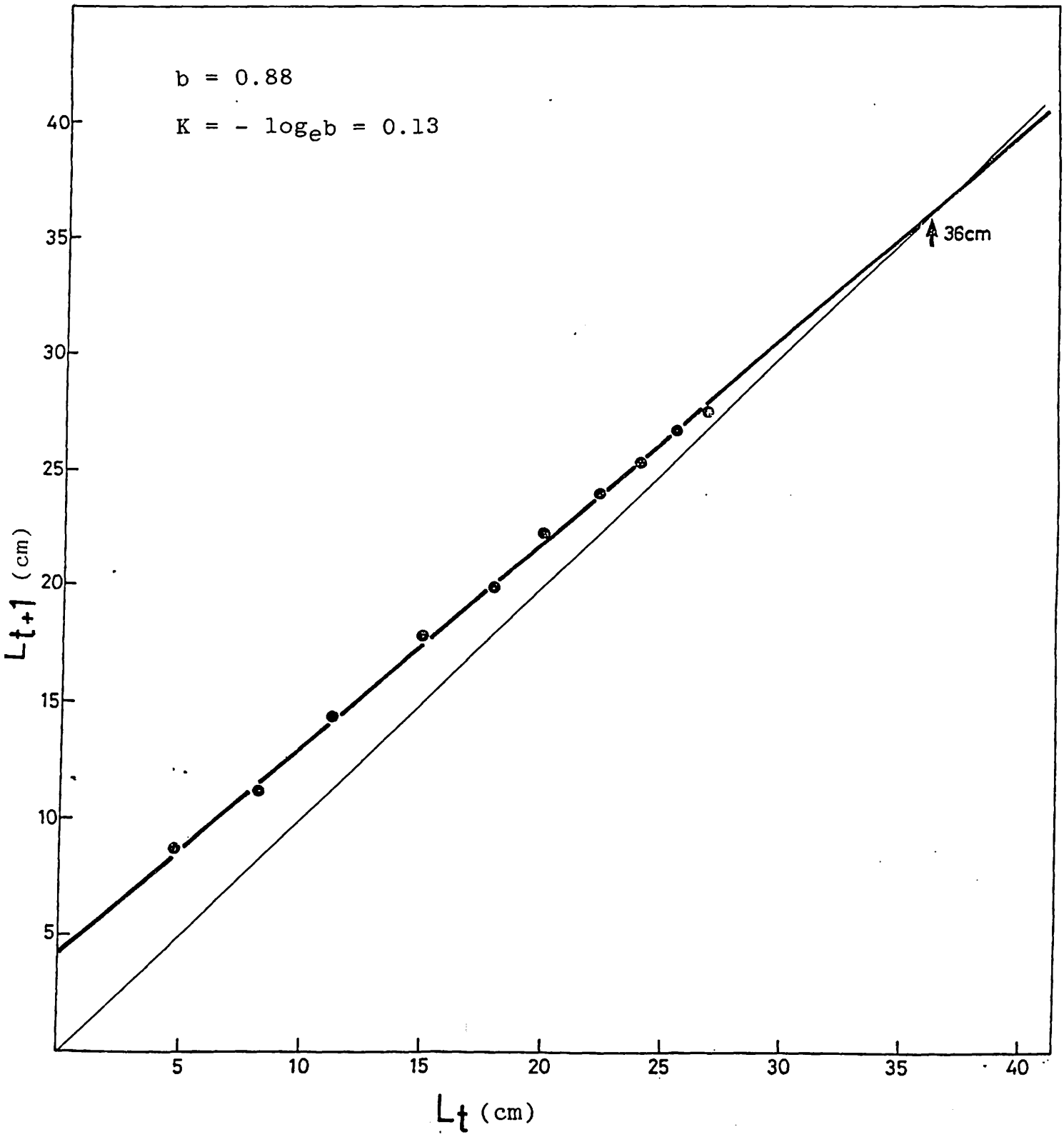

Fig. 4.3: A Ford-Walford plot for S. sutor. The L_∞ from this plot is at 36.0 cm standard length.

A Ford-Walford plot with data from fig. 4.2 is shown in fig. 4.3. This figure provides estimates of intercept of a = 4.3 and slope b = 0.88. From this the estimated L_∞ and K for S. sutor at the Kenya coast are 36 cm standard length and 0.13 respectively.

4.4 Discussion

Juveniles cultured in the laboratory did not show distinct growth rings for the time they were cultured, so it proved impossible to validate the daily basis of ring deposition by determining the number of rings deposited in a given duration in the laboratory. Perhaps the reason for this is due to the continuous lighting the aquaria were kept. If the deposition of the rings is affected by light directly or indirectly then the continuous lighting that was provided to the aquaria at K.M.F.R.I. might probably have affected the daily pattern of ring deposition. However, Pauly (personal communication) states that work on a Siganus sp. at ICLARM shows that such growth increments on the otolith were found to be deposited on a daily basis.

Fig. 4.1 shows that there is a linear relationship between the standard length of the fish and the otolith radius. Results in fig. 4.2 show that there are

clusters of the numbers of rings at various parts of the curve. These clusters are very distinct for the juveniles. The smallest juveniles collected in February 1985 show a ring count of between 21 to 60. Assuming that these are deposited at a rate of one a day these juveniles are between three to eight weeks old, that is, the oldest of these were spawned in December 1984. It appears from the length frequency distribution of the juveniles that they come in cohorts. There is an indication in fig. 4.2 of a grouping of ring counts which may be a reflection of different cohorts. If this indication is valid then the first two cohorts consist of an earlier one with a mean ring count of 25 ± 1 (s.e.m.) while the second one has got a mean ring count of 52 ± 2 (s.e.m.). For the adult fish there seem to be clusters of ring counts at about 210, 270, and 420. Fig. 4.2 also shows the expected pattern of growth changes where the growth rate is greater when an animal is young and then slackens with age.

For S. sutor at the Kenya coast an estimated L_∞ of 36 cm standard length and K of 0.13 have been obtained by plotting a Ford-Walford plot (fig. 4.3). The largest fish observed in the sample from which the assessment is made is 28.6 cm standard length. The largest fish caught during the period this work

was in progress measured 33.4 cm standard length. The L_∞ that has been estimated for S. sutor in the present work is about 10% larger than the largest fish sampled and this lies within the limits of 5-20% which is used as a standard (Pauly, 1980).

From the FAO species identification sheets, Fishing Area 51, Vol. IV, the L_∞ for S. sutor is 45 cm total length. De Souza (in press) has related the standard length (SL) and the total length (TL) for S. sutor with an equation of the form

$$\text{Log}_{10}SL = 0.9891 \log_{10}TL - 0.0858$$

Using this equation the L_∞ for S. sutor in terms of total length in the present work is 45.7 cm. The L_∞ for S. sutor given in the FAO Species Identification Sheets is 35.4 cm in terms of standard length. This therefore means that the L_∞ for S. sutor obtained in the present work agrees very well with what is stated by Woodland (1985) in the FAO Species Identification Sheets, Fishing Area 51, Vol. IV. This is a confirmation that the rings that were counted on the otolith of S. sutor are actually daily bands. Should these rings have not been deposited with a daily periodicity the growth curve shown on fig. 4.2 would have resulted in a wrong L_∞ and a different K. The L_∞ for S. canaliculatus is 25.2 cm total length and has a K value of 1.87 in the southern

Negros, Philippines (Pauly, 1980). This is another confirmation that the commonest siganid species we have at the Kenya coast is really not S. canaliculatus but S. sutor.

All in all the importance of such growth studies is to enable us to make generalized description of the pattern of growth, compare growth among species or of species at various times and places. The present study provides important growth parameters which can be used in the assessment of the siganid stocks in Kenya.

CHAPTER 5

5. LENGTH-WEIGHT RELATIONSHIP AND CONDITION FACTOR

5.1 Introduction

Fish length is more rapidly, easily, and correctly measured in the field than weight. In addition back calculations of past growth from scales and other bony structures of fish usually yield data on length. It is therefore more convenient and more useful to measure the length of fish in a sample and then later determine the weight from a regression equation of weight on length (Le Cren, 1951). Length-weight relationship of fish is generally expressed graphically by plotting the observed lengths and weights as a dot diagram on double logarithmic paper. Such logarithmic transformation of length-weight relationship gives a straight line relationship but obviously with some scatter due to individual variation.

Individual variations from the general length-weight relationship of fish are studied under the name "condition" and they describe the "degree of well being" of fish (Tester, 1940; Le Cren, 1951). According to Tester (1940) condition factors calculated on the basis of weight and length alone are not a satisfactory index of fatness and hence

described a new index, "fat factor" (F), which is related to the specific gravity (G) of a fish by the equation $F = G/(G - 1)$. Changes in condition of fish have, however, been analysed by means of condition factor and the fat factor of Tester (1940) has not been much used by subsequent workers.

5.2 Material and Methods

The data used for length-weight relationship and condition factor is obtained from fish samples that were taken on a monthly basis throughout this work. The fish were caught in dema traps.

The standard length, distance from the anterior part of the snout or upper lip to the caudal base (junction of hypural bone and caudal fin rays) in a straight line was measured on a measuring board to the nearest millimeter. The total body weight of the ungutted fish was weighed to the nearest gramme using a top loading balance.

Fish in monthly samples were separated into males and females and the length-weight relationship for each sex plotted. Also a logarithmic transformation of length and weight for each sex was done and were plotted to give an equation of the form $\text{Log } W = \log a + b \log l$ according to Le Cren (1951) and

Bagenal (1978). In this equation:-

a = the intercept of the line on y - axis.

b = regression coefficient representing the slope of the line.

W = weight

l = length.

An analysis of covariance showed that there was no significant difference between the linear regression of weight and length for both sexes, $F = 1$; d.f. 38, 38; $P > 0.05$ (Snedecor & Cochran, 1967). Having found homogeneity of the residual variances of the two sexes the two slopes were tested for any differences; there was no significant difference between the two slopes, $F = 1.89$; d.f. 1, 76; $P > 0.05$ (Snedecor & Cochran, 1967). This gives a strong justification for combining length-weight data for the two sexes. The log transformation of length-weight data for each month for pooled sexes was regressed; an analysis of variance showed that there was no significant difference between the monthly slopes (b values) throughout the year, $F = 1.14$; d.f. 11, 8; $P > 0.05$. For both sexes the log transformation data was pooled to give one general equation for the whole year. This equation was used to calculate the expected weight, $\hat{W}$, for each individual fish in the pooled annual sample.

To calculate condition factor the length-weight relationship is first calculated and given as in the expression earlier in this section (5.2) and the expected weight, $\hat{W}$, for each fish is calculated from such an expression or simply read off on an accurate graph representing this equation. Relative condition factor was calculated according to Bagenal (1978) using the expression:-

$$K_n = \frac{W}{\hat{W}} \quad \text{where,}$$

K_n = relative condition factor.

W = observed weight

$\hat{W}$ = expected weight.

5.3 Results

5.3.1 Length-weight relationship

The logarithmic transformation of the pooled length-weight data was calculated and given in fig. 5.1 showing a straight line relationship. This is described by the equation $\log W = 2.96 \log l - 1.56$, $r = 0.97$, $P \leq 0.01$., i.e. $W = 0.031^{2.96}$.

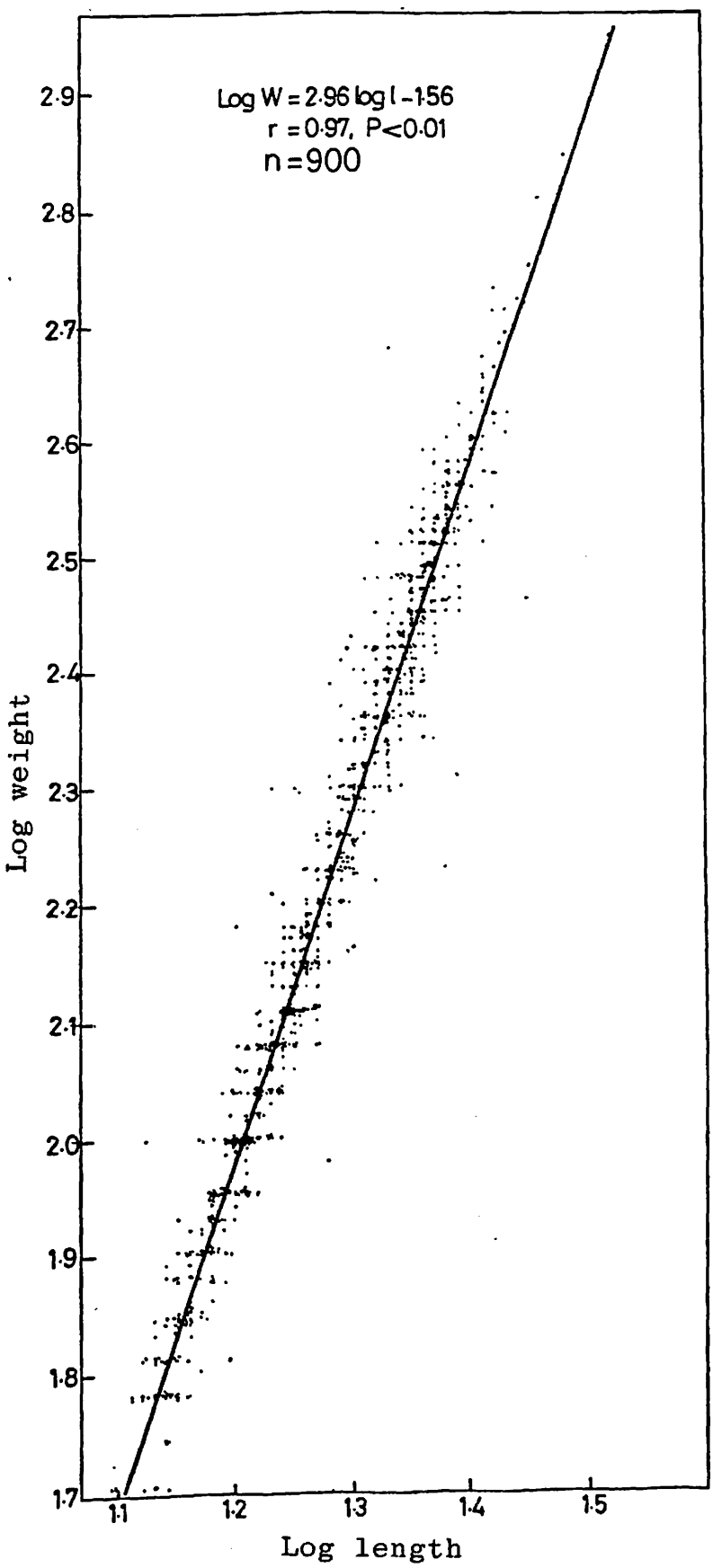

Fig. 5.1: Logarithmic transformation of the length-weight relationship for S. sutor.

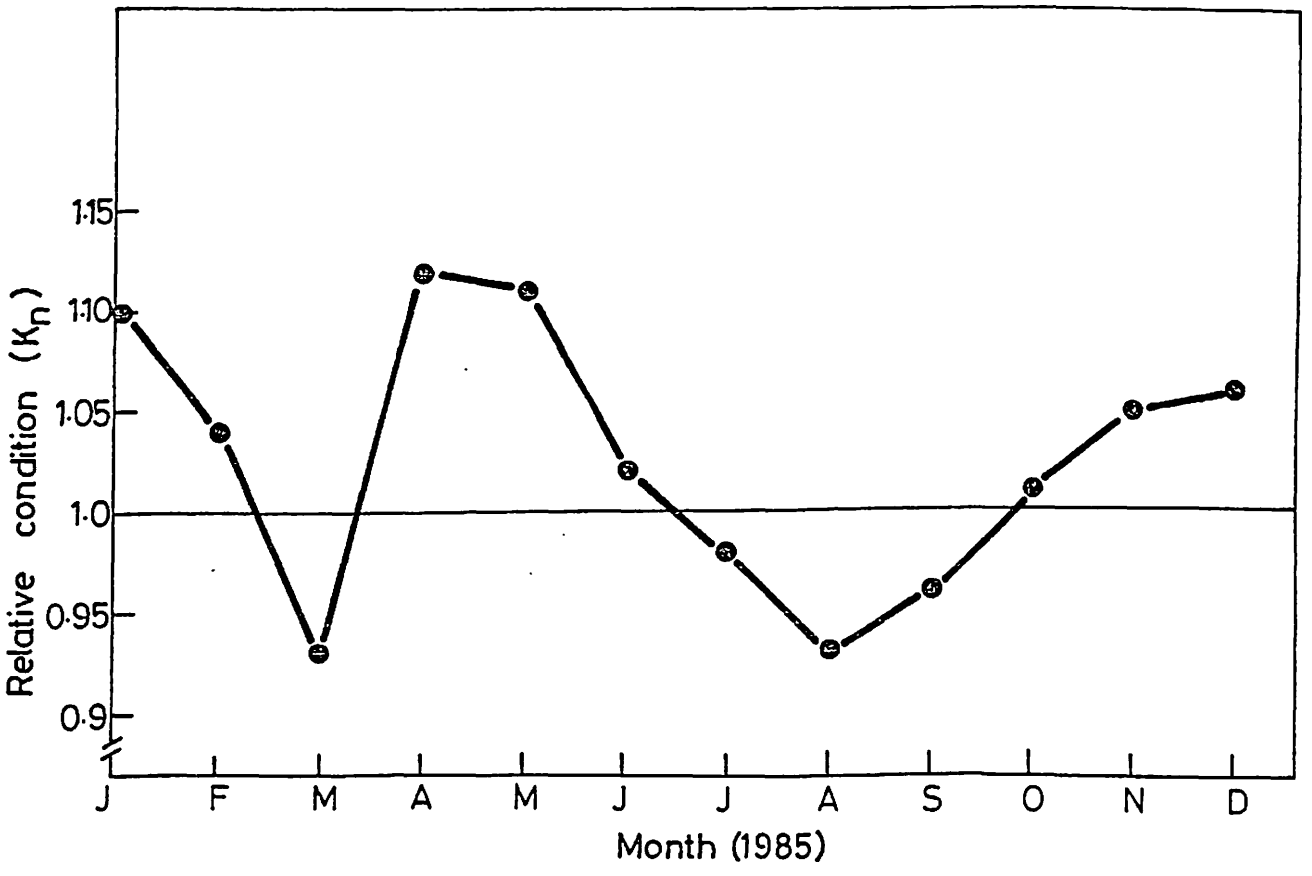

Fig. 5.2: Seasonal variation of the relative condition factor (K_n) for S. sutor. n=900

5.3.2 Condition factor

The monthly relative condition factor of S. sutor was calculated and plotted in fig. 5.2.

5.4 Discussion

Allen (1938) advocated a cube law relationship between length and weight in which the b value is equal to 3, in an ideal fish that maintains its shape. The general b value for S. sutor throughout the year is 2.96 (fig. 5.1). Since the monthly b values showed no significant difference ($F = 1.14$; d.f. 11, 8; $P > 0.05$) this value can be taken with confidence. According to Le Cren (1951) rarely is the b value equal to 3 in many fishes worked upon and that most species of fish progressively change their shape as they grow. Since the monthly fluctuations of b value for S. sutor is close to 3 it appears that throughout their life time they do not change greatly in shape as growth proceeds. Also there is no difference in shape between the male and female S. sutor.

Workers dealing with fish believe that the heaver fish of a given length is in better condition (Bagenal, 1978). Several condition factors have been used but Fulton's condition factor (K) has found wider application (Bagenal, 1978). But this factor

is affected by several variables such as those correlated with length, those associated with selective sampling and by the features of the environment like food supply, degree of parasitization e.t.c. In view of all these variables affecting K, relative condition factor, K_n, was calculated for S. sutor (Le Cren, 1951, Bagenal, 1978, Nair et al., 1983). Weatherley (1972) outlines the relative merits of calculating K as compared to that of calculating K_n. But according to Le Cren (1951) and Bagenal (1978) K_n, unlike K which only measures the deviation of an individual fish from the average weight for lengths, is a measure of the deviation of each fish from a hypothetical fish.

A relative condition factor of 1.0 and above shows that the fish are in good condition. According to Nair et al., (1983) immature first maturity stages and almost senile fish show K_n values below 1.0 while the actively breeding adults show higher K_n values. The results given in fig. 5.2 indicate K_n for S. sutor is below 1.0 in March, July, August and September and above 1.0 in the other months of the year. The first sharp drop of K_n value in March is obviously after the January/February spawning. The K_n value then rapidly peaks again in April and starts falling fairly slowly into May.

A rapid fall in K_n then follows into June and is 0.98 in July. This drop in K_n obviously points to a second spawning season during the months of May/June. K_n value is again lowest in August with a value that corresponds to that of March earlier in the year. The K_n then starts rising and is only slightly above 1.0 in October. The month of October probably marks a time when rapid recovery of most spent fish that are quiescent from July (after the second spawning) and perhaps from March (after the first spawning) occurs. This period also probably marks a time when most virgin fishes are maturing for the first time and therefore joining the other recovering adults in preparation for the next spawning early in the year. Following all this it is apparent that during the spawning season fish expend most of their energy on spawning purposes and thus the fall in K_n at such times. In this work, therefore, K_n seems to be a sensitive index of the breeding seasons obviously with minor deviations. Nair *et al.*, (1983) made similar observations in the tropical glassy perchlet *Chanda* (= *Ambassis*) *commersonii* (Cuv. and Val.) in India.

CHAPTER 6

6. THE GONAD MATURATION CYCLE

6.1 Introduction

The reproductive biology of the siganids at the Kenya coast has received relatively little study (Nzioka, 1979). Cyrus and Blamber (1983) point out that the study of the gonad maturation in teleosts has been largely concerned with species occurring in temperate regions and only very few detailed investigations of tropical species have been done. This is confirmed by James, 1946; Bowers & Holliday, 1961; Mackay & Mann, 1969; Macer, 1974; Emery & Brown, 1978; Wootton & Mills, 1979; Abu-Hakima, 1984. Among works relating to tropical species there are the following:- Turner, 1919; Yamamoto, 1956; Nair, 1958; Yamamoto and Yoshioka, 1964; Dadzie, 1974; Guraya *et al.*, 1975; Monaco *et al.*, 1978 and Geevarghese & John, 1982. Nzioka (1981) gives an account of gonad maturation of a marine species, *Scolopsis bimaculatus* Ruppell, based on macroscopic examination of the gonads.

The work done on the siganids (George, 1972; May *et al.*, 1974; Bryan *et al.*, 1975; Kami & Ikehara, 1976; Von Westernhagen & Rosenthal, 1976; Hasse *et al.*, 1977 and Gundermann *et al.*, 1983) contains no details on gonad maturation.

6.2 Material and Methods

The standard length of all the fish for routine sampling was measured on a fish measuring board and a random subsample of 50 fish was taken for further analysis. Sex, total body weight, total gonad weight, gonad length and width and length of gonad duct behind the posterior tip of the gonad was determined. The appearance of the gonad-texture and colour-was recorded and for each fish in the subsample a maturity stage was assigned by inspection using a modified Nikolsky (1963a) method.

Preliminary analysis of variance showed that there was no significant difference between the right and the left ovary and between various antero-posterior regions of the ovary. For all subsequent analysis a small portion of the ovary was cut from the mid-region, weighed to the nearest 0.01g and preserved in Gilson's fluid for fecundity counts. The rest of the ovary was preserved in Smith's formol dichromate and sometimes in Bouin's fixative for histological study. The relative weight of the gonad to the body weight- Gonadosomatic Index (GSI)- was calculated using the formula:-

$$GSI = \frac{\text{weight of whole ovary}}{\text{weight of fish - weight of ovary}} \times 100$$

Size at first maturity was calculated by taking the percentage occurrence of male and female S. sutor in different stages of maturity in various size groups and then take size at first maturity as the length at which 50% of all the fish are mature. Monthly sex ratio for S. sutor was also determined.

6.3 Results

6.3.1 Sex ratio

The percentage of males and females in monthly samples was calculated and given in table 6.1. The variance test for homogeneity of the binomial distribution (Snedecor & Cochran, 1976) showed that there was no significant difference between months in sex ratio (X^2 = 10.511; d.f. 11; P ≃ 0.5). The overall sex ratio for the whole year does not depart from 1:1 (X^2 = 0.11; d.f. 1; P > 0.5).

6.3.2 Gonad maturity stages

Different workers use different gonad maturation staging schemes (Bowers & Holliday, 1961; Dadzie, 1974; Macer, 1974). The scheme of staging gonadal development in this work is based on that of Nikolsky (1963a) and consists of six stages. The description of maturity stages for both male and female S. sutor is given in table 6.2. The criteria for assigning

Table 6.1: Sex ratio of S. sutor in monthly samples January - December 1985

Month	Total no. of fish examined	No. of females	No. of males	% of females	% of males	Sex ratio female: male
January	28	16	12	57.14	42.86	1:0.75
February	34	18	16	52.94	47.05	1:0.89
March	50	27	23	54.00	46.00	1:0.84
April	73	39	34	53.42	46.58	1:0.87
May	125	62	63	49.60	50.40	1:1.02
June	63	31	32	49.21	50.79	1:1.03
July	90	43	47	47.78	52.22	1:1.09
August	171	75	96	42.86	56.14	1:1.31
September	102	48	54	47.10	52.90	1:1.12
October	47	24	23	51.10	48.90	1:0.96
November	85	51	34	60.00	40.00	1:0.67
December	36	13	23	36.10	63.90	1:1.80
Total	904	447	457	49.45	50.55	1:102

Table 6.2: The maturity stages of the gonads of S. sutor.

Maturity stage	Testis	Ovary	
	Macroscopic appearance	Macroscopic appearance	Microscopic criteria
1 Virgin	Small and flat, smooth, translucent; colourless to light grey. No blood vessels visible. Testis length/width ratio of 10, extends for 35% of the abdominal cavity.	Small, rounded, surface rough, translucent. No oocytes visible through ovary wall. No blood vessels. Ovary length/ width ratio of 8; extends for less than 50% of the abdominal cavity.	Few oocytes larger than 90 µm, oocytes have a thin densely staining cytoplasm; no cytoplasmic vacuoles; large rounded nucleus with many small nucleoli. Oocytes are irregularly shaped with no defined cell membrane. Oocytes are arranged in ovigerous lamellae. Ovary wall < 15 µm thick.
2a Developing virgin	Small, flat, smooth and soft in texture as compared to 2b fish. Tiny blood vessels	Small, rounded with a rough surface and soft in texture. Translucent with tiny blood	Few oocytes larger than 120 µm; oocytes have a densely staining cytoplasm. No cytoplasmic

	start forming. Testis length/width ratio at a mean of 3.5; gonad extends for 44% of the abdominal cavity.	vessels forming internally. No oocytes visible through ovary wall. Ovary length/ width ratio of 3; gonad extends for $\simeq$ 50% of the abdominal cavity.	vacuoles; cells have a large rounded nucleus on the periphery of which are several nucleoli two of which are quite large. Oocytes are irregularly shaped but few are rounded. Oogonia visible in between resting oocytes; oocytes arranged on ovigerous lamellae. Ovary wall is about 50 µm thick.
2b Resting and recovering (mature fish)	Same as 2a but tough in texture, deep brown in colour and just slightly larger than 2a lengthwise; an apparent cavity in the centre of gonad.	Soft and flabby with a cavity at the centre of the gonad. Greyish in colour and no oocytes visible through ovary wall.	Same as 2a but residual atretic oocytes present and the septum not very organized. Reorganization of ovigerous lamellae starting.

3 Early developing	Becoming broader, smooth, light brown. Waterly milt comes out at cut regions. Blood vessels (internal) visible through testis wall. Gonad length/width ratio of 2.8 and gonad extends for 53% of the abdominal cavity.	Becoming broader with a rough texture, whitish. Tiny oocytes visible through ovary wall. Dense net work of blood vessels visible internally through the ovary wall. Ovary length/width ratio of 2.5 and gonad extends for ≃50% of the abdominal cavity.	Many oocytes larger than 120 µm to a maximum diameter of 210 µm. Stage I, II and III oocytes present. Large oocytes have cytoplasmic vacuoles and some have started acquiring yolk. Larger cells are rounded and have a small nucleus relative to size of cytoplasm. Some oocytes have a doubly staining cytoplasm and there is a rich supply of blood vessels. Oocytes are arranged in well organized ovigerous lamellae. Large oocytes start forming a definite chorion. Ovary wall is about 360 µm thick.

4 Late developing	Broad and firm in texture; smooth, flat, light grey and thick bloody milt comes out on cutting. Lobulations of the right and left testis starts. Length/width ratio of 2.4 and gonad extends for 92% of the abdominal cavity.	Becoming broader, firm, granular and rounded. A heavy network of blood vessels now appears externally on the surface of the ovary wall. Large yellow oocytes visible through the ovary wall. Ovary length/width ratio of $\simeq 2$ and gonad extends for about 90% of the abdominal cavity.	Many oocytes between 210-450 µm. A mode of large oocyte appears at 370 µm. Stage II, III and IV oocytes present in various proportions. Many cells with cytoplasmic vacuoles and many of the largest oocytes are filled with red staining yolk granules. Chorion of the largest cells is well defined and starts becoming striated. Organization of ovigerous lamellae still apparent although disappearing and some yolky oocytes are undergoing active atresia. Ovary wall about 120 µm thick.

5 Ripe and sometimes running	Broadest and firm although some are flaccid (perhaps have already lost some milt prior to arriving in the lab.) Flat, smooth and highly lobulated. Completely white but the posterior tips sometimes grey with white speckled appearance. No blood vessels and thick milt comes out on slight pressure. Testis length/width ratio of 2.2 and it extends for 99% of the abdominal cavity.	Broadest and firm-where shedding of eggs has not yet commenced-otherwise soft. Rounded and with a rough granular surface. Blood vessels join up to form larger ones on the external surface of the ovary wall. Yellowish in colour possibly due to the large yellow oocytes that are visible through ovary wall. Ovary length/width ratio $\simeq$ 2 and and ovary extends for 99% of the abdominal cavity.	Many oocytes between 210-560 µm. A mode of large oocytes at 460 µm. Many oocytes are in stage V and II but a few others are in stage III and IV. Many of the largest cells have densely staining yolk granules in the cytoplasm and have a well defined striated cell membrane. There are no blood vessels internally but some of the yolky oocytes are atretic. Ovary wall about 90 µm thick.

6 Spent	Reduced in size and sometimes really small, flaccid and hard in texture. Flat, lobules disappearing. Dark brown in colour and no blood vessels visible; no milt. Testis length/width ratio of 3.2 and gonad extends for 56% of the abdominal cavity.

Reduced in size, flaccid but ovary wall is tough and smooth (no granulation). Round to ovoid in shape. Reddish in colour. Residual oocytes are visible through flabby wall. Ovary length width ratio is 2.5 and gonad extends for 50% of the abdominal cavity.	Many oocytes between 30-90 µm, and the largest oocytes are 180 µm in diameter. Small oocytes have a thin densely staining cytoplasm. A few atretic residual oocytes present. Invasion of oocytes by follicular cells and a dense net work of blood vessels indicate a high level of oocyte atresia. Septum disorganized; no definite empty follicular coats. Ovary wall 300 µm thick.

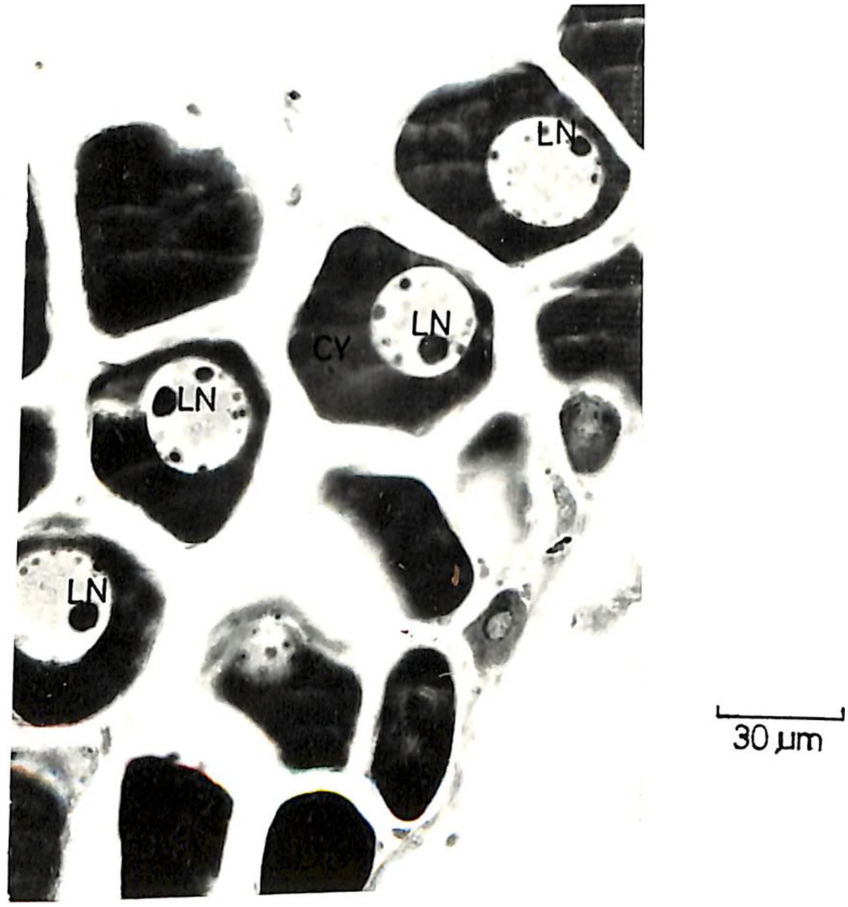

Plate 6.1: Darkly staining cytoplasm (CY) and presence of several nucleoli of which one is usually larger (LN) than the rest in stage II oocytes of S. sutor.

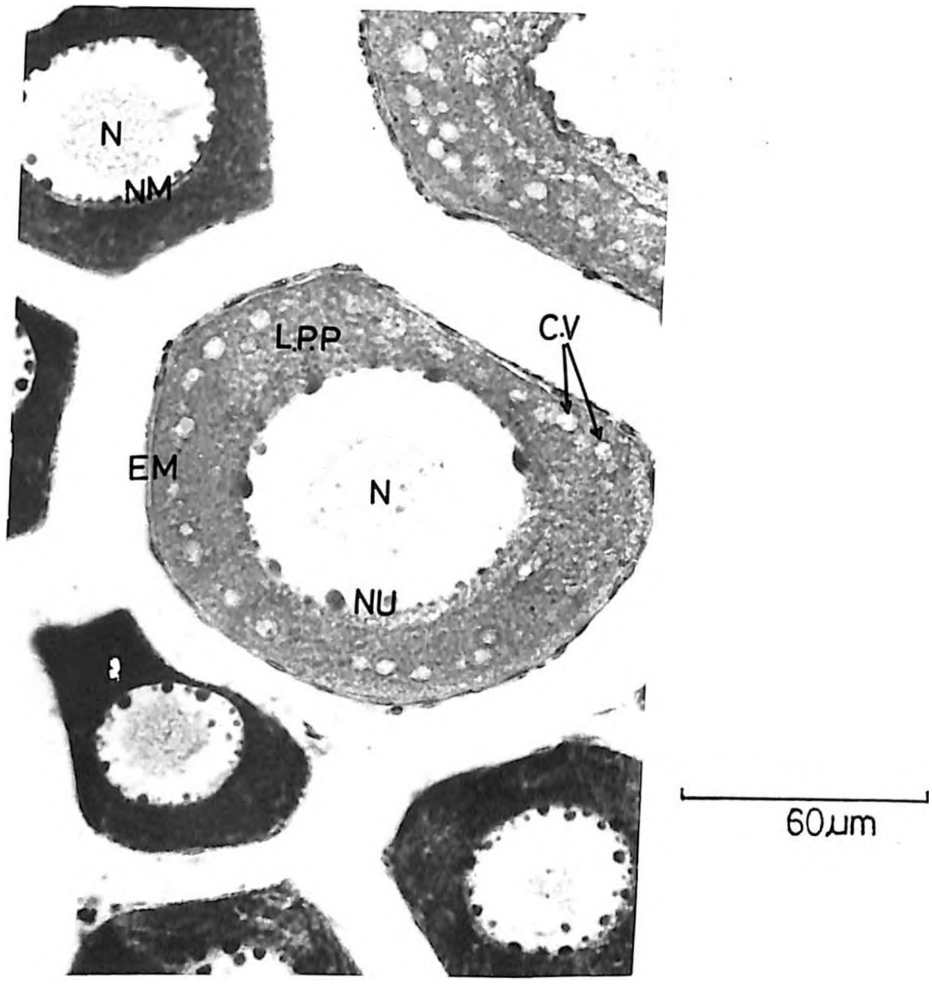

Plate 6.2: Stage II and stage III oocytes. The egg membrane (EM) and cytoplasmic vacuoles (C.V) are distinct in stage III cells. The cytoplasm is lighter staining in stage III cells than in stage II cells. N-nucleus; NU-nucleoli: NM-nuclear membrane.

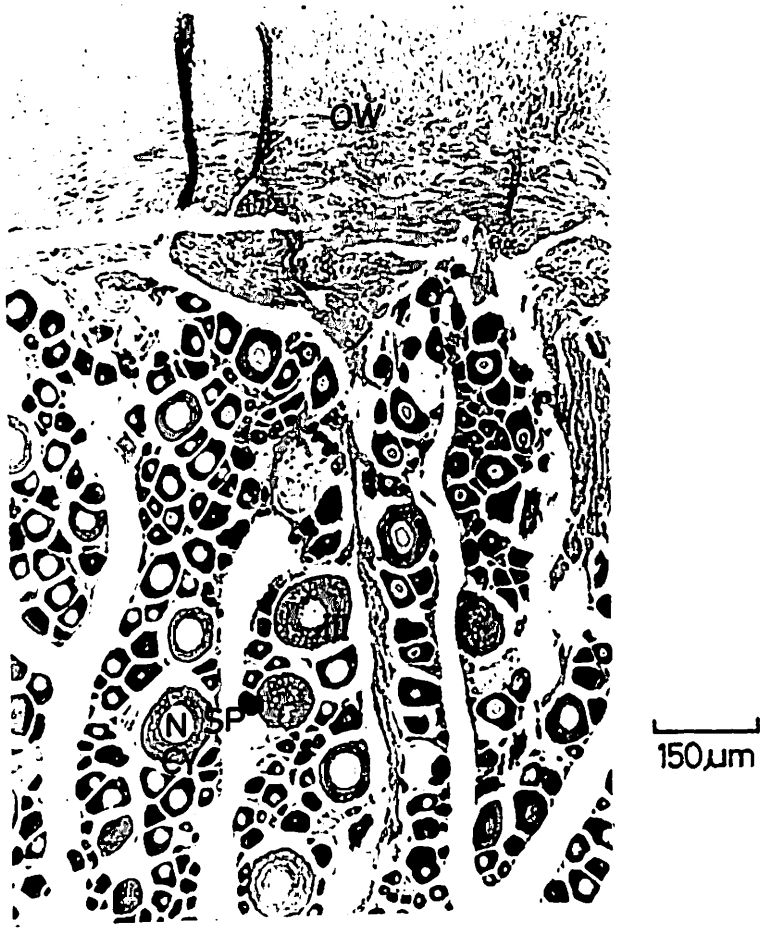

Plate 6.3: The salient features of a stage 3 ovary: a thick ovary wall (OW), organized ovigerous lamellae and septum (SP), a few large cells in stage III with cytoplasmic vacuoles in the cytoplasm (CY). The majority of cells are in the earlier stages.

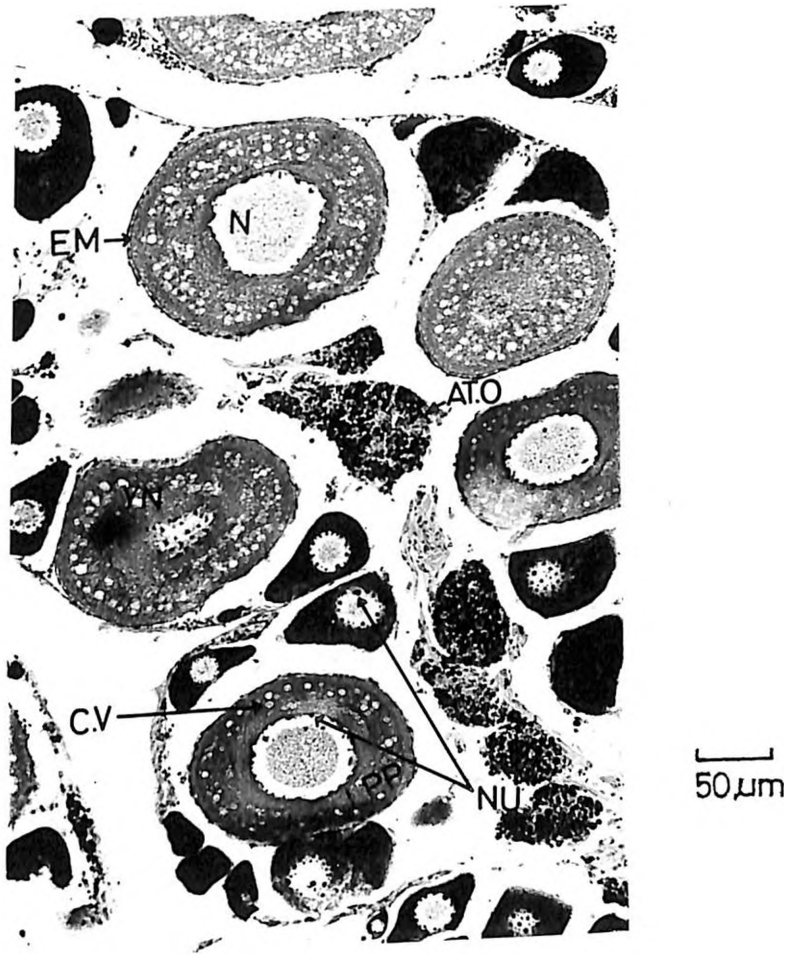

Plate 6.4: High level atresia in a stage 3 ovary of S. sutor. ATO-atretic oocyte ; YN-Yolk nucleus.

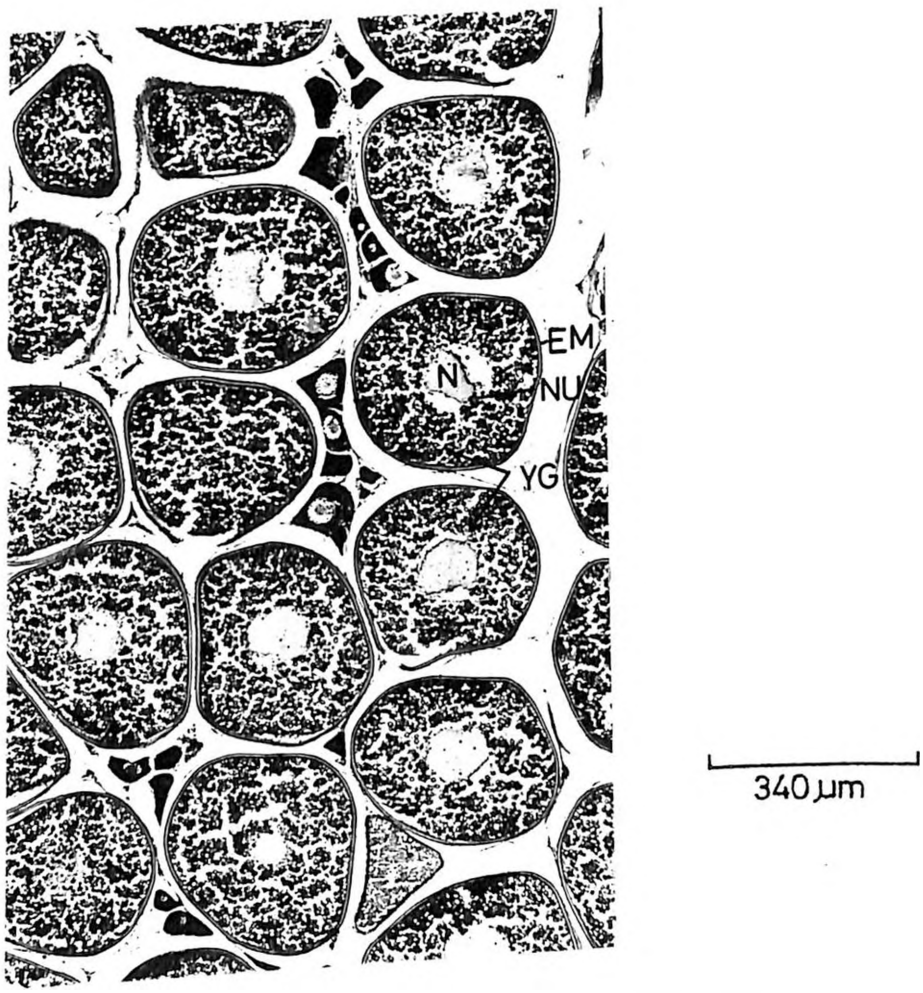

Plate 6.6: Ovary of S. sutor at the peak of development in stage 5. Many oocytes are in stage V - the final vitellogenic stage characterized by many yolk granules (YG) in the cytoplasm; highly developed egg membrane (EM) and migration of the nucleoli (NU) towards the central region of the nucleus (N).

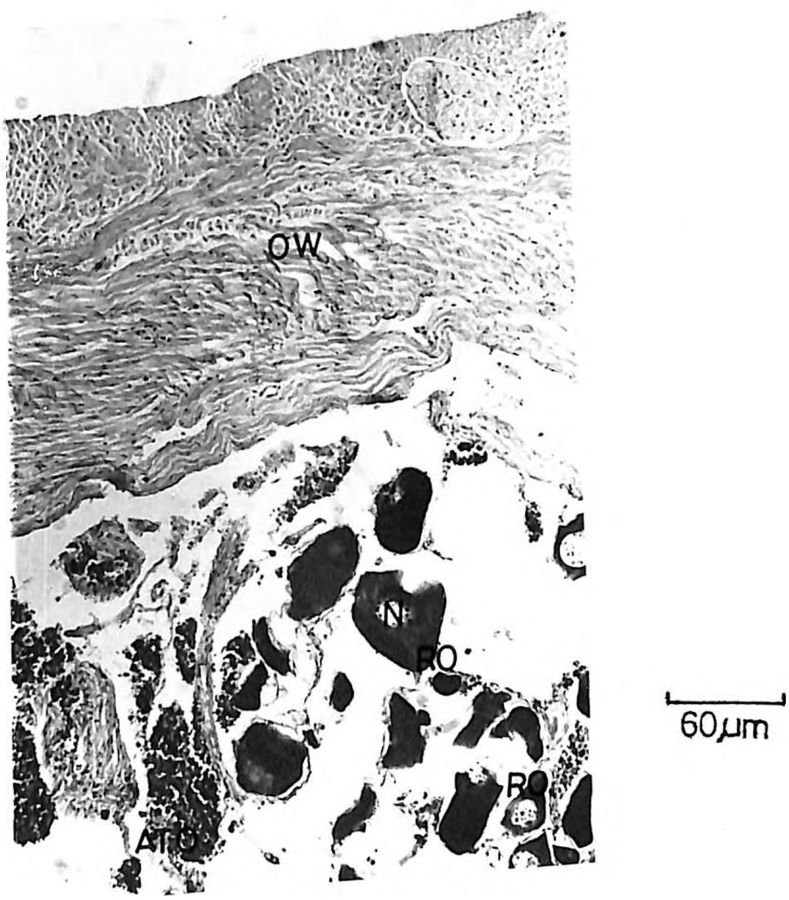

Plate 6.7: The salient features of a spent ovary of S. sutor: a thick ovary wall (OW); total disorganization of the ovigerous lamellae and septum; high level of atresia (AT.O) and many stage II resting oocytes (R.O.)

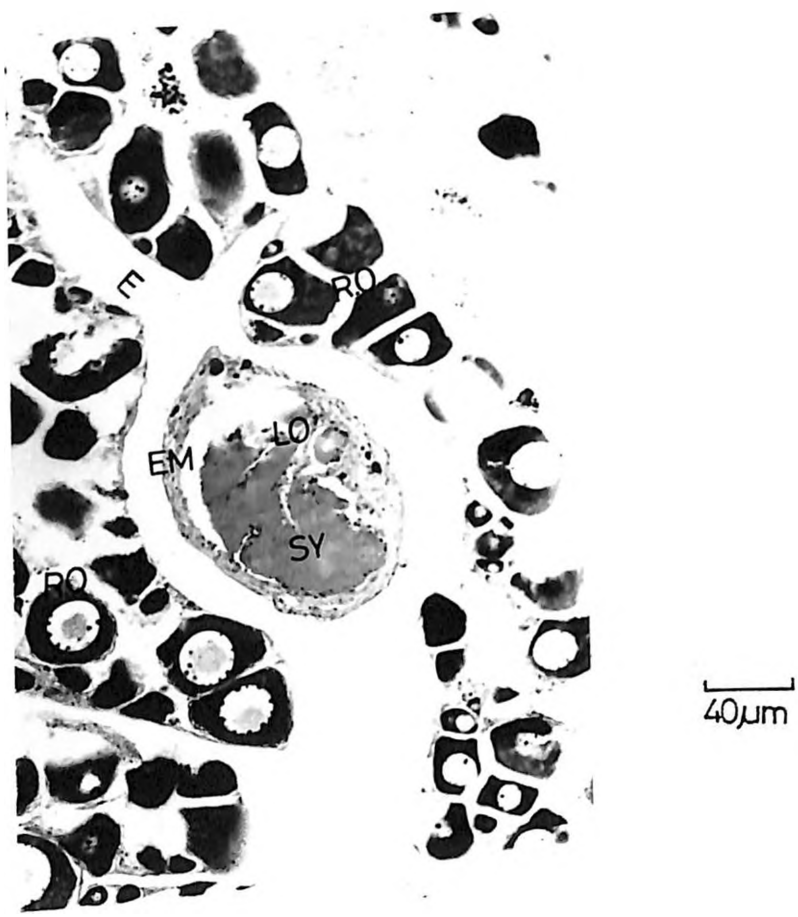

Plate 6.8: Residual oocyte (LO) among resting oocytes is probably an indication of a recent spawning. Note the empty space (E) possibly vacated by this oocyte. Egg membrane (EM) is already invaded by atretic follicular cells and yolk has already started liquefying to form smooth yolk (SY).

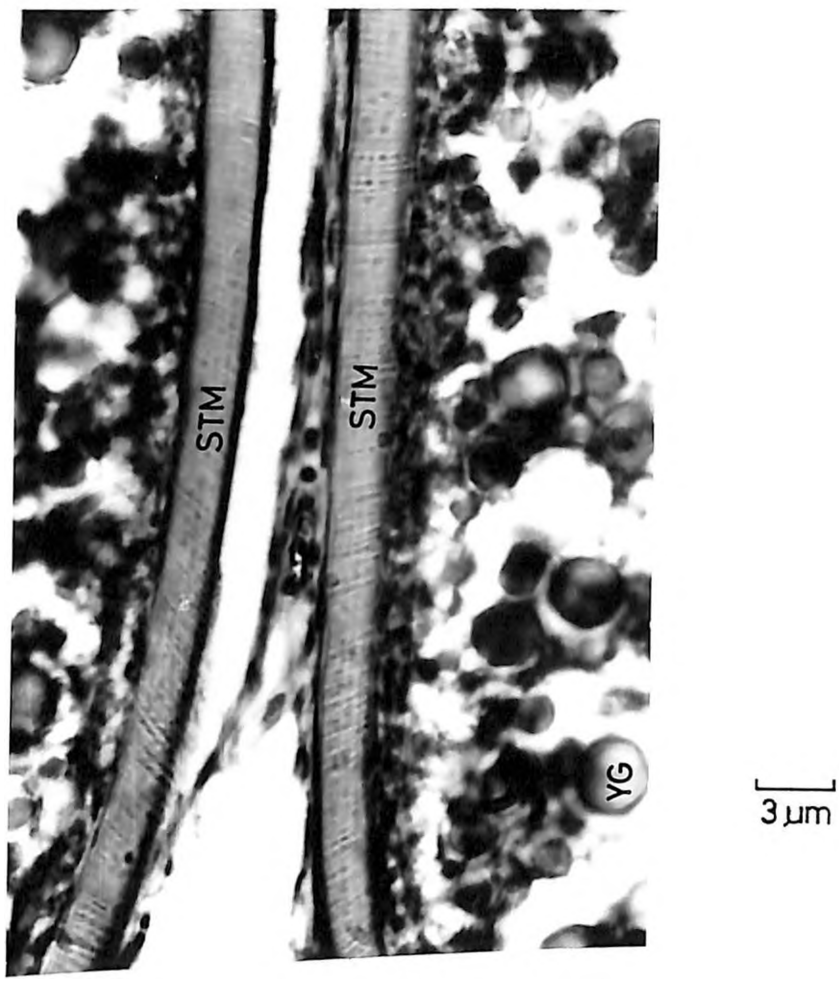

Plate 6.9: Eggs of S. sutor have a complex egg membrane organization such as striations on the radiata (STM). The gelatinous layer of the egg membrane is not developed. YG - Yolk granule.

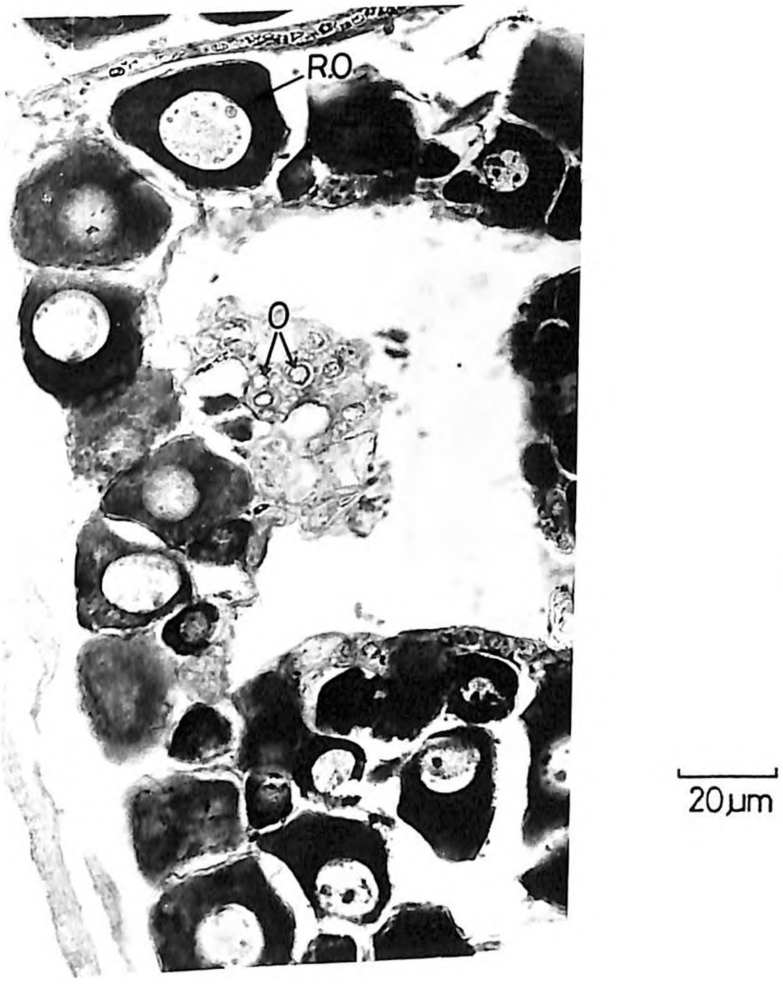

Plate 6.10: A group of oogonia (O) among resting oocytes in a stage 2 ovary of S. sutor. Note that they have a large nucleus and a thin cytoplasm.

the testis to a given maturity stage are macroscopic. In this study the assignment of ovary to individual stages by macroscopic criteria is further validated by histological examination and analysis of oocyte size classes (which will be described in Chapter 7) on Gilson's preservations.

6.3.3 The maturity cycle

Throughout gonadal development, involving oogenesis and spermatogenesis, the gonad undergoes several morphological and physiological changes that can be monitored as changes in weight from the early stages of development into maturation and eventually a decrease in weight after spawning. For all the maturity stages adopted in this work (Table 6.2) changes in the gonad weight as a percentage of body weight are shown in figs. 6.1 and 6.2 for males and females respectively.

6.3.4 Temporal variation in the weight of the gonads

The variation in the weight of the gonads with time can supply information on the main spawning season(s) of fish. Such temporal variation in the weight of the testis and ovary of S. sutor were calculated on a monthly basis, and are plotted in

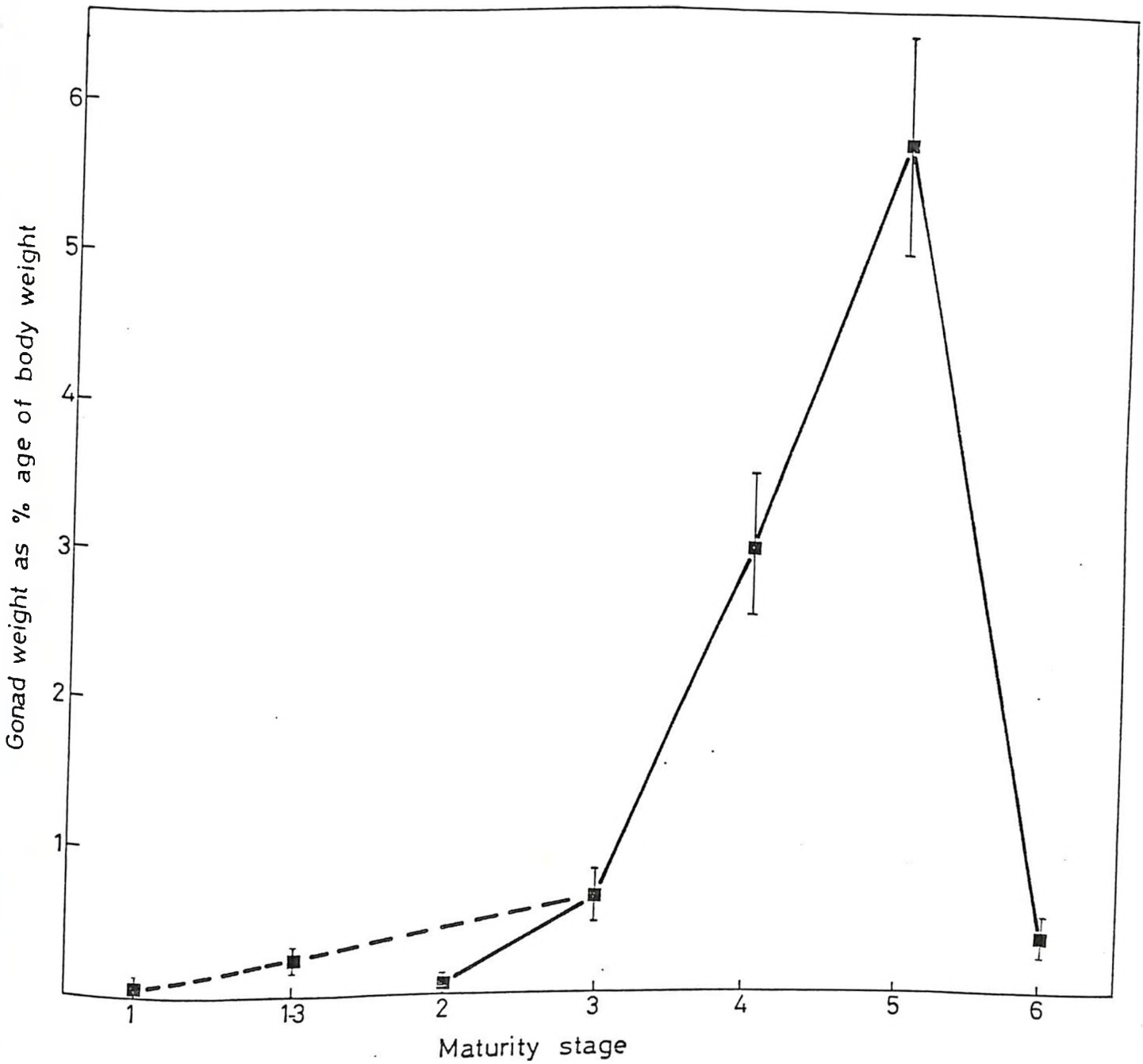

Fig. 6.1: The relationship between relative gonad weight and maturity stage for male S. sutor. Gonads of virgin males developing to stage 3 are shown with the dotted line and indicated as maturity stage 1-3 which is similar to stage 2a described in table 6.2.; vertical bars show $\bar{X} \pm$ s.e.; n = 118.

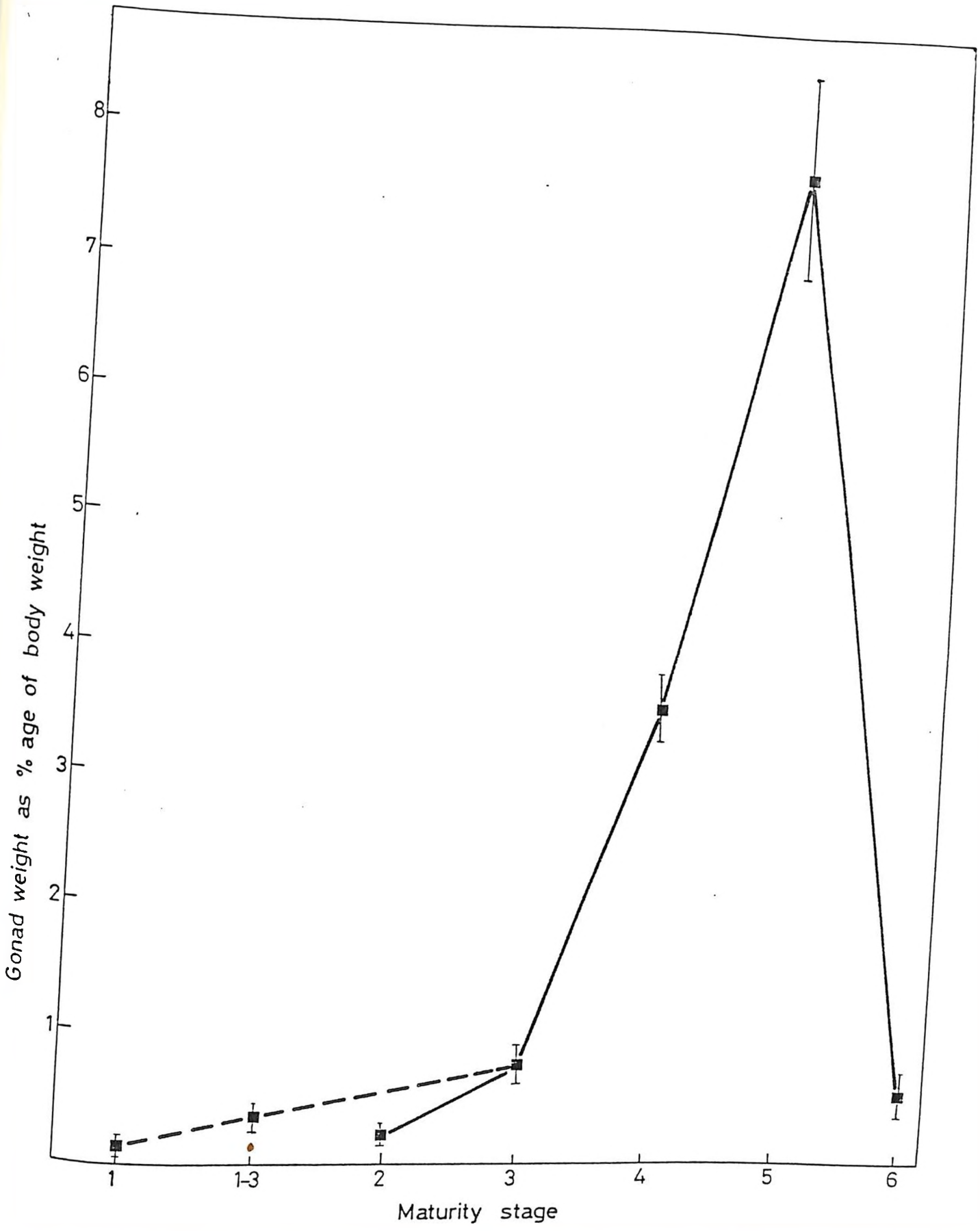

Fig. 6.2: The relationship between relative gonad weight and maturity stage for female S. sutor. Gonads of virgin females are shown with the dotted line and indicated as maturity stage 1-3 which is similar to stage 2a described in table 6.2.; vertical bars show $\bar{x} \pm$ s.e.; n = 114.

figs. 6.3 and 6.4. It is apparent from these figures that there is very strong congruency in the temporal variation in the weights of testis and the ovary. There is an indication too, that the weight of both gonads reach a peak in January and May after which there follows a rapid fall obviously due to spawning processes. It also appears that except for rare occassions there exists a difference between males and females in that from April to November the testis remains at a higher relative weight than the ovary. However, it must be pointed out that owing to the impossibility of continuing sampling at the mouth of Tudor creek from late March to September the single graphs in figs. 6.3. and 6.4 are based on samples from two different sites and as such we might be dealing with different populations. However, there is no jump in the data between February and March and hence if we are dealing with different populations at all their spawning seasons are synchronous.

6.3.5 Annual appearance and abundance of siganid juveniles

The monthly appearance of siganid juveniles, their abundance in single beach-seine trawl and their size ranges is given in table 6.3. This table points to two spawning seasons of S. sutor at the Kenya coast. There are differences in the size of

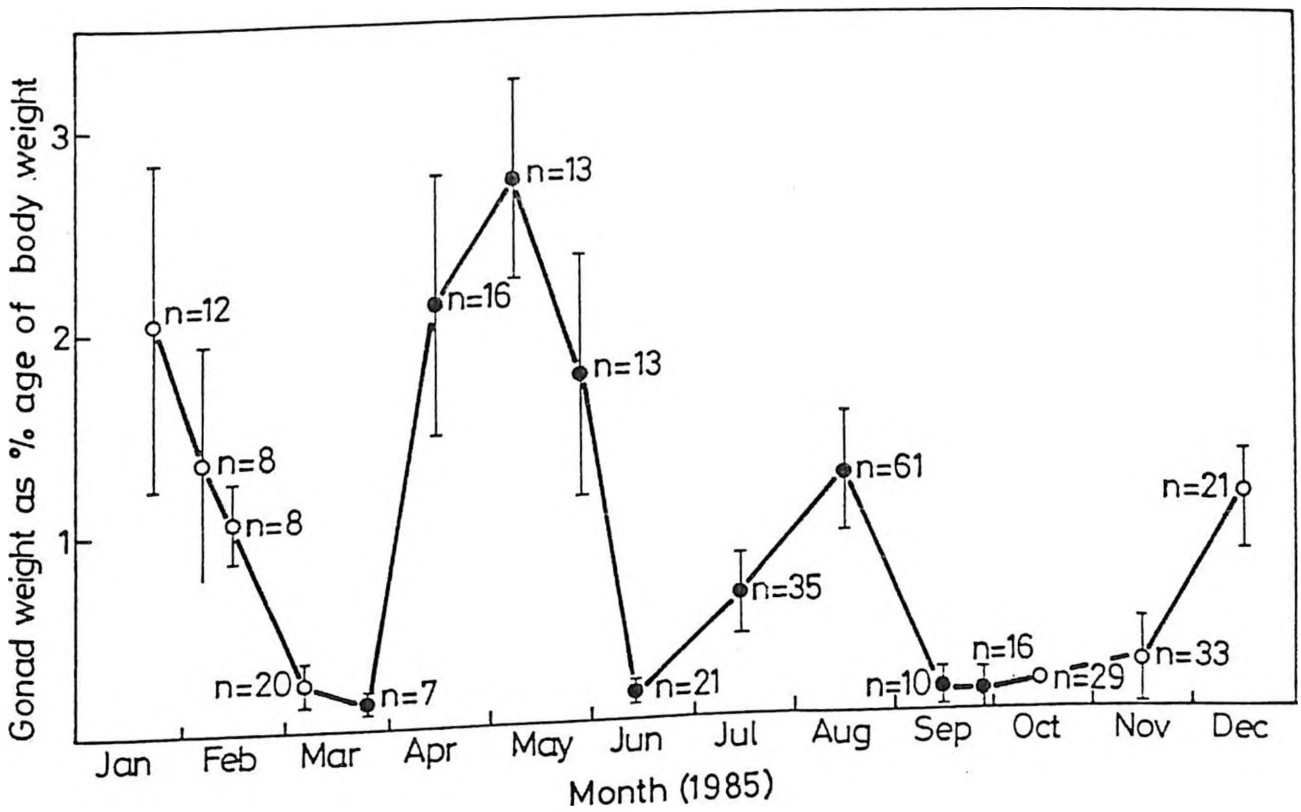

Fig. 6.3: Temporal variation in weight of the testis of S. sutor. The body weight excludes the weight of the gonads. Data does not include immature (stage I) fish. Vertical bars are equal to $\bar{X} \pm$ s.e. o,. mouth of Tudor creek; ●; outside reef edge at Bamburi, 4 km Northeast of Mombasa.

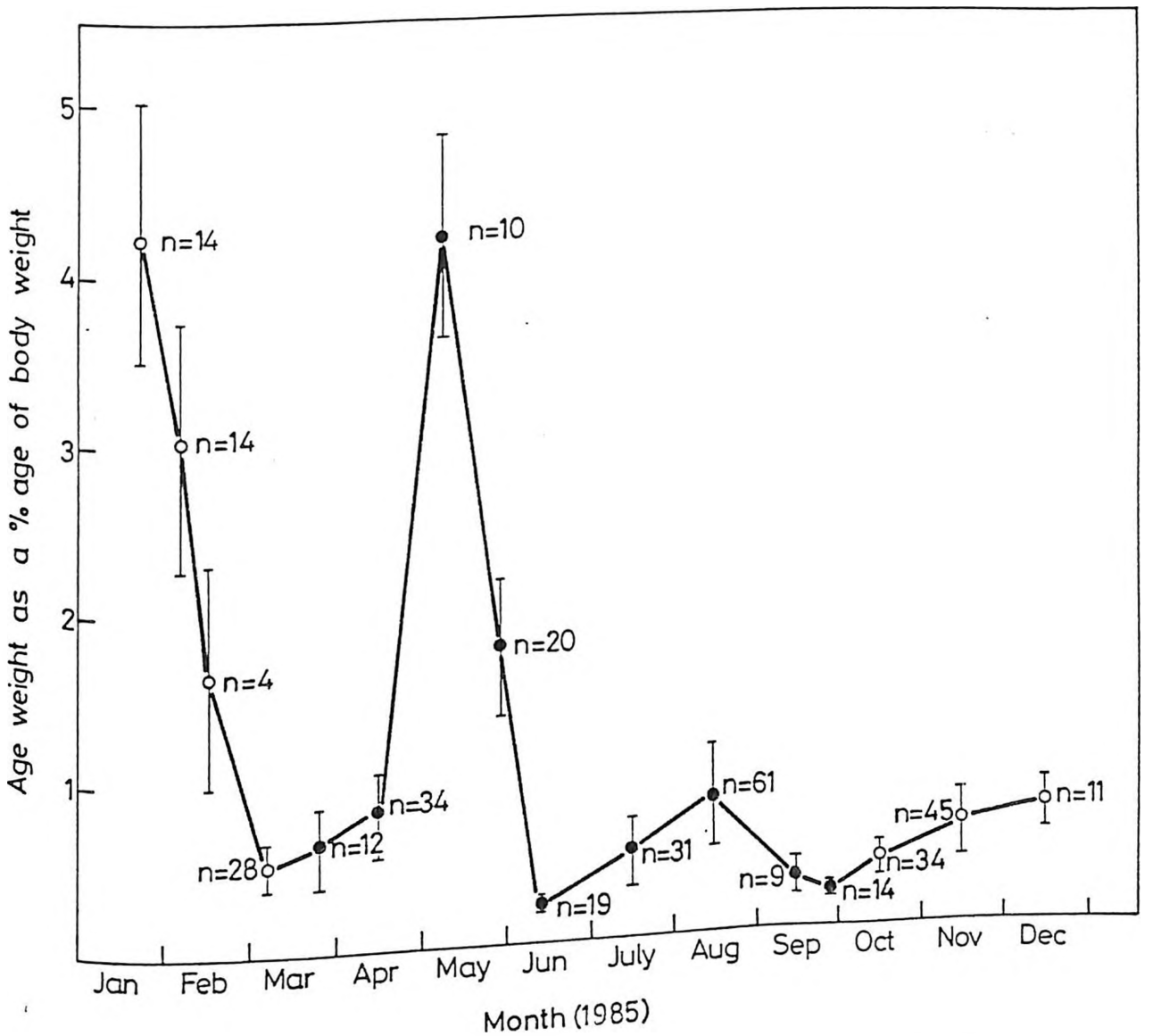

Fig. 6.4: Temporal variation in weight of the ovary of S. sutor. The body weight excludes weight of the gonad. Data excludes immature (stage I) fish. Vertical bars are equal to $\bar{X} \pm$ s.e. o; mouth of Tudor creek; ●, outside reef edge at Bamburi, 4 km North-east of Mombasa.

Table 6.3 : Appearance and abundance of siganid juveniles

Month		No. in a single trawl	Range of length (SL) cm.
January		-	-
February	6	557	2.2 - 4.5
	20	261	1.9 - 8.7
March	6	164	2.2 - 6.0
	22	15	3.2 - 5.2
April		-	-
May		-	-
June		-	-
July		-	-
August		-	-
September	1	3	4.3, 4.6, 6.5
	15	3	4.7, 4.5, 3.0
October	7	5	6.0, 5.6, 4.7 3.8, 3.6
November		-	-
December		-	-

the catch between the two spawning seasons which may suggest that there are differences in the level of spawning between the two seasons. Another interesting phenomenon is the disappearance of the juveniles a month or two after their first appearance.

6.3.6 Seasonal occurrence of maturity stages.

In each monthly sample the proportion of fish in each maturity stage was calculated and presented as a percentage for both males and females of S. sutor in fig. 6.5.

There is an indication from these graphs that, on the whole, a more or less gradual progression of maturity stages throughout the year is evident. Although fish in each maturity stage occur throughout the year this figure strongly indicates two main spawning seasons. It appears that major testicular and ovarian activities start towards the beginning of November coinciding with the beginning of the Northeast monsoon. During this time there occurs a rapid fall of fish in stage 1 and 2 which is consequently accompanied by a surge of the percentage of fish in stage 3.

While in December majority of the male S. sutor develop to stage 4 - a trend that continues into

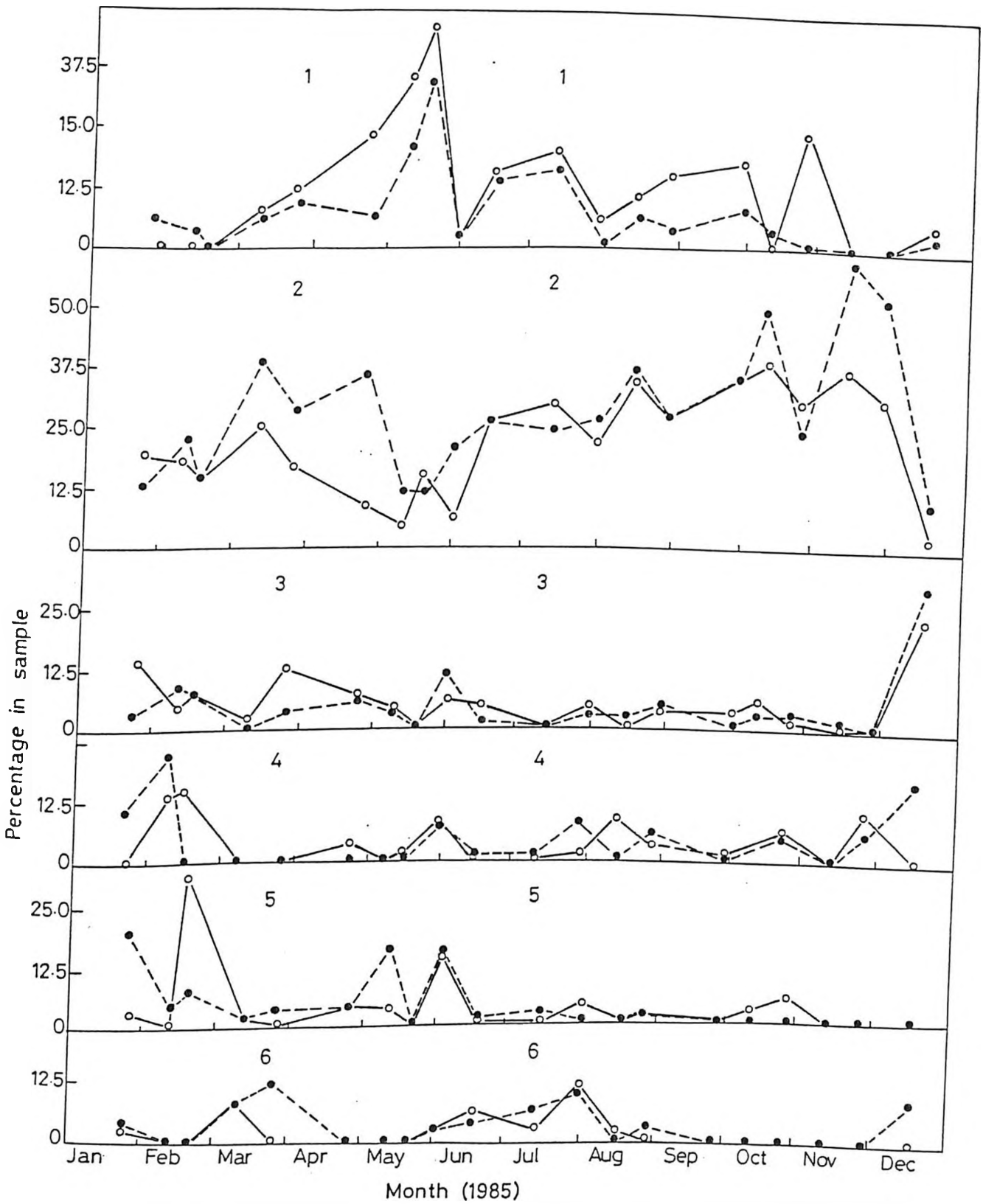

Fig. 6.5: The percentage occurrence of maturity stages in monthly samples for both male and female S. sutor. The stage of maturity is indicated by the number above each column. o—o—o, males; ●---●---●---● females.

January - they rapidly mature into stage 5 in February. Most females seem to be arrested at stage 3 of development in December and may be early January, but they rapidly mature to stage 4 and 5 through January into February. Stage 6 fish of both sexes become abundant in March, obviously after the January-February spawning, and yet again in June and July after the late spawning peaks in May and June. The second spawning season may be minor as indicated by the few numbers of juveniles in the catches in September and October in the reefflats (Table 6.3).

6.3.7 Size at first maturity

The percentage occurrence of different maturity stages in each chosen length groups of males and females of S. sutor were calculated and presented in tables 6.4 and 6.5. Although other workers (Nzioka, 1981; Geevarghese & John,. 1983) do not term stage 2 fish as mature, it was decided in this work to include them in calculating size at first maturity, moreso since it is at the commencement of rapid gonadal activity that we say a fish has entered into stage 2 of development. Moreover, fish that have spawned and are restarting active gonadal activities are included in stage 2. These tables show that the

Table 6.4: Percentage occurrence of male S. sutor in different stages of maturity in various size groups.

Maturity stage	1	2	3	4	5	6	(2, 3, 4, 5, 6)
standard length (cm)							
9 - 10.9	-	-	-	-	-	-	-
11 - 12.9	100	-	-	-	-	-	-
13 - 14.9	69.0	4.0	-	-	-	-	4.0
15 - 16.9	92.6	7.4	-	-	-	-	7.4
17 - 18.9	53.3	46.7	-	-	-	-	46.7
19 - 20.9	30.3	48.5	18.2	3.0	-	-	69.7
21 - 22.9	6.9	58.6	17.2	5.2	6.9	5.2	93.1
23 - 24.9	6.0	28.0	12.0	16.0	22.0	14.0	94.0
25 - 26.9	-	11.1	33.3	11.1	22.2	22.2	100.0
27 - 28.9	-	-	100.0	-	-	-	100.0
29 - 30.9	-	-	-	100.0	-	-	100.0
31 - 32.9	-	-	-	-	-	-	-

Table 6.5: Percentage occurrence of female S. sutor in different stages of maturity in various size groups.

Maturity stage	1	2	3	4	5	6	(2, 3, 4, 5, 6)
Standard length (cm)							
9 - 10.9	-	-	-	-	-	-	-
11 - 12.9	-	-	-	-	-	-	-
13 - 14.9	94.1	5.9	-	-	-	-	6.0
15 - 16.9	88.0	12.0	-	-	-	-	12.0
17 - 18.9	43.5	56.5	-	-	-	-	56.5
19 - 20.9	13.6	79.6	2.3	2.3	2.3	-	86.5
21 - 22.9	3.2	66.7	6.4	9.5	4.8	9.5	96.8
23 - 24.9	-	46.5	9.3	20.9	9.3	14.0	100.0
25 - 26.9	-	25.0	18.8	12.5	25.0	18.8	100.0
27 - 28.9	-	25.0	25.0	-	25.0	25.0	100.0
29 - 30.9	-	-	-	-	-	-	-

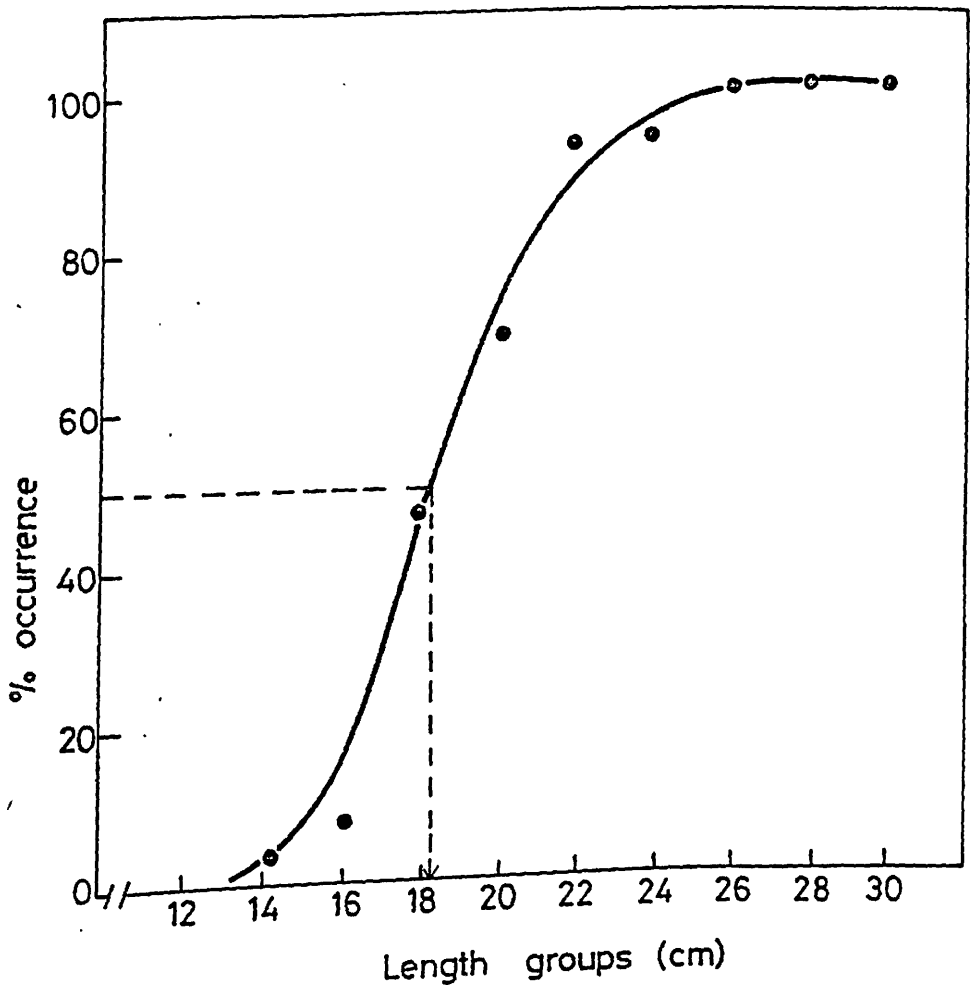

Fig. 6.6: Percentage occurrence of mature males of S. sutor in length groups.

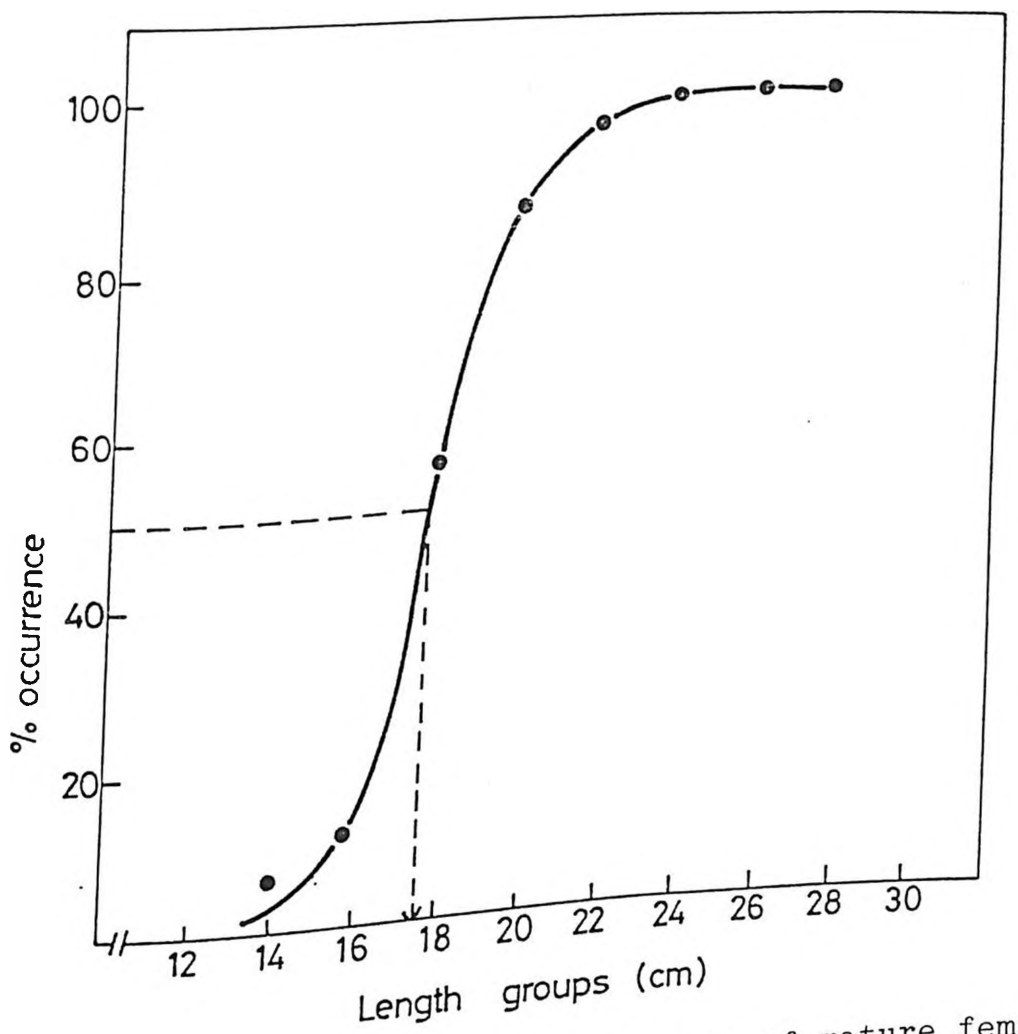

Fig. 6.7: Percentage occurrence of mature females of S. sutor in length groups.

smallest mature male and female S. sutor is between 13-14.9 cm standard length ($\bar{X}$ = 13.95). According to Kagwade (1968) the minimum length at first maturity is that length at which 50% of the fish are mature. According to Bagenal (1978) size at first maturity is the length at which 50% of the total stage 1 and 2 fishes have reached maturity.

From tables 6.4 and 6.5 the length at first maturity is between 18 and 19.9 cm standard length for males and between 17 and 18.9 cm standard length for the females. The actual graphical representation of this data (figs. 6.6 and 6.7) indicate that the size at first maturity for S. sutor is 18.4 cm and 17.8 cm standard length for the males and females respectively. The maximum size above which all individuals are mature is 25.0 cm and 23.0 cm standard length for males and females respectively.

6.3.8 Growth rate of gonads during maturation cycle

In most reproductive biology studies of fish the size of the gonad is taken as one of the indicators of maturity (Bowers & Holliday, 1961; Macer, 1974; Guraya et al., 1975). To quantify the growth of the gonad the length and width of the gonad was measured to the nearest 1 mm and the length/width ratio calculated and plotted against maturity stage

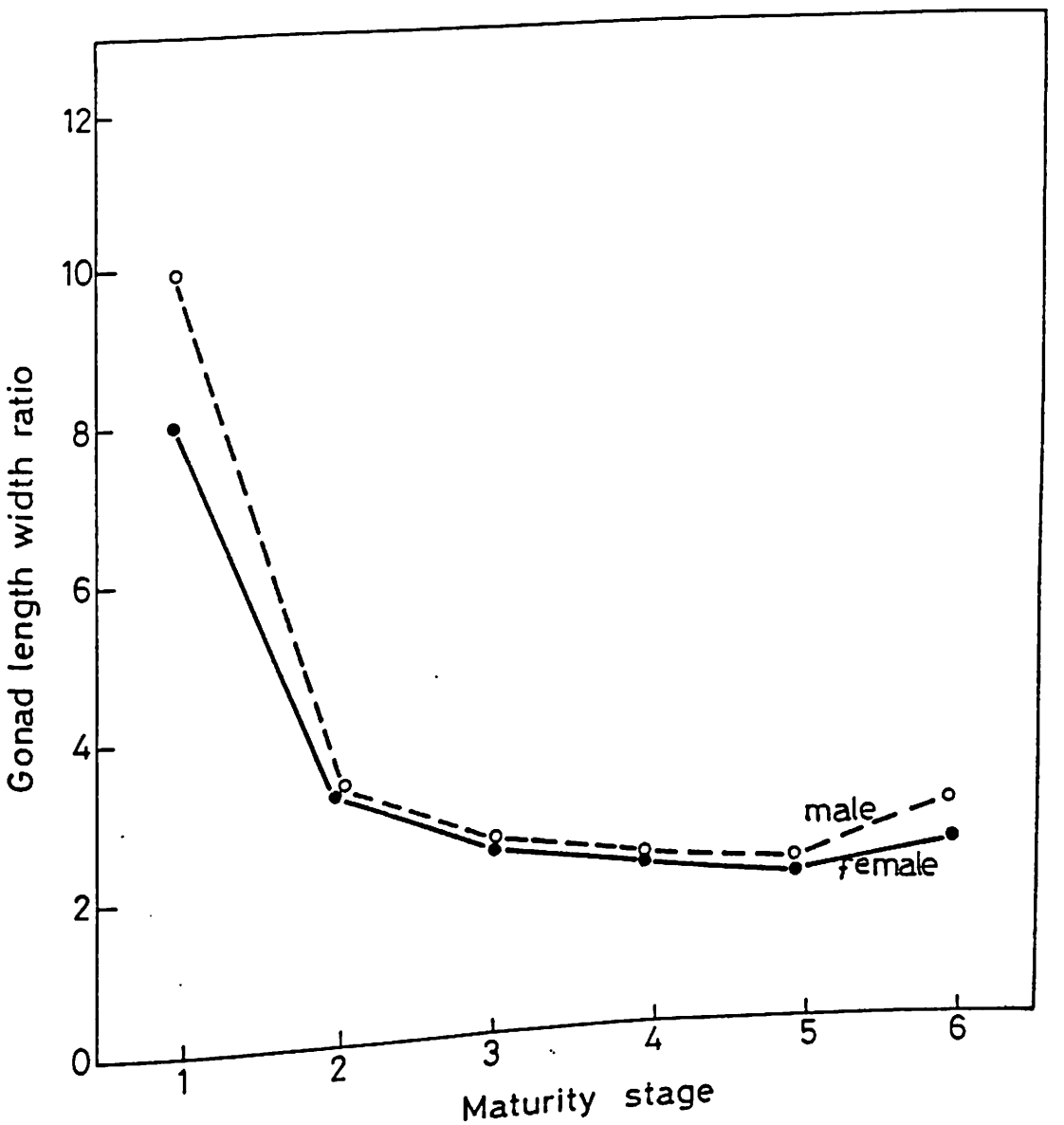

Fig. 6.8: The relationship between gonad length/ width ratio and the maturity stage for male and female S. sutor. Gonad length and width are in centimeters and gonad width was taken laterally at the broadest part.

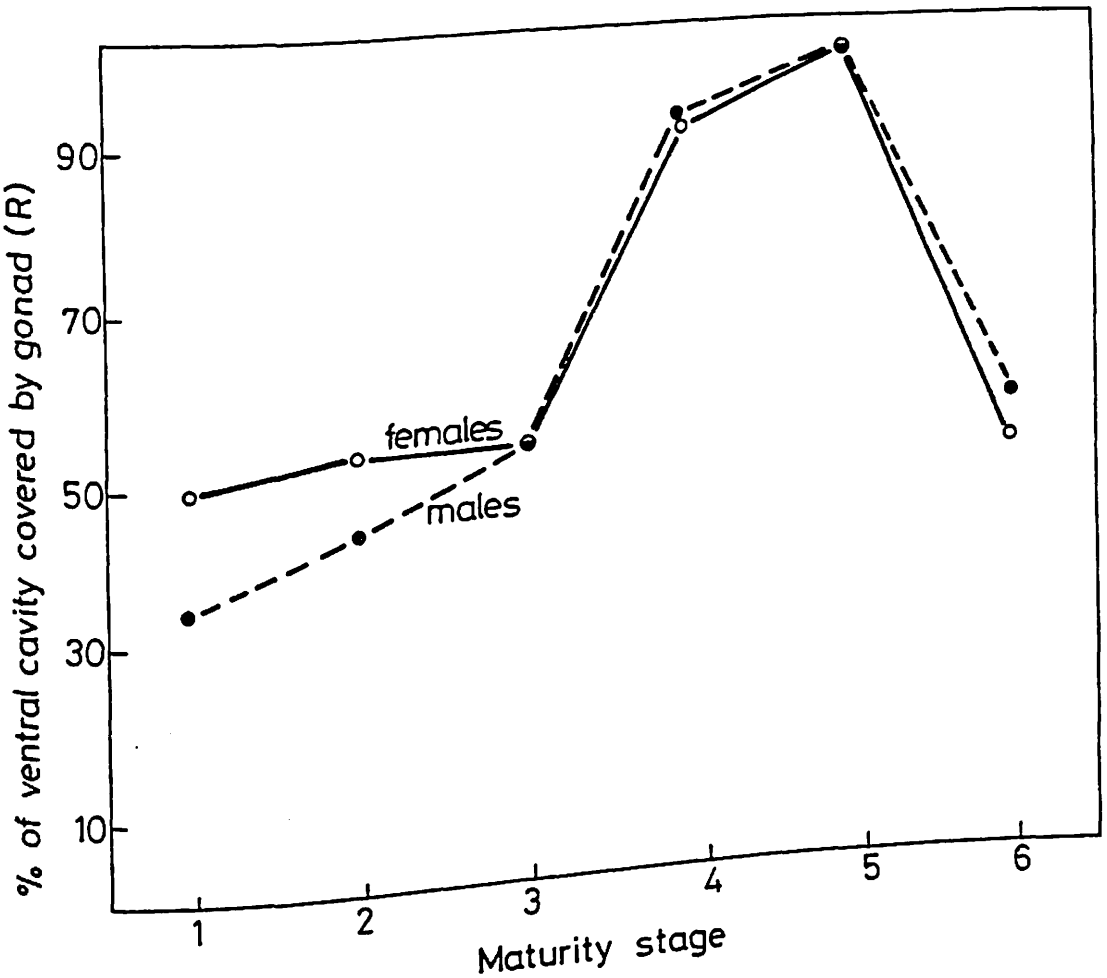

Fig. 6.9: Proportion of length of abdominal (ventral) cavity covered by male and female gonad of S. sutor.

(fig. 6.8).

The gonad length was expressed as a percentage of the total length of the abdominal cavity (ventral cavity) using the formula:-

$$R = \frac{G}{G + D} \quad X\ 100 \text{ where,}$$

R = % age of abdominal cavity covered by gonad

G = Total gonad length

D = Length of gonadal duct behind the tip of the gonad.

R is plotted against the maturity stages in fig. 6.9.

There is an indication from fig. 6.8 that throughout the maturation both gonads grow at a relatively faster rate widthwise than in length up to stage 5 of development after which they suddenly narrow again obviously due to releasing the material they contained in the spawning process. The most rapid increase in width for both gonads is between stage 1 and 2 and then there follows a gradual progressive increase up to the peak of development in stage 5.

One point that emerges from fig. 6.9 is that between stage 1 to 3 the ovary undergoes very little growth lengthwise while between these stages the testis changes by over 15% of the length of the ventral cavity.

6.4 Discussion

The sex ratio of S. sutor in the catches is 1:1 at the Kenya coast. This contrasts with a sex ratio of 3:1 females to males found for a related species, S. canaliculatus, in Palau (Hasse et al., 1977). For some siganid species death after spawning is speculated (Lam, 1974). But Bryan et al., (1975) never witnessed death of S. canaliculatus after inducing them to spawn in artificial systems.

The siganids described in the literature grow rapidly and are sexually mature in less than one year. From the growth curve, S. sutor grows to about 19.5 cm standard length in 1 year. From length at first maturity data S. sutor matures first at 18.4 cm and 17.8 cm standard length for the males and females respectively. The smallest mature male and female recorded in this work had a mean standard length of 13.95 cm. However, a majority of fishes reach sexual maturity between 18-19.9 cm and 17-18.9 cm standard length for males and females respectively. But results in figs. 6.6 and 6.7 indicate that, at the Kenya coast, females of S. sutor mature at a slightly smaller size than the males. S. canaliculatus of 12 cm standard length were found to be ripe in Palau (Hasse et al., 1977). Monacop (1973) gives the standard length of mature males and females of S. canaliculatus

as 11-14 cm and 13-21 cm resepctively. Lam (1974) recorded mature males of S. canaliculatus of < 14 cm standard length. The smallest mature females of S. vermiculatus are 12 cm standard length (Gundermann et al., 1983).

From the growth curve, based on daily band counts on otoliths, and length at first maturity data there is a strong indication that S. sutor at the Kenya coast is a fast grower reaching sexual maturity in less than one year. The standard length, 19.5 cm, to which S. sutor grows in one year seems to have been probably fairly estimated since a related species, S. canaliculatus, grows to about 16.0 cm standard length in Palau (Hasse et al., 1977) with an estimated L_∞ of 25.2 cm total length (Pauly, 1980). All in all what seems to be happening is that S. sutor is sexually mature over a wide range (13.95-25.0 cm and 13.95-23.0 cm standard length for males and females) in their life time which is not unexpected and this agrees with the findings for S. canaliculatus in Palau (Hasse et al., 1977).

Figs. 6.3, 6.4, and 6.5 indicate that S. sutor populations at the Kenya coast have two spawning peaks per year. The first peak is in January/February and the second is in May/June. Juveniles of S. sutor appear in February to March and in September to October.

Many spent fish (fig. 6.5) appear in March and again in June-July. This means that in Kenya S. sutor has two definite spawning seasons. In Guam juveniles of S. spinus and S. argenteus appear in April-May and occasionally a third and a fourth time in June and October and their appearance being always after the last quarter of the moon (Kami & Ikehara, 1976). In Palau, the juveniles of S. canaliculatus appear in March-April and a second time in November-December while in Singapore juveniles appear first in February-May and again in August-October. Similarly, in the Philippines the juveniles of S. canaliculatus appear for a second season in August and September but no ripe fish had been obtained either prior to or during the second period (Lam, 1974). The reproductive pattern of S. sutor is thus very similar to that of S. canaliculatus in Singapore, the Philippines, and Palau. As has been found in these areas there is a second season of juveniles but no ripe fish had been obtained prior to or during this latter period. At the Kenya coast there is a second gonad to body weight peak in May. But the appearance of juveniles in September and October certainly means that these were not from the May/June spawning peak. These juveniles, therefore are, perhaps, from another population of S. sutor which spawned in August. There are chances,

therefore, that the juveniles from the May/June spawning appeared elsewhere and not in the vicinity of K.M.F.R.I. where beach seining was actually concentrated. De Souza (in press) has found a spawning peak in late December-January and a second time in May in Mombasa area for S. sutor which agrees very well with the present findings. In Tanzania, Bwathondi (1981) points out that siganids (species not indicated) breed throughout the year with peaks occurring between November and March/April. Since as we have seen there are reports by many workers of two spawning peaks based on appearance of juveniles, on changes in gonad to body weight ratios and the seasonal appearance of spent fish (in this work) one can assume that each sexually mature female spawns at least once per year and perhaps twice.

In the present work the numbers of juveniles caught in the latter part of the year were much smaller than in the first part. This may be an indication that the second spawning peak is a minor one. But considering the long time lapse between the second spawning peak and the appearance of juveniles it appears that these juveniles were, probably, not a product of the May/June spawning. This could suggest that several spawning populations of S. sutor exist at the Kenya coast but spawning at different times

of the year. Another explanation could be that growth rate of the juveniles is much slower in June to September than in December to March.

Although the female and male gonad differ morphologically, the ovary being rounded and the testis being flat and lobulated, they follow a similar pattern of weight changes throughout maturation. Also the maturity cycle graphs indicate that the maturity stages chosen do fit an expected and logical pattern of weight changes in gonads thereby providing an additional degree of confidence in the criteria used to assess the maturity stages.

CHAPTER 7

7. FECUNDITY STUDIES

7.1 Introduction

One major problem in fecundity studies of fish is how to identify the oocytes which are potentially capable of release in the coming season (Macer, 1974). A related problem is deciding at what stage of maturity it is best to determine fecundity. In estimating fecundity many workers use a criteria based on the presence or absence of yolk and counting yolked oocytes as representing the oocytes to be spawned. Another method is to estimate directly the size of a batch of oocytes released at a single spawning - but never has it been easy to determine the number of spawnings per female in a year.

Although acquisition of yolk is the most obvious sign of oocyte development - and has thus been used by many workers - appearance of vacuoles in the cytoplasm is an earlier indication of oocyte development prior to acquisition of yolk (Macer, 1974). It may be better, therefore, to use these as a criteria of oocytes to be spawned at the first future spawning since using acquisition of yolk as the sole criteria of oocyte development could seriously underestimate fecundity by omitting a latter batch of oocytes which are actively developing and which may be spawned to-

gether with the earlier yolked oocytes.

Atresia is another equally important phenomenon that characterizes oocytes development throughout maturation (Macer, 1974, Wallace & Selman, 1981; Cyrus & Blamber, 1984). While much work has been done on this topic in the teleosts, such studies have failed to investigate the causes of atresia and more importantly no work has clearly quantified its role in regulating the numbers of oocytes which progress from stage to stage (Wallace & Selman, 1981). Inspite of this it is clear that atresia plays an important role in fecundity determination and hence recruitment into the fishery.

7.2 Material and Methods.

7.2.1 Histological techniques.

Some of the material for histological studies was fixed for 24 hours in Smith's formol dichromate, washed in running tap water for another 24 hours and stored in 10% formalin. This material, together with other ovaries that had been fixed in Bouin's fixative were dehydrated in graded alcohols, cleared in xylene and embedded either in paraffin wax or in esters wax (Steedman, 1960). Sections were cut at 4-10 μm and stained in iron haematoxylin and eosin.

7.2.2 Gilson's isolation and counting of oocytes.

Pieces of ovary were cut longitudinally and turned inside out and treated with Gilson's fluid in 50 ml specimen bottles. The bottles were vigorously shaken every 2 days - to aid the release of oocytes from the ovarian fragments. Before counting the oocytes, they were poured into a petri-dish and those oocytes which had not been liberated from the ovarian tissue during the vigorous shaking were removed by teasing. The ovarian tissue free from oocytes was discarded and the oocytes were allowed to settle in the specimen bottles; Gilson's fluid decanted and tap water added followed by settlement and decanting. The process was repeated several times to clean the oocytes. Each time water was decanted, the supernatant was checked under a dissecting microscope, lest tiny oocytes were thrown away.

The clean oocytes were poured into a one-litre capacity beaker and a known volume of water added. To ensure even distribution of the oocytes in the water, a plastic ruler was used to stir the oocytes vigorously using a to and fro motion. A subsample was taken after 10 strokes of the ruler by means of a LABSYSTEM finelet pipette of 1000 µml capacity. One aliquot usually gave subsamples that contained sufficient of the large and small oocytes to yield

satisfactory counts and diameter distributions.

The oocytes were pipetted into a solid watch glass and their diameter measured under a standard microscope using a calibrated eye-piece graticule and a total magnification of X 40. Each oocyte was measured along a horizontal axis regardless of its shape. The accuracy of the subsampling method was tested by taking seven replicates and calculating the coefficient of variation which was 6.2%. The total number (N) of oocytes in any size class in the ovary was calculated as follows:-

$$N = \left(\frac{V}{Vl}\right)n \times \left(\frac{W}{Wl}\right) \quad \text{where,}$$

n = number of oocytes of a given size class in the subsample

V = volume of sample

Vl = volume of the subsample

W = weight of whole ovary

W^l = weight of portion of ovary preserved.

7.3 Results

7.3.1 Maturity stages of developing oocytes.

In order to make accurate fecundity estimates it was first necessary to identify oocytes that were developing. Secondly, it was necessary to establish whether there were any original differences in the

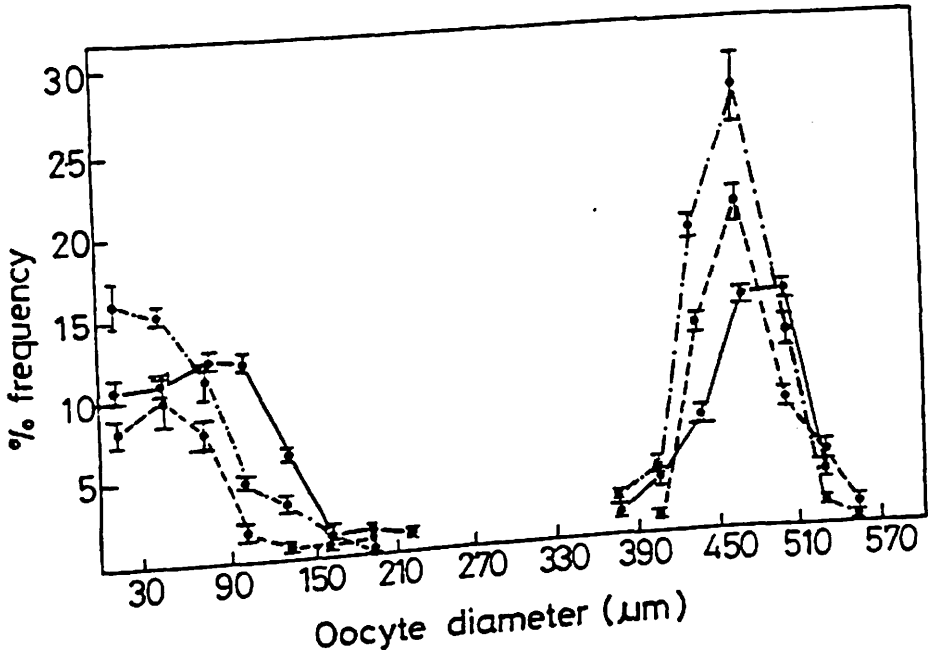

Fig. 7.1: Oocyte diameter frequency distribution from the anterior ●--●--●--●; mid, ●-·-●-·-● and posterior, ●——●——● regions of ovary of S. sutor. Vertical bars show $\bar{X}$ ± s.e.

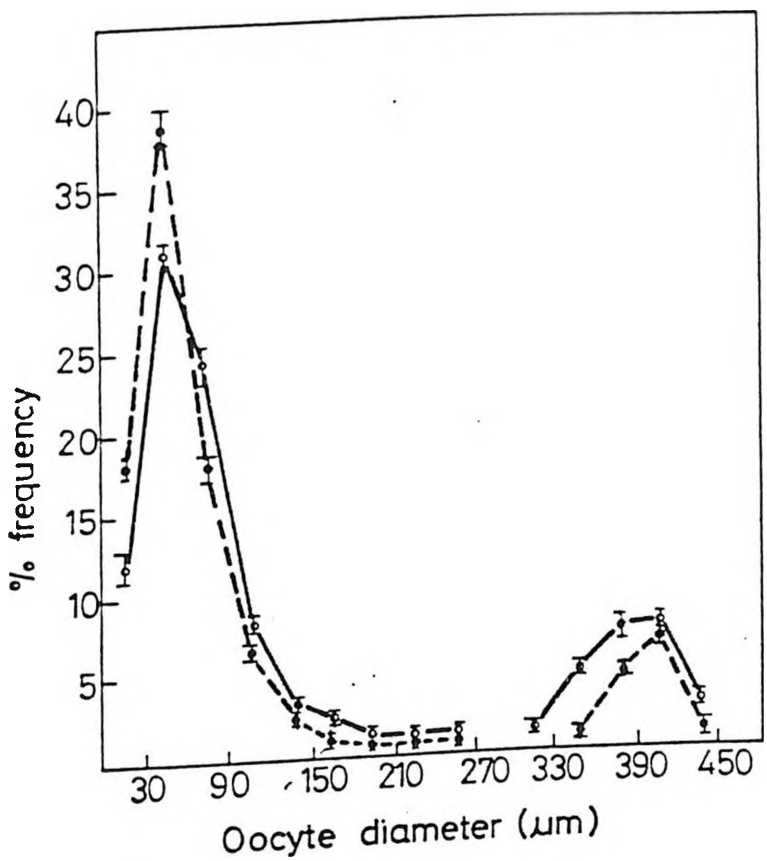

Fig. 7.2: Oocyte diameter distribution of the right ●--●--●, and the left *lobes of six stage 4 ovaries of S. sutor. Vertical bars are equal to $\bar{X}$ ± s.e.
*●——●——●

distribution of oocytes of different stages of development including differences between the right and the left ovary. To find this out, oocyte counts in the anterior, mid and posterior regions of the ovary and in the right and left ovary were made and the results are presented in figs. 7.1 and 7.2. An analysis of variance showed that there was no significant difference in oocyte diameter distributions among the three regions of the ovary and that such differences do not exist between the right and the left ovary ($P > 0.05$). Therefore it was decided that portions for oocyte counts could be cut from any region of the right or the left ovary. Throughout this work, however, portions were cut from the mid-region of left or right ovary.

The oocyte frequency distribution for all the maturity stage for S. sutor is plotted in fig. 7.3. It is clear from these results that stage 4 and 5 ovaries of S. sutor have an oocyte diameter distribution that is strongly bimodal containing modes of small and large oocytes with, in some ovaries, intermediate size oocytes completely missing. Stages 1, 2, 3, and 6 ovaries have got only one mode, made up of small oocytes only; obviously large oocytes have either been shed or have not yet been formed.

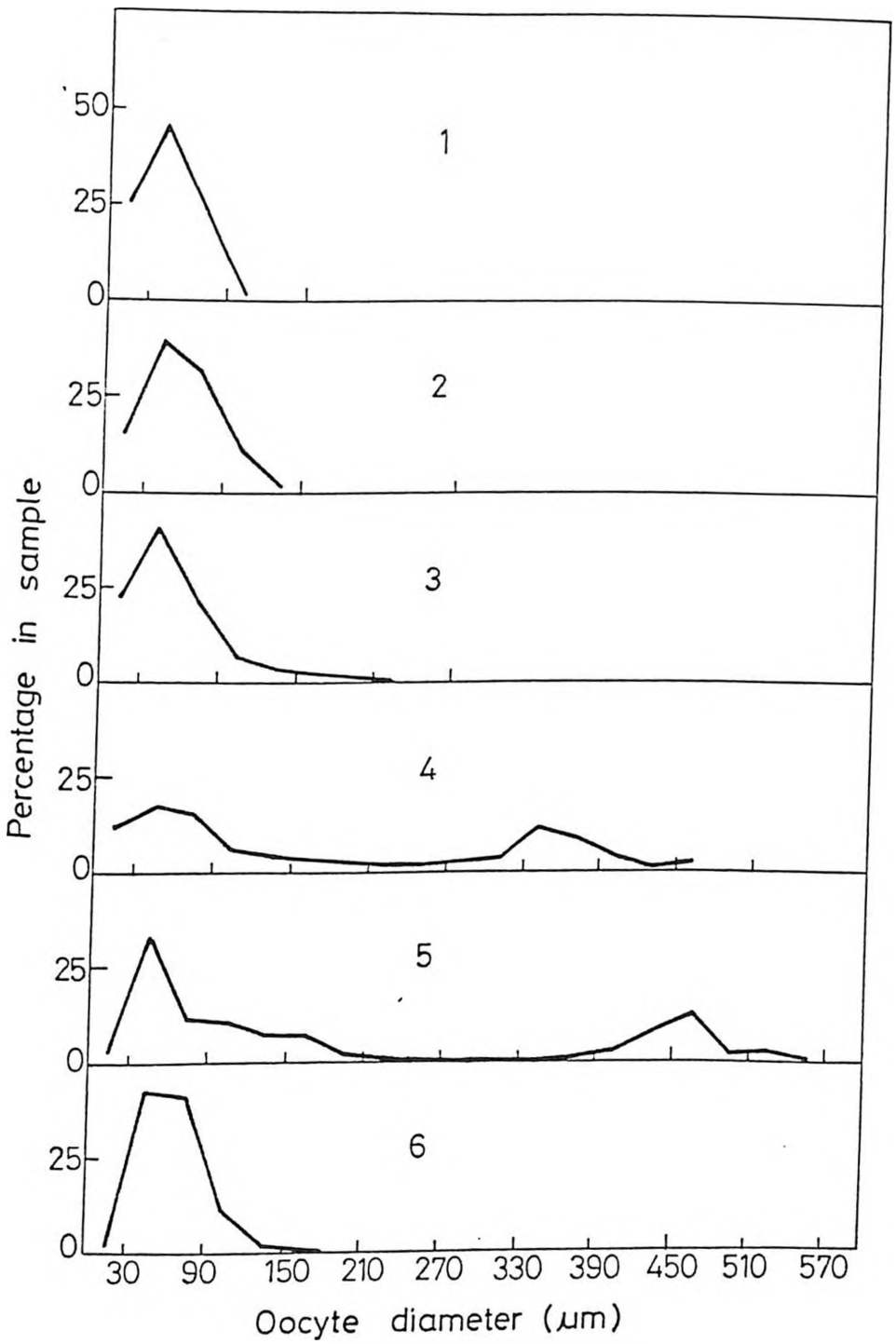

Fig. 7.3: Oocyte diameter frequency distribution for each maturity stage for S. sutor. The maturity stage is indicated by the number above the polygon, each of which is based on measurements of whole counts from six separate ovaries treated by Gilson's fluid.

As expected bimodal ovaries are heavier than the unimodal ones since the former have large oocytes. Oocytes of 480 µm have a volume which is 885 X as great as oocytes of 50 µm. Bimodal ovaries show great ranges in weight due to differences in the number and sizes of the larger oocytes among such ovaries (fig. 7.4). Such differences in weight among bimodal ovaries are also due to the proportion of the heavy yolk taken up by the oocytes as they advance in growth.

With such a strongly bimodal distribution of oocytes in stage 4 and 5 ovaries, it appears fairly safe to assume that only oocytes in the mode of larger oocytes will be spawned in a given spawning. But it was observed that by comparing Gilson's count oocyte diameter distribution of these ovaries with corresponding histological sections of the same ovaries the fate of the middle size oocytes was unclear. It was apparent that at stage 4 (stage at which fecundity was determined in the present work) there was the danger of underestimating fecundity by omitting a latter group of oocytes which are actively developing and are bound to be spawned with the much larger oocytes.

Many oocytes had vacuoles in the cytoplasm at stage 4 and since these are an earlier indication of oocyte development prior to acquisition of yolk which

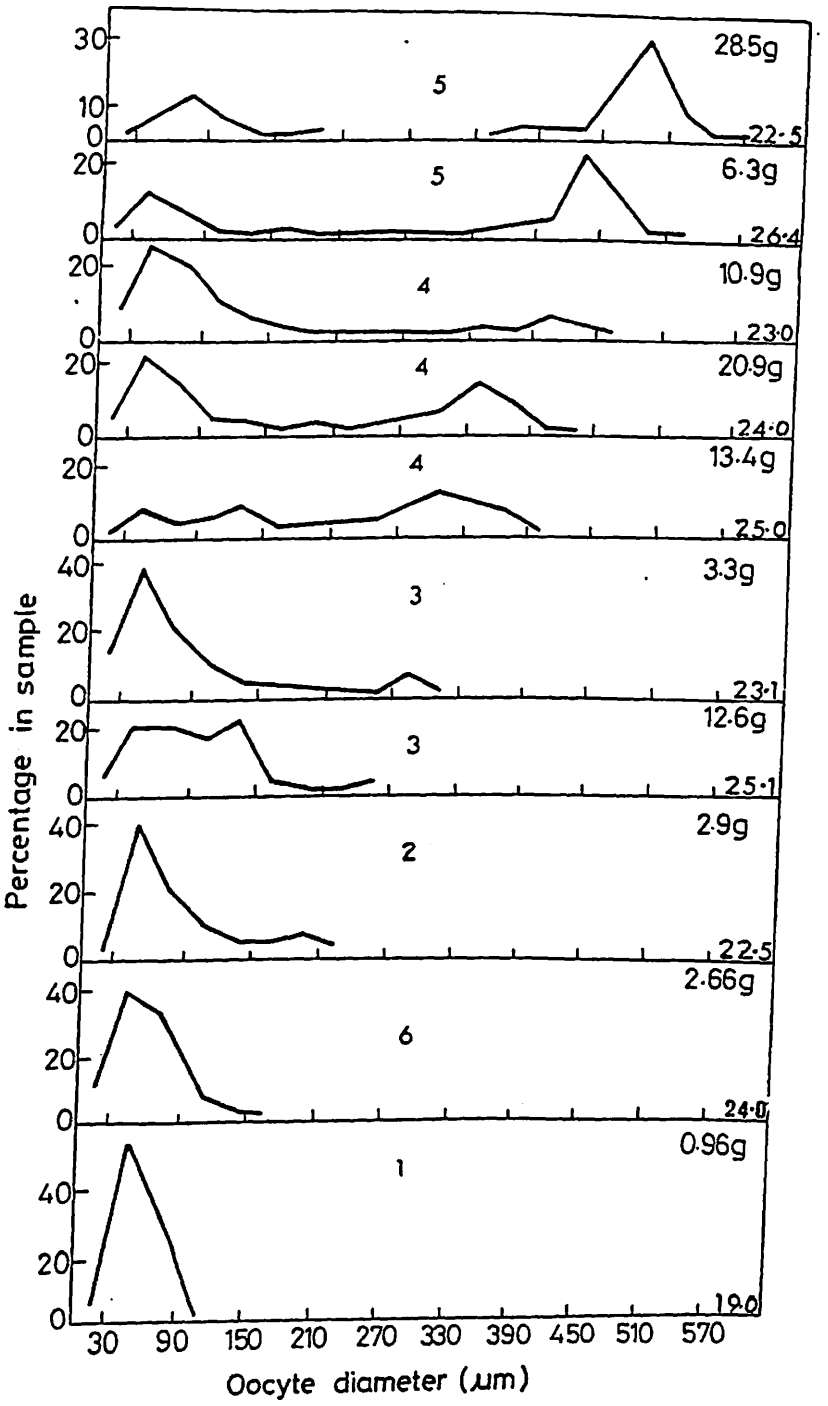

Fig. 7.4: Oocyte diameter frequency distribution on a selected number of individual ovaries of S. sutor. The maturity stage is indicated by the number at the middle above the polygon. The number above on the right side of each polygon indicates the weight of the ovary in grammes and the one below indicates the standard length of the fish.

most workers use as the sole criterion of oocyte development (Macer, 1974), then it was considered fair to use them as one of the criterion of oocyte development. Therefore at stage 4 the total fecundity is found by combining all oocytes with vacuoles in the cytoplasm together with those that are yolked. This is obviously on the assumption that once young oocytes start becoming vacuolated they will grow to acquire yolk and eventually be spawned together with the larger oocytes. With such an assumption it was important to find out at which size (diameter) oocytes first start developing vacuoles - in the cytoplasm. For this purpose proportions of oocytes containing vacuoles in the cytoplasm was done by examining histological sections of eight stage 4 ovaries of S. sutor and the results are shown in fig. 7.5. The sections were examined at X 40 and oocytes were measured using a calibrated eye-piece graticule. Only oocytes cut through the nucleus were measured.

To ensure a standard procedure for oocytes counted on the sectioned material only oocytes that were within the limits of the graticule calibrations were counted and measured. It must be pointed out, however, that it was difficult to decide which oocyte was cut through the greatest nuclear diameter but in this part only oocytes that were distinctly cut through the nucleus

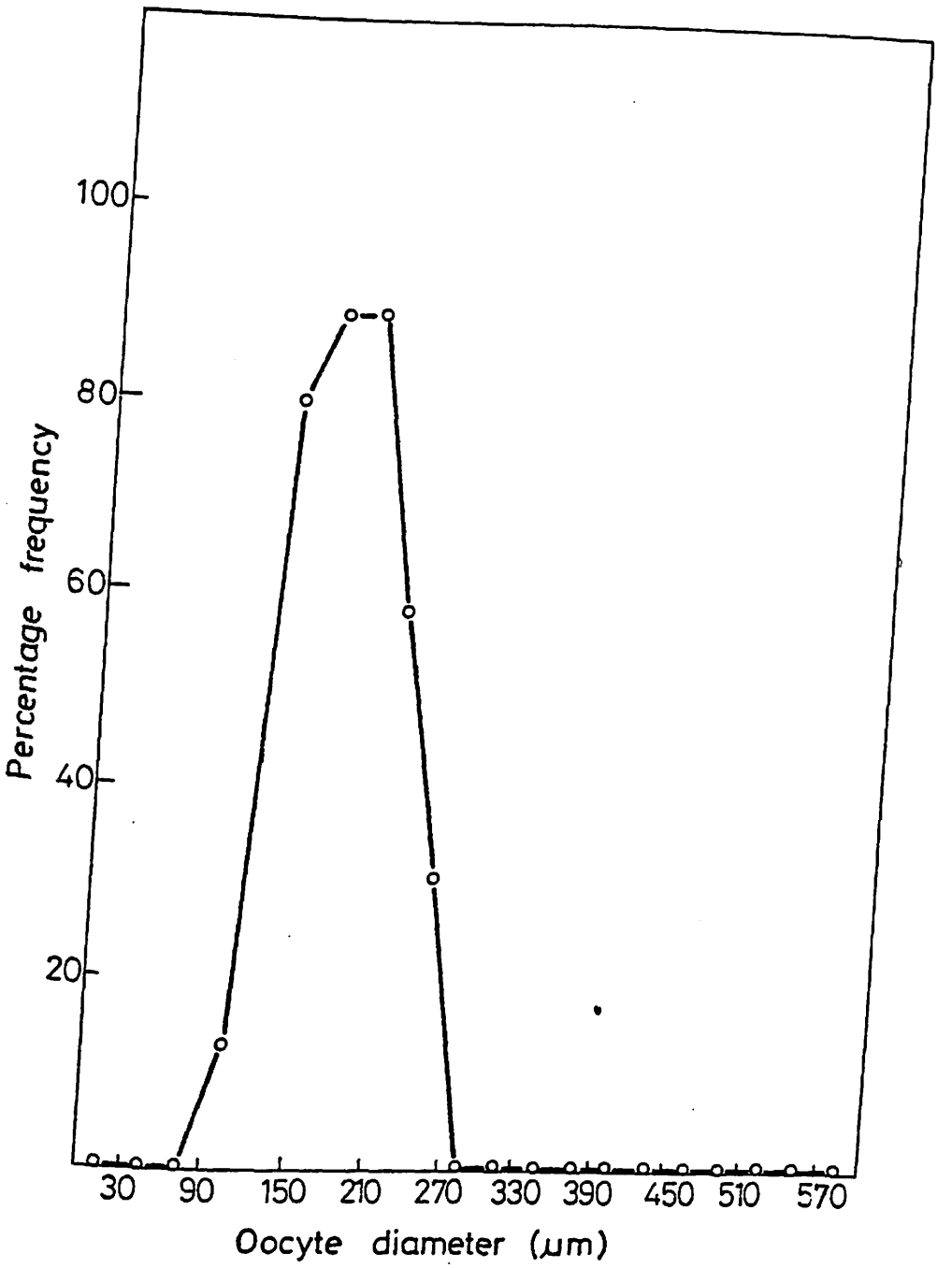

Fig. 7.5: Proportion of oocytes with vacuoles in the cytoplasm in each diameter class in histological sections of eight stage 4 ovaries of S. sutor. The diameters have been corrected to equivalent Gilson's measurements.

were considered. The actual procedure involved moving the section along the graticule graduations on a vertical axis and then measuring and classifying oocytes cut through the nucleus as vacuolated or not.

Since the material considered were preserved in different fixatives then the chance of differential shrinkage due to the two treatments was considered. With this end in view a comparison of oocyte diameters from six stage 4 ovaries in both fixatives were made; and analysis of variance showed that there was a significant difference between the two sets of data ($P < 0.01$) and that the mean diameter of the histological material was, on the average 9.3% less than the Gilson's fixed material. Therefore the histological measurements shown in fig. 7.5 have been corrected by this amount. These data show that vacuoles start appearing in the cytoplasm of oocytes when they are as small as 90 μm in diameter and that at about 170 μm about 90% of oocytes have a vacuolated cytoplasm. From about 200 μm the oocytes start losing vacuoles in the cytoplasm very rapidly, perhaps by rapid acquisition of yolk, so that at about 290 μm no vacuolated oocytes remain.

7.3.2 Oocyte numbers.

By applying the equation $N = (V/Vl)n \times (W/Wl)$ using the histological data given in fig. 7.5 and Gilson's counts, an estimate of oocytes in each size class and hence the potential fecundity of each female can be obtained. Such data-showing the total developing oocytes - for 16 stage 4 ovaries of S. sutor were determined and plotted against the cube of body length in fig. 7.6. All oocytes above 150 µm were counted in the fecundity estimates. A relationship of the form $Y = 0.012 X - 0.97$ ($r = 0.56$; d.f. 14; $P < 0.05$) was found. Although there are individual variations a mean of 585,000 developing oocytes was estimated for an ovary of S. sutor in a single spawning.

7.3.3 Egg atresia

Atresia is an important phenomenon that characterizes oocyte growth and development in fishes (Yamamoto, 1956; Macer, 1974; Guraya et al., 1975; Monaco et al., 1978; Wallace & Selman, 1981 and Cyrus & Blamber, 1983). Cyrus and Blamber (1983) have described in detail the process and types of atresia in Gerres sp. But in general atretic oocytes in histological sections have a chorion which initially becomes less distinct, then disintegrates and eventually sinks into the cytoplasm of the oocyte. Associated

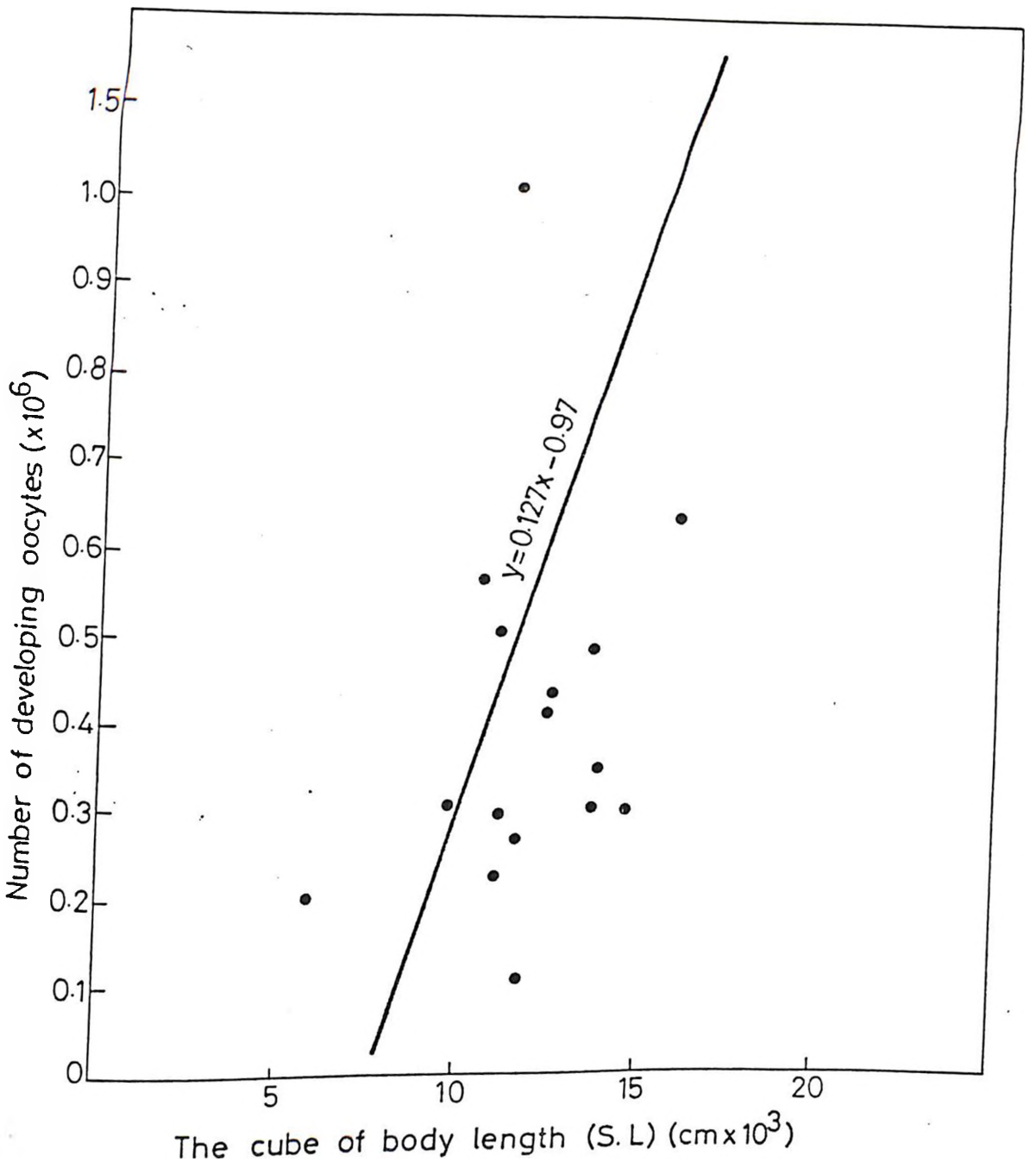

Fig. 7.6: The relationship between the number of developing oocytes and cube of body length in stage 4 ovaries of S. sutor.

with such oocytes is a multitude of squamous atretic follicular cells and many blood vessels - their invasion of atretic oocytes is perhaps to transport material from the atressing oocytes. Both post and pre-spawning involution of oocyte are common in fishes.

Since both pre- and post-spawning atresia of oocytes were observed in the ovary of S. sutor, (Plates 7.1 and 7.2), it is clear that there was need to investigate this phenomenon in the present work. Moreover, it is important to know if it was a major factor affecting the fecundity estimates that were made (fig. 7.6). Therefore it was decided to follow first, the degree of atresia throughout the maturation cycle since there was evidence from the sectioned material that atresia differs with the maturity stage. Six ovaries of all the maturity stages were sectioned and all developing oocytes were counted and classified as atretic or not. As done earlier (see 7.3.2) the limits of a calibrated eye-piece graticule were used to give standard treatment to all the sections that were considered. It was considered that by moving the section on a vertical axis only within the limits of the calibrated eye-piece graticule the chance of counting an oocyte more than once was very low. However, it must be pointed out that it was not considered to be of importance in this part that oocytes

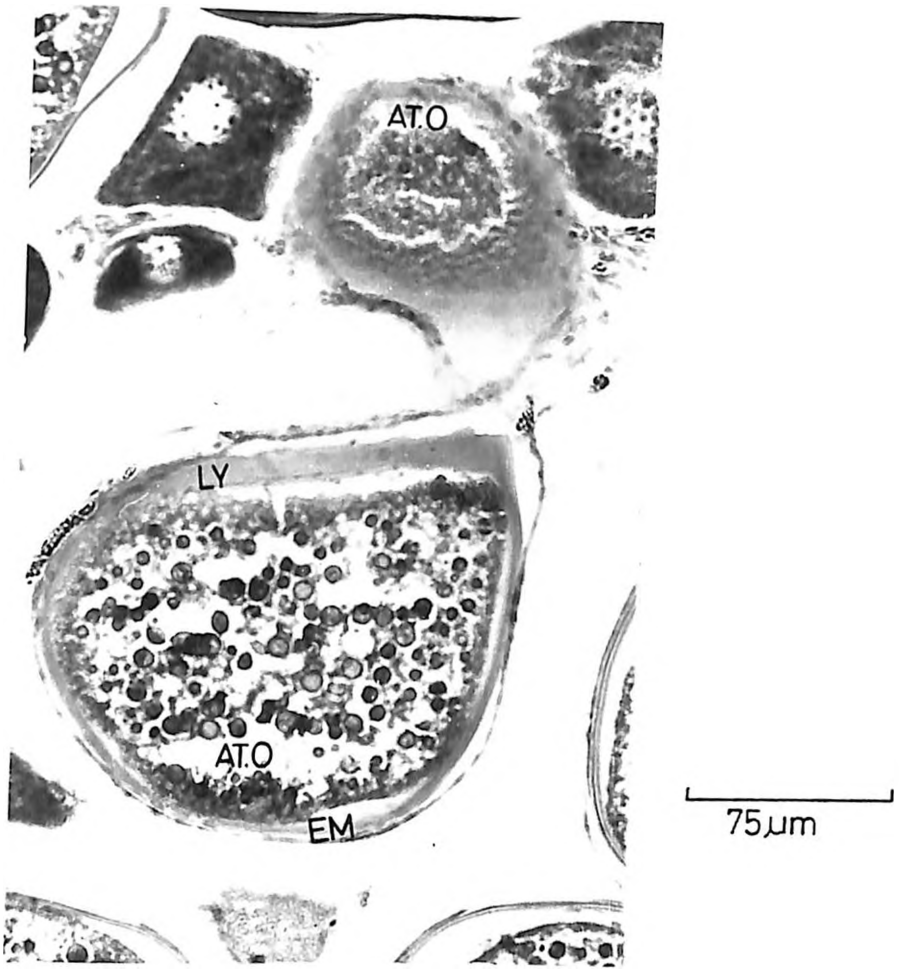

Plate 7.1: Appearance of atretic oocytes in advanced stages of development. Note the disorganization of the egg membrane (EM) and its invasion by squamous follicular cells. AT.O - atretic oocyte, LY - liquefying yolk.

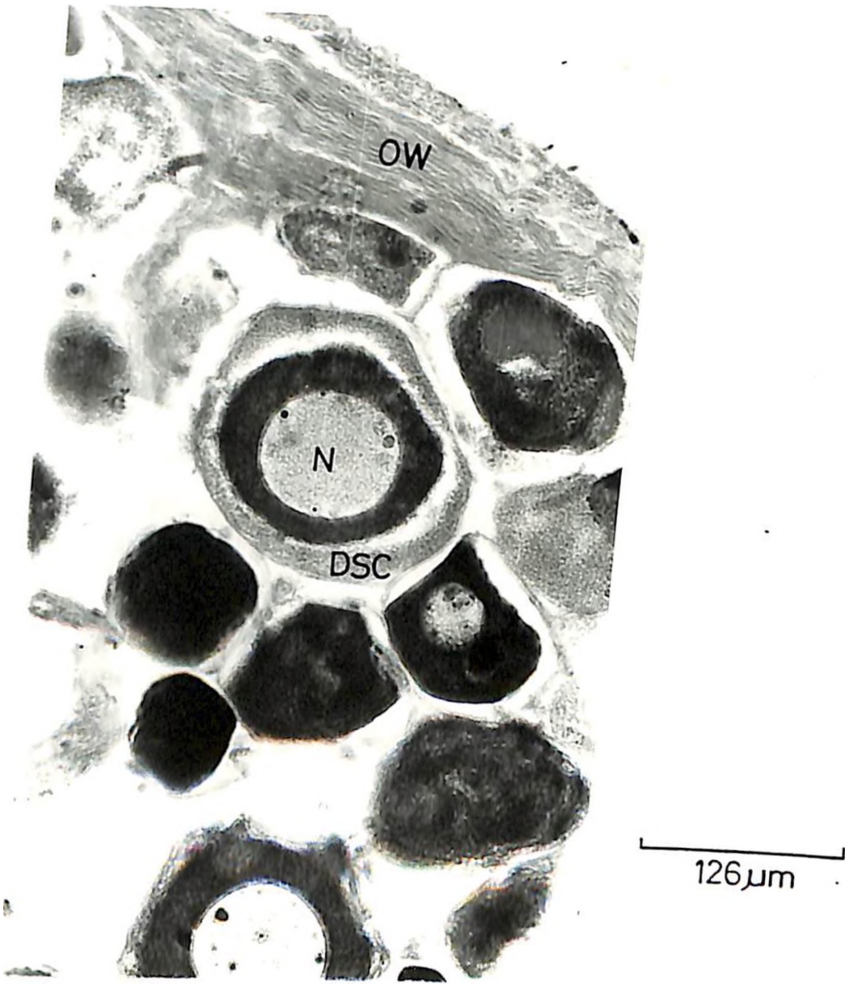

Plate 7.2: Cells with a dual-stained cytoplasm (DSC) in the ovary of S. sutor probably indicated pre-spawning atresia of oocytes. N - nucleus; (OW) - ovary wall.

counted and classified as atretic or not, had to have been cut through the nucleus. These results are plotted in fig. 7.7. It is apparent from this figure that the degree of oocyte atresia is lowest in stage 1 (< 20%) and rises to 27% and 32% for stages 4 and 5 respectively. Atresia can be said to be relatively high in stage 2 (40%) and rises to about 45% in stage 3. It is highest in stage 6 reaching about 58%.

Another significant observation in the ovary of S. sutor is that oocyte diameter distribution of Gilson's material of some stage 4 and 5 ovaries had the intermediate size oocytes missing altogether leaving the small and large mode oocytes separated by a gap. In contrast, in histological sections of the same ovaries there was no obvious gap i.e. there was an appreciable proportion of oocytes of intermediate size. All the intermediate size oocytes in such ovaries had a disintegrated chorion and were already invaded by a number of phagocytic squamous follicular cells. As a result of this it was decided to make a comparison of oocyte diameter frequency distribution of the same ovaries fixed in Smith's formol dichromate and in Gilson's fluid separately. In histological material of these ovaries all the oocytes were measured and classified as atretic or not. Fig. 7.8 shows the proportion of those that

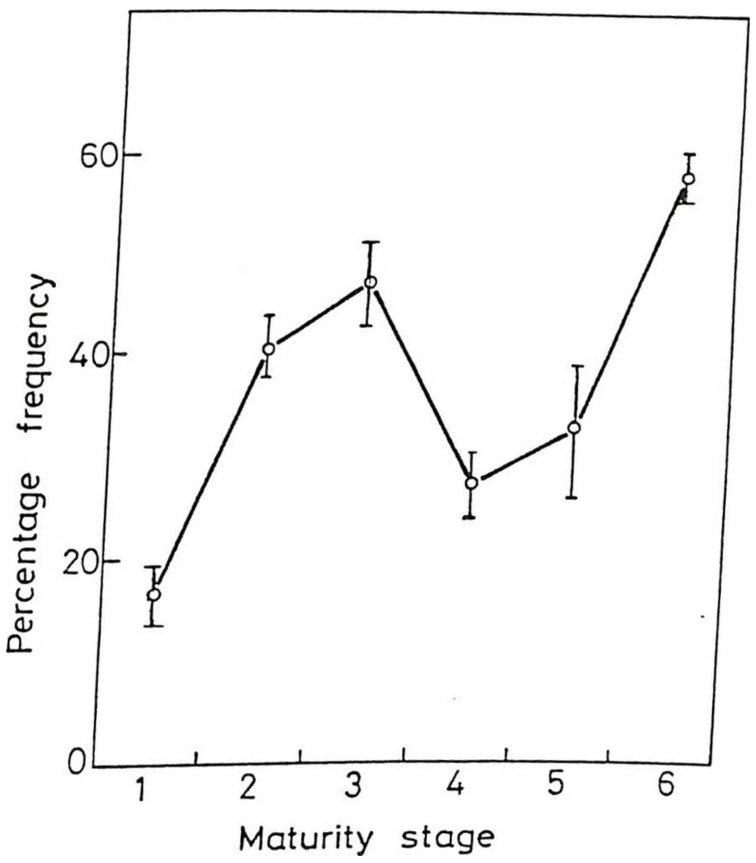

Fig. 7.7: Relationship between number of atretic oocytes and maturity stage in histological sections of ovaries of S. sutor. The data are from six ovaries from each maturity stage. Vertical bars are equal to $\bar{X}$ ± s.e.

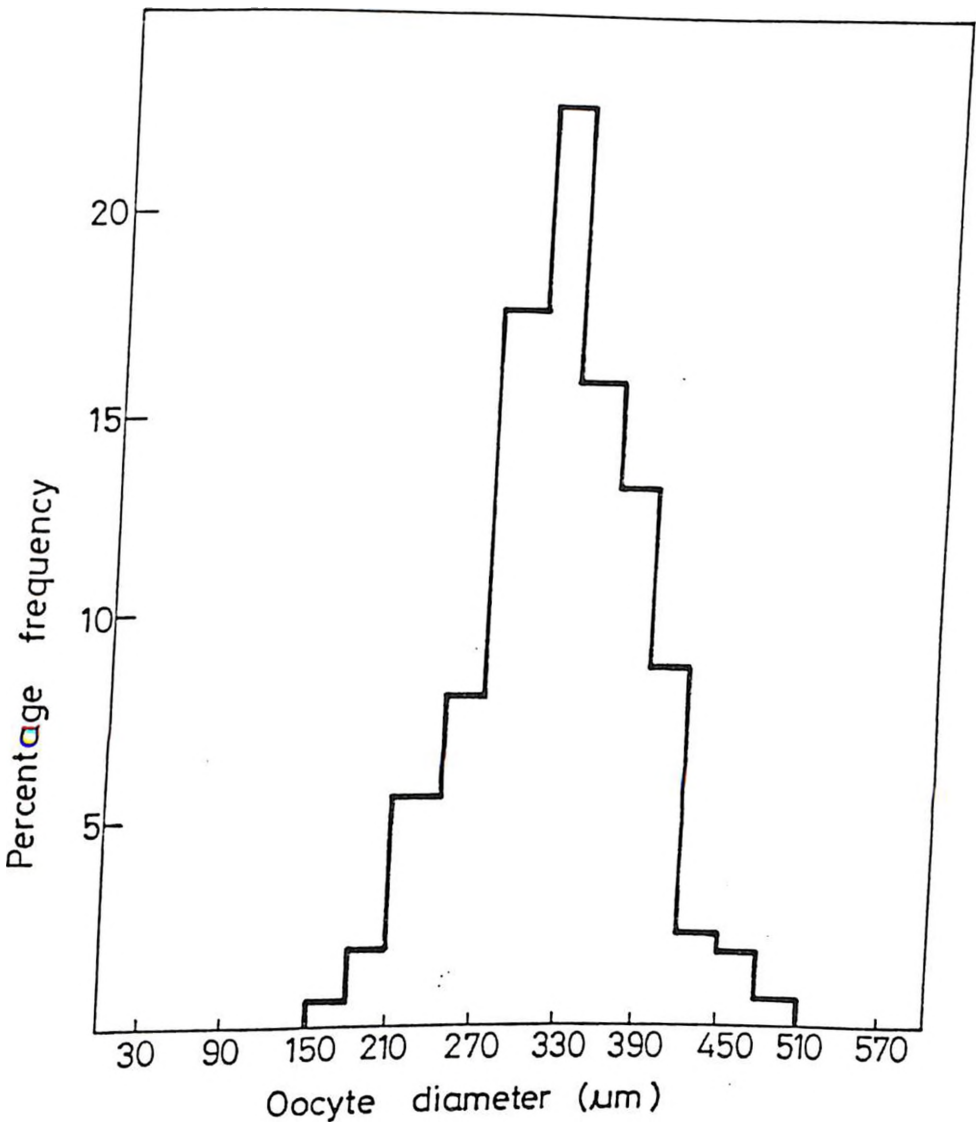

Fig. 7.8: Proportion of atretic oocytes in histological sections of 10 ovaries of S. sutor that were in advanced stages of oocyte development.

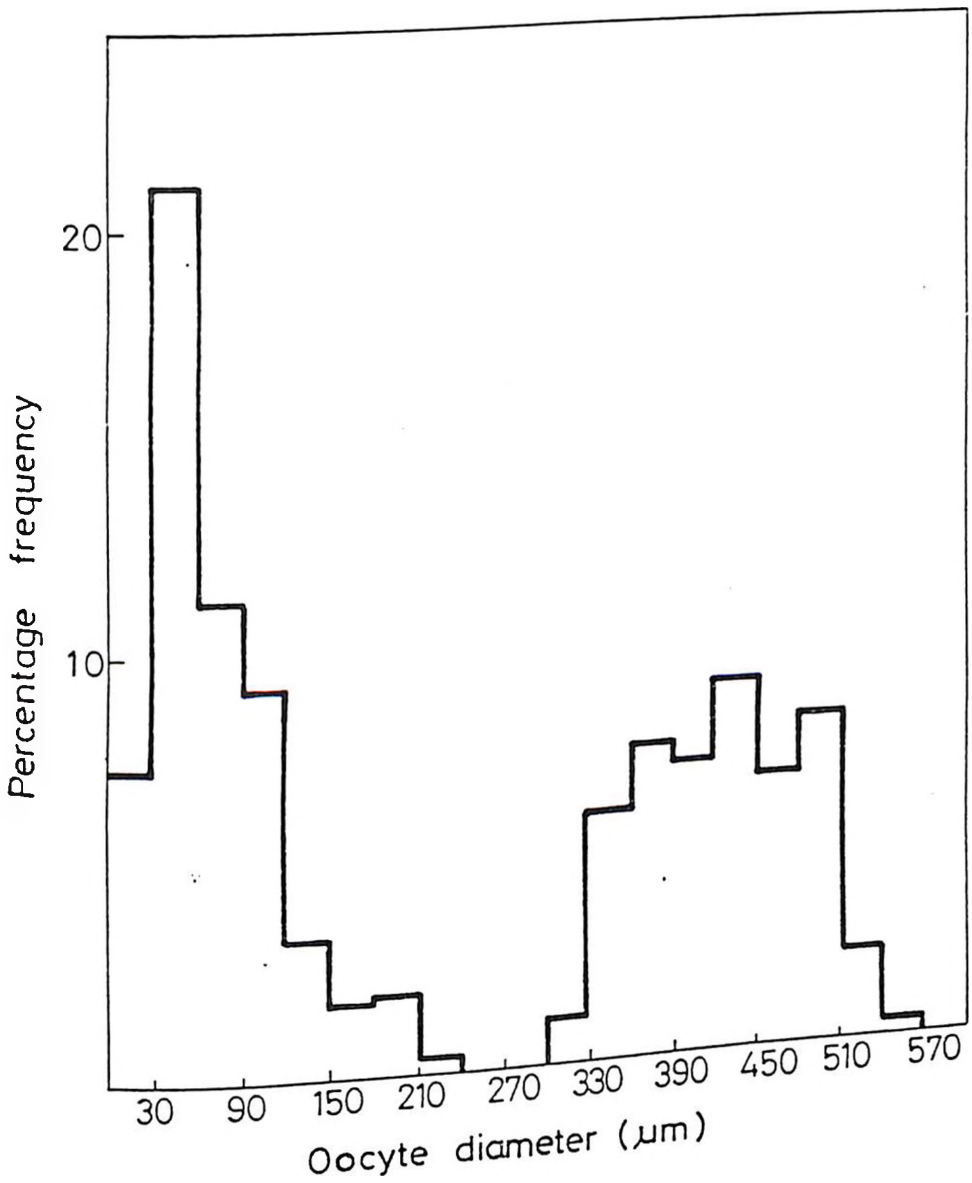

Fig. 7.9: Gilson's count oocyte diameter frequency distribution of 10 ovaries of S. sutor that were in advanced stages of oocyte development.

were atretic in 10 ovaries of S. sutor. For comparison the oocyte diameter distribution for the 10 ovaries fixed in Gilson's fluid is plotted in fig. 7.9. Super-imposing the two figures makes it clear that most of the intermediate size oocytes in stage 4 and 5 ovaries are atretic. Perhaps these form the 27-32% of atretic oocytes shown in fig. 7.7.

7.4 Discussion.

Ovaries of S. sutor that are in advanced stages of development show an oocyte diameter distribution that is strongly bimodal containing a mode of small and large oocytes and, in some ovaries, the intermediate size oocytes completely missing. Younger ovaries and of course those that are spent have got only one mode of oocytes since in the former the large oocytes have not been formed while in the latter such oocytes have been shed.

Such an oocyte diameter frequency distribution pattern suggests that oocyte development in the ovary of S. sutor is group synchronized. In this type of development two populations of oocytes are distinguished, a more advanced fairly synchronous population of large oocytes and a less advanced heterogenous population of small oocytes from which the larger

ones are recruited (Wallace & Selman, 1981). Taking the fecundity for that spawning season to be the total number of all developing oocytes in the ovary (Macer, 1974), the fecundity of S. sutor in the Kenyan coastal waters is averaged to be 585,000 eggs minus what will be lost to atresia at stage 4. De Souza (in press) has obtained a total fecundity of 700,000 eggs for S. sutor at the kenya coast by counting yolked eggs only from stage 4 and 5 ovaries. Lam (1974) cited Monacop (1937) to have reported that S. canaliculatus, a closely related species to S. sutor, has between 300,000-500,000 oocytes in it's ovary. There are individual variations ranging from as low as 50,000 to well over 2 million eggs in the ovaries of artificially spawned S. canaliculatus (Bryan. et al., 1975) while Hasse et al., (1977) reported a mean of 300,000 eggs per female with a mean diameter of 0.5 mm. In marine fishes the range of fecundity for a given fish length is rather wide (Macer, 1974). This has already been demonstrated by the work of Bryan et al., (1975) on S. canaliculatus. The same case appears to be true for S. sutor at the Kenya coast; the fecundity ranged from 200,000 in a fish of 18.0 cm standard length to well over 1.3 million in a fish of 25.2 cm standard length. What appears to have been anomalous is a case of a single

ovary that throughout this work was found to contain 2.9 million developing oocytes. The fecundity estimate given by De Souza (in press) for S. sutor in Mombasa area is very close to the estimate obtained in the present work but he does not clearly state the method used in deciding the oocytes counted. Other workers have a tendency to use already running fish obtained from commercial fishermen (Hasse et al., 1977; De Souza, in press). But the dangers of this are certainly obvious, that such fishes have already shed some eggs which therefore means not all oocytes are counted, even though it is quite evident that the siganids are highly fecund fishes but with a lot of individual variations. The high fecundity of these fishes may be a suggestion of high egg and larval mortality.

It is most probable that each sexually mature S. sutor spawns twice in a year. This is indicated by the temporal variation in the weights of the gonads, the appearance of juveniles, the relative condition factor (K_n) and especially by the seasonal occurrence of spent males and females in the catches. As has been observed in the present work and in Palau, Singapore and The Philippines (Lam, 1974; Kami & Ikehara, 1976; Hasse et al., 1977) the above phenomena have a twice yearly peak for the majority of the siganids.

Along these lines therefore it would be logical to suggest that each female S. sutor at the Kenya marine waters has a mean potential annual fecundity of close to 1.2 million oocytes since a mean fecundity of 585,000 developing oocytes has already been determined per single spawning at stage 4.

As is indicated by fig. 7.7 at stage 4 the atretic oocytes (27%) constitute probably the intermediate size oocytes. But an investigation into whether egg atresia could have affected the fecundity estimates made in the present work showed that all atretic oocytes had weak membranes (Plate 7.1) and they had a very slim chance, if any, of withstanding the vigorous shaking subjected to the oocytes in Gilson's fluid to aid release of oocytes from the ovarian tissue (Macer, 1974). Since, therefore, it is Gilson's stored material that was used in fecundity estimates all the atretic oocytes most probably disrupted and were thus not counted. It can thus be stated with some confidence that, at stage 4, each oocyte that was counted in the fecundity estimates was viable and capable of getting fertilized. However, there is evidence from fig. 7.7 that although at stage 4 no atretic oocytes were included in the fecundity estimates the growth of oocytes from stage 4 to stage 5 is associated with a 5% rise in atresia.

Since it is at stage 5 of development that the eggs are spawned this loss of oocytes towards the peak of development from stage 4 has to be accounted for. For this reason the fecundity estimates made at stage 4, in the present work, has to be less by 5% at the peak of development at stage 5. Following this, therefore, the corrected fecundity estimated for S. sutor is at a mean of 556,000 developing oocytes per spawning and hence a mean potential annual fecundity of about 1.1 million eggs. Fecundity was not determined at stage 5 in the present work because it is probable that at this stage of development some oocytes have already been shed.

In group-synchronous ovaries, a variety of oocyte recruitment strategies exist (Wallace & Selman, 1981); it could be, directly from oogonia, at the end of the gonadotropin-independent stage, from previtellogenic to vitellogenic stages and lastly oocytes which have terminated vitellogenesis may be recruited into maturation. For S. sutor recruitment of oocytes seems to be at the end of the gonadotropin-independent stage where oocytes in the gonadotropin-independent stage are always present in the ovary, but oocytes in the newly recruited clutch sequentially elaborate yolk vesicles and yolk proteins, undergo maturation and are ovulated from the ovary. Such type of oocyte

recruitment was shown in the herring, Clupea harengus (Bowers & Holliday, 1961). Considering the results given in fig. 7.3 and plates 6.5 and 6.6, it appears that at stage 4 there is an appreciable proportion of the intermediate size oocytes; at stage 5 there is the occurrence of two distinct modes separated by a gap. These results show that during development, from stage 4 to 5, in the ovary of S. sutor the largest oocytes perhaps wait for the small oocytes to catch up. Also it seems that a few oocytes recruit from the ganodotropin-independent stage few at a time and not en masse which results into the bimodal distribution seen. Both pre- and post-spawning atresia of oocytes are prevalent in the ovarian development processes of S. sutor. While the latter aids the removal of unwanted material from the ovary or perhaps represents the utilization of the needed material, the function(s) of the former are in many cases unknown. However, Wallace & Selman (1981) suggest that poor nutrition and hormonal imbalances, especially of the gonadotropins, may cause such involution of developing oocytes in the pre-spawning phase i.e. the ovaries may function as storage organs.

The chorion of the oocytes of S. sutor, especially in the last stages of development prior to ovulation in stage 5, is striated. Eggs of S.

canaliculatus are demersal and adhesive after fertilization (Bryan et al., 1975; Hasse et al., 1977). Since this is a siganid species very closely related to S. sutor it may be probable that the eggs of S. sutor are also demersal and adhesive after fertilization thus suggesting the reason why they were not found in the plankton during the preliminary survey. The early developmental stages were missing in the plankton presumably because siganid larvae spend their first few weeks of their life in the open sea and only come to the reeffflats much later (Hasse et al., 1977).

Evidence of a recent spawning is indicated in histological sections by empty ovarian follicles, presence of hyaline oocytes, free follicular cells in the ovarian lumen, internal disorganization of ovigerous lamellae and lastly some lone residual oocytes among very young oocytes (Macer, 1974). What was unexpected in the present work has been the lack of empty ovarian follicles and hyaline oocytes, but with evidence of disorganization of ovigerous lamellae (Plate 6.7) and residual oocytes (Plate 6.8). Macer (1974) points out that cases like this are common when samples contain fish on passage to or from one of the spawning grounds. This could be the case with S. sutor since so far knowledge on the spawning grounds

at the Kenya coast is non-existent. But Yamamoto & Yoshioka (1964) note that evacuated follicles disappear fairly quickly in about 3 days in the ovary of the medaka, Oryzias latipes. This is what could be taking place in S. sutor because even in spent fish (Plate 6.7) in the samples never showed evidence of empty follicular coats. This means therefore that to observe free follicular coats sampling should have been done close to the sampling grounds.

CHAPTER 8

8. GENERAL CONCLUSIONS

1. There are four siganid species at the Kenya coast namely, Siganus sutor (Valenciennes, 1835), S. luridus (Rüppell, 1828), S. argenteus (Quoy & Gaimard, 1825) and S. stellatus Forsskal, 1775. S. sutor is the commonest and the other three are quite rare.

2. S. sutor has two major spawning seasons, the first spawning peak occurring in January/February and the other in May/June.

3. Siganid fish eggs and larvae are absent from the plankton. The eggs are probably adhesive since they are absent from the water column. The absence of larvae in the plankton probably means that the early stages of the life cycle of the siganids are spent offshore in the open sea.

4. The siganid juveniles appear twice in a year at the Kenya coast. The first appearance comes in February lasting up to late March and then they suddenly disappear. Their second appearance comes in September and lasts only up to early October.

5. S. sutor has a group synchrony type of oocyte maturation where there is separation of developing from resting oocytes in the advanced stages of

oocytes maturation. The oocyte diameter frequency distribution of some ovaries of S. sutor is strongly bimodal with, in some Gilson treated ovaries, missing intermediate size oocytes completely. In other ovaries the large mode oocytes (> 150 μm) are missing either because they have not yet been formed in the young ovaries or have been spawned.

6. Cytoplasmic vacuoles, caused by fat droplets dissolving during histological preparation, appear in histological sections of ovaries of S. sutor quite early in the ovary maturation cycle and have hence been used as the main criterion of oocyte development.

7. S. sutor has an average fecundity of 5.85×10^5 eggs per spawning at stage 4. However, after taking into account the 5% loss to atresia as oocytes grow from stage 4 to stage 5, when spawning actually takes place, the mean fecundity for S. sutor is 5.56×10^5 per spawning and hence a potential annual mean fecundity of 1.1×10^6 eggs per female.

8. S. sutor has been aged by counting daily bands on the otolith and an L_∞ of 36.0 cm standard length and K of 0.13 have been determined.

9. Since the siganids contribute 50% of the total catches of all the artisanal fishery (Nzioka, 1984) much more work needs to be done on their biology. Areas that need attention now are: (a), age and growth studies using daily bands on the otolith, (b), causes of atresia of oocytes and its effect on fecundity and (c), the selectivity of the dema trap and hence the fishery of the siganids.

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